Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Exploration in Some Interesting Geothermal Area in Republic of Yemen

Al-Sabri A., Al-Kohlani T., Al-Nethary M., Sharian A., Al-Dukhain A., Al-Hosam A., Al-Hosam M., and Sultan M.,

Ministry of Oil and Minerals, Geological Survey and Mineral Resources Board, Sana'a, Republic of Yemen, P.O. 297,

Fax: 967-1-217575.

Mobile: 00967-777701663 & 00967-736628973

E-mail: ali_alsabri2000 @YAHOO.COM

ABSTRACT

The first geothermal area (Al Lisi–Isbil Geothermal field) is located about 100 km from Sana'a capital city of Republic of Yemen, and the second geothermal area (Alsyani – Algandeah Geothermal field) is located about 250 km from Sana'a capital city of Republic of Yemen. In addition, the third geothermal area (Red Sea geothermal area) is located about 290 km from Sana'a capital city of Republic of Yemen. The geothermal mapping was carried out in the western area of Yemen (Al Lisi and Isbil and Alsyani – Algandeah Geothermal field).

The rock's type in Al Lisi–Isbil Geothermal area was classified to six groups, trap series, the post trappic volcanic activity, Isbil volcanic complex, Al Lisi volcanic complex, Basaltic Fissur volcanism and recently active sedimentary deposits. The main structural features are NNE-SSW and NE-SW trend. The rock's type in the second geothermal area, i.e., Alsyani – Algandeah Geothermal area, was classified to 4 types of Rocks, Tertiary Volcanic (Basalt, Rhyolite, and Tertiary intrusive rocks), Tawilah Sandstone Group, Medj- Zir Sandstone and Quaternary Deposits. The main structural feature is NE-SW trend.

In Al Lisi and Isbil Geothermal area, the geothermal manifestations (steam, clay alteration and slight alteration) are common in many different sites in the Geothermal area. Two types of alteration zones are distinguished. Slight alteration was mostly characterized by slight color change of the brownish, reddish, yellowish to white colors and also involving some silica minerals (opal) and calcite veins. Some altered rocks assume a whitish color due to the presence of opline silica, clay minerals and iron oxides. The temperature of steam exceeds 92ºC and there are 118 hot wells in the area in which the temperature is between 25 to 59 ºC. And the geothermal manifestations (slight alteration) in Alsyani – Algandeah Geothermal area are common in many different sites in the geothermal field. There are 42 hot wells in the area where the temperature ranges from 27 ºC to 75 ºC. The thermal wells at 340 meters deep had a temperature of 75 ºC in the area.

The Red Sea geothermal area is located in west area of western Yemen volcanic part and was not more than 3000 km^2, but data from several areas throughout the world, including neighboring countries such as Ethiopia, yielded similar temperatures and geothermal gradients. In the present, the temperature logs from the boreholes show a temperature of 190°C at 2458 m depth in the Red Sea geothermal area.

1 INTRODUCTION

1.1 Objective of the Study

The main goals of this study were to Explored the geothermal energy resources and to make geological and geothermal maps of a volcanic field and to find out if a relationship could be established between the tectonic setting and the geothermal manifestations of the study area.

The geological mapping exercise was carried out in 2010 in the first geothermal area (Al Lisi–Isbil Geothermal field) and in 2012 in the second geothermal area (Alsyani – Algandeah Geothermal field). Instruments and tools were used to carry out the fieldwork included the following:

- A Garmin - GPS 72 to locate and track the structural, stratigraphic and alteration features such as faults, fractures, dykes, stratigraphic boundaries, and alteration zonation.
- Satellite image and compass used to trace the aerial extent of the major structures, their strike, dip directions and distribution within the study area.
- A geological hammer, a metric tape and a hand lens used for field inspection of rock samples and unit thicknesses.
- A shovel, and small plastic sample bags to collect samples from the different alteration zones and different rock units for XRD and petrographic studies, in order to figure out the degree of alteration and the mineral assemblages that exist in the hydrothermally altered areas, and also to differentiate and correlate the different rock units from outcrop to outcrop in the study area.

2 THE FIRST GEOTHERMAL AREA (AL LISI–ISBIL GEOTHERMAL FIELD)

2.1 Study area

Al Lisi–Isbil Geothermal field is located about 100 km from Sana'a capital city of Republic of Yemen.

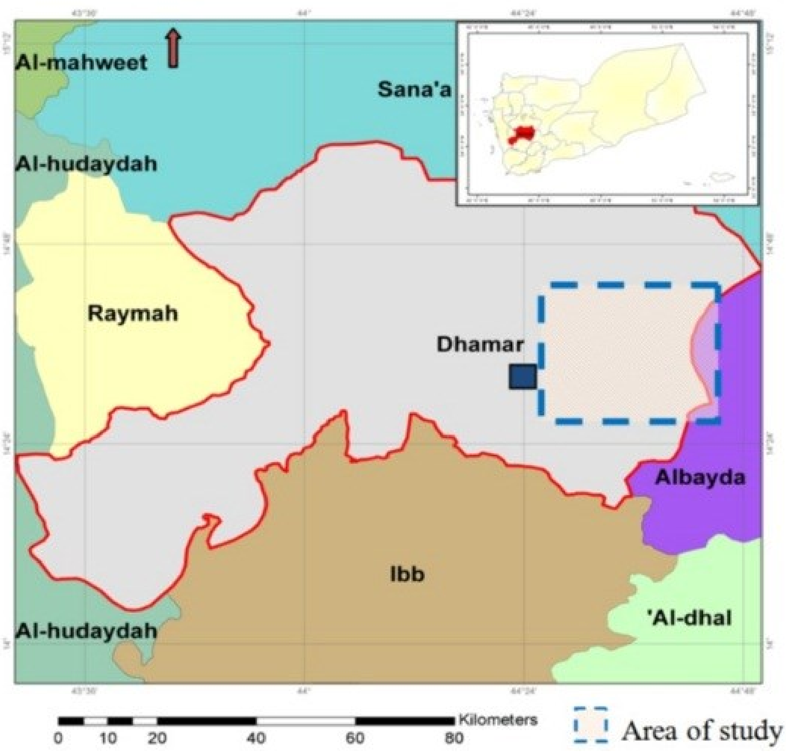

Figure 1: The map of first geothermal area (Al Lisi–Isbil Geothermal field)

2.2 Previous work

The area has been explored intermittently by many geoscientists work. The Exxon Company planned to drill exploration production well in Risabah area. The well was drilled to provide geologic information regarding the potential for hydrocarbon source, reservoir and seal in the in the Dhamar Basin the programmed depth of gooft (or shallower basement) was not reached because the well wall was still drilling volcanic rock at 5331ft. The well drilled alluvium to depth of 105f (KB), then to total depth a complex of allernating inlerbedded layers of sub aerial basalt flows, basaltic ash flows, basaltic sills, acid tuffs, rhyolitic flows, and possible cinder cones, Numerous sub aerial erosion surfaces were recognized but no sediments or reworked clastic sediment were present the volcanic are presumed to be oligo – Miocene in age. The highest bottom hole temperature recorded was 220◦F, the extrapolated equilibrium bottom hole temperature is 232◦F, demonstrating a high thermal gradient and heat flow (Exxon Exploration Production Mideast INC, Risabalt-1 Well).

In the period January 81 – January 82, ElC Elecro consult under an agreement with Yemen oil& minerals Resources corporation performed geo-scientific investigations in the Dhamar – Rada'a area with the aim of assessing, at a prefeasibility level, the possible geothermal potentiate of the area. Geochemical thermometry of the waters emerging in the Dhamar–Rada'a area gives somewhat scattered ((numbers)) (ELC, 1982). Although the maximum temperature so calculated may well be above 200^{o}C, (ELC, 1982). Geochemical anomalies give a consistent pattern, indicative of more permeable zones and higher temperature, in the area of the depression (graben) extending from the Al Lisi volcano to the ESE, Passing just to the south of the Isbil volcano (ELC, 1982). On the floor of this depression, this outcrop depression, these outcrops trap sources basalts through the overlying quaternary volcanic, and there exists a very high concentration of sputter cones. This localized area is structurally quite favorable for the slow upwelling of any warm water from the depths (ELC, 1982).

The Dhamar Rada'a volcanic field covers an area of about 1477.1 km^2. The region is characterized by both central and fissural activities and has been affected by intensive vertical tectonism, resulting in the formation of horst and graben structural patterns. It is also characterized by a sequence of pyroclastic flow deposits (ignimbrites), which are widespread on the floor of the graben. Outpouring of basalt through fissures locally followed this explosive activity (basalt). Subsequent central activity produced cones, ash rings and pyroclastic fall deposits. The explosive activity was followed by the extrusion of two rhyolitic lava domes and the formation of an ash ring.

2.3 Some Geochemical Results

During two missions carried out in February 2001 and December 2002, almost all known thermal emergences of continental Yemen, including thermal springs, fumaroles and several CO_2-rich gas vents, were sampled and analyzed for major, minor and some trace components. Further, some isotopic ratios: 18O/16O and D/H in water samples, 13C/12C in CO_2 (in DIC=dissolved inorganic carbon and free gas) and some 3He/4He ratios (in the free gas phase) were measured (Minissale et al, 2010).

An example of the first situation in the T-depth diagram of Figure 2 could be represented by the well sample # 64, where an apparently very high gradient of 370 °C/km can be estimated in a well, which is only 60 m deep, but with a relatively high temperature of 37 °C. An example of the second situation (excessive cooling from cold rainfall infiltration) in Fig 2 could occur in the well sample # 105, where the measured temperature of water is as low as 26 °C at about 250 m depth, generating an apparent thermal gradient as low as 41 °C/km, just a little higher than the average Earth gradient 33 °C/km (Minissale et al., 2010).

Apart from this area, there are six additional closed thermally anomalous areas in Figure 3 where the calculated temperature at 1,000 m should be above 120 °C. In total, the area where temperature at 1,000 m should exceed 100 °C is likely to exceed 200-250 km^2, a very large area that suggests that the deep geothermal system is large (Minissale et al, 2010). According to our interpretation of thermal and chemical data for a large number of wells drilled around the city of Dhamar, we believe that the thermal anomaly in this area is not caused by regional convective fluid circulation of deep fluids ("intracratonic fluids"; Minissale et al., 2000), but rather is caused by local high conductive heat flow. The conductive high heat flow is undoubtedly related to the presence of the magma associated with the Quaternary volcanics, still under cooling. This (ese) magma chamber(s) have possibly generated active hydrothermal systems inside the sedimentary substratum or at the base or inside the YTS volcanic sequence. The platform limestone series of the Amran-Tawila groups, if present in the horst described in the Dhamar area (Chiesa et al., 1983) might be best place to generate the ascending brunch of such hydrothermal system. The anomalous heat flow of the Dhamar aquifer might be the shallow manifestation of such deep convection. Unfortunately, typical chemical components of active hydrothermal systems (NH4, B, CO_2 vents, H_2 etc.), in both gas and liquid phases, are missing at the surface. Therefore, the presence of an active hydrothermal system, although probable, can only be speculated (Minissale et al, 2010).

From a geothermal viewpoint, the hypothesized hydrothermal system could be well sealed (e.g. by silica precipitation), thus preventing escape of chemical components to the surface. Our computed geothermal gradients show temperature gradients exceeding 100-120 °C/km in several places. Although these gradients cannot be extrapolated to define a clearly assessed geothermal reservoir below the volcanic cover, the area between the Al Lisi and Isbil craters represents a promising area for the drilling of a geothermal exploration well (Minissale et al, 2010).

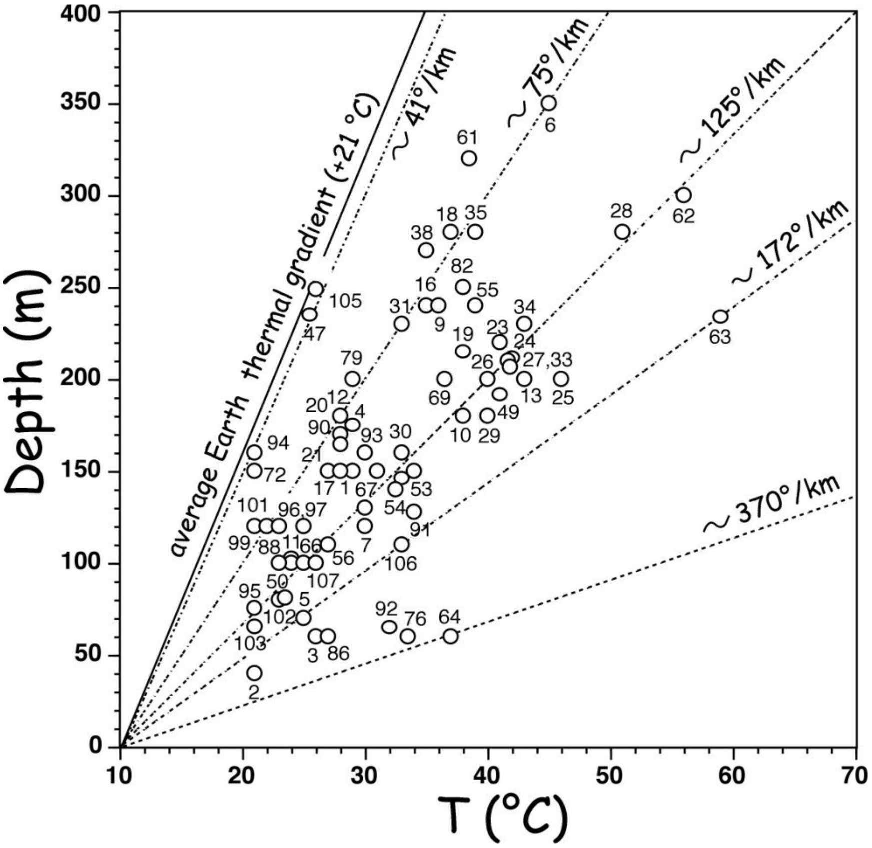

Figure 2: Iso distribution maps of the measured temperature in the wells, the temperature calculated at a depth of 1,000 meters (Minissale et al, 2010).

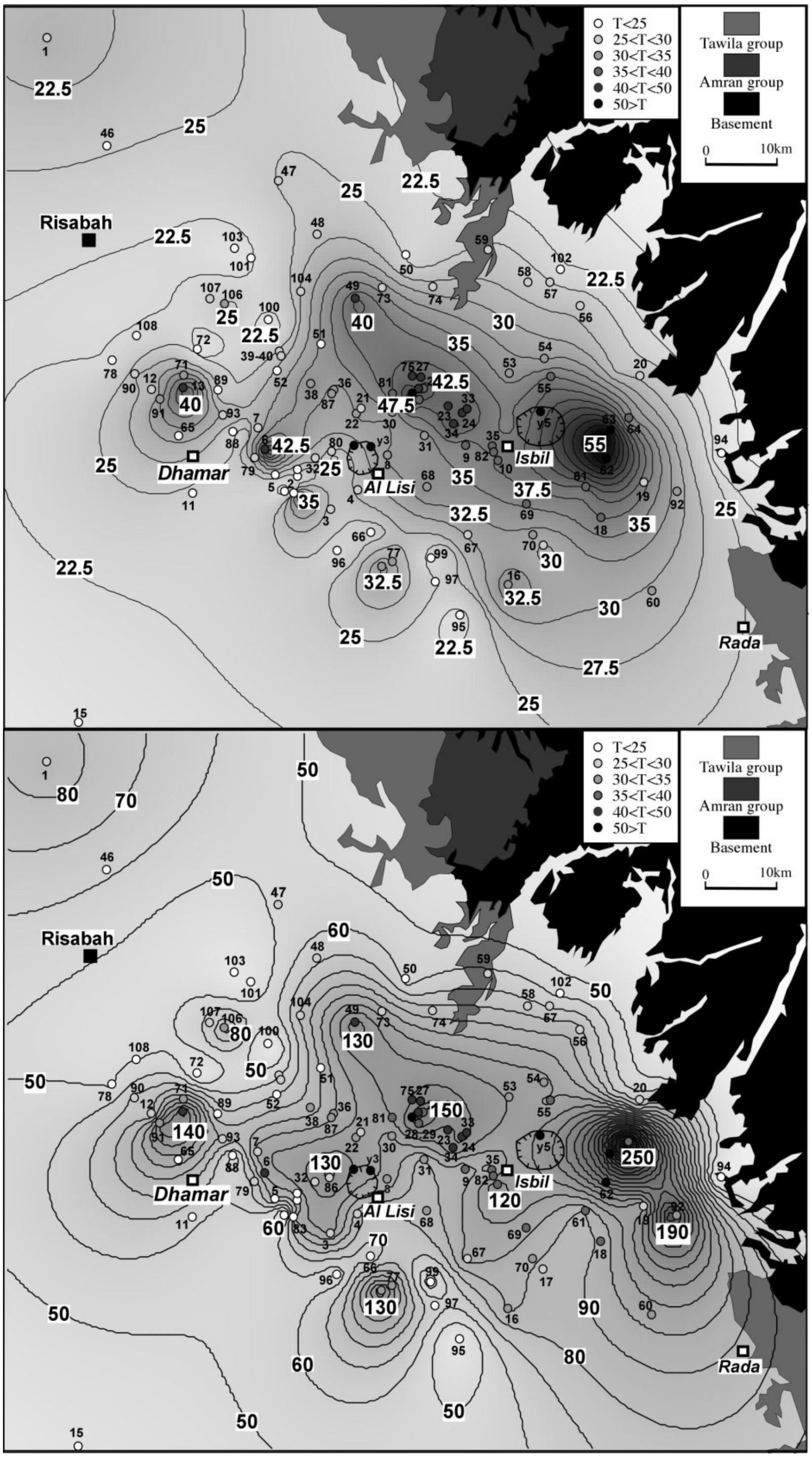

Figure 3: Diagram of the measured temperature versus the depth of wells, (Minissale et al, 2010).

2.4 Geophysics studies

The result of technical geophysics work gives ISO- resistivity contour map. Figure 4 shows the anomalies low resistivity zone is located in the meddle part of study area (Wahib, 2010).

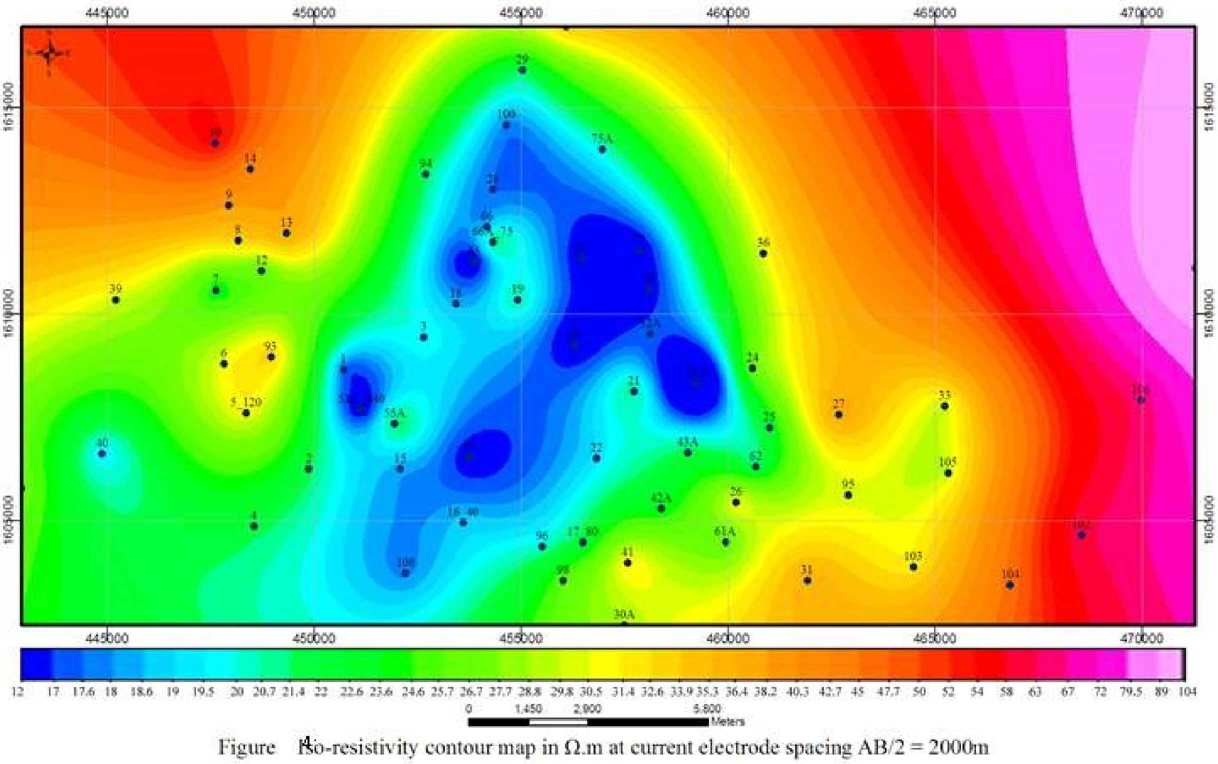

Figure 4: ISO- resistivity contour map (Wahib, 2010).

2.5 Update the geological map in the first geothermal area (Al Lisi–Isbil Geothermal field)

2.5.1 Forming the main layers of the digital maps.

- Transfer the data and base maps from Raster to vector data.
- Digitizing the main layers of the maps.
- Update the Geological Map by the new field data.
- Produce digital map.

2.5.2 The volcanic rock in the study area

Figure 5 shows a map of volcanic rocks in the area. It was classified to four groups:-

The Trap Series

The Trap Series in the area mapped occurs as isolated outcrops bordered ether by recent and active sedimentary deposits or by post trap basaltic volcanic. It is generally horizontally lying and has been disjointed by vertical tensional tectonic forces without tilting of the blocks. The trap series outcropping in the area mapped is made up mostly of basaltic rocks, which are often deeply weathered.

These rocks are overlain in places, above an erosional surface, by a thick sequence of pyroclastic pumice flow deposits with different degrees of welding (ignimbrites).

The post Trappic volcanic Activity

The post Trappic volcanic activity is represented by central and fissure volcanism. The central volcanism consists of volcanic complexes, central apparatus, lava domes and explosive craters. The fissure volcanism is characterized by wide spread basaltic lava fields and numerous, scattered spatter cones. Its main activity is definitely younger than the central volcanism. The complex, interlayered nature of the surface features of both lava flows and spatter cones indicate that the volcanic activity occurred over a long time span.

Central Volcanism Plinian Fall Deposits

The oldest products of the central volcanism are represented by scattered outcrops of plinian fall deposits reaching maximum thickness of about 6m. They consist of angular pumice clasts with maximum observed diameter between 15 and 20cm. They contain unsupported lithic clasts (ømax 60cm) mainly of Crystalline Basement rocks (gneiss, mic–schist, amphibolite, pinkish granite) and subordinately of pinkish violet rounded quartz fragments of the Tawilah Group. The areal distribution of the outcrops and the variation in grain size of both pumice and lithic fragments indicate that they belong neither to the same eruption nor to the same vent. The latter cannot be located due to the lack of significant field evidence.

Isbil Volcanic Complex

The Isbil is a complex strato volcano made up mainly of lava flows and subor dinate ignimbritic sheets and pyroclastic fall deposits. It was partially destroyed by a caldera collapse leaving an exposed wall 100m high. The lava flows have compositions ranging from trachytic to rhyolitic. The first is generally represented by porphyritic units, maybe linked to dome or cryptodome effusive activity. The rhyolites are generally microcrys talline glassy rocks with fluid and convolute textures; sometimes they are vesiculated, producing pumiceous textures. The ignimbrites generally occur as non-welded pumice flow deposits. They occur definitely in the latest stages of the volcanic activity and possibly in the early ones also. In particular the oldest are ash and pumice flows with a continuous basalt layer of collapsed pumice and elongated obsidian fragments. Small pyroclastic fall and surge deposits occur in the upper part of the edifice. After the formation of the caldera and following with NNW-SSE tectonic trends, there followed a volcanic activity mainly represented by domes. In particular, the Hamman Isbil dome was built up on an older tuff cone. A basaltic fissure one with the formation of lava flows and spatter cones followed this silicic volcanic activity.

Al Lisi Volcanic Complex

The Al Lisivolcanic complex is composed of a tuff ring, lava domes and by a tuff cone with a final effusive activity; 2.5km south of this complex there occurs an explosive crater. The tuff ring consists of surge and fall deposits of slightly vesciculated glass clasts. The domes occurring west of the Al Lisi village consist of black rhyolitic obsidian with a high luster and breaking with a conchoidal fracture. At times, the obsidian is vesicular and shows fluidal texture. The first activity of the Al Lisi volcano is represented by a deeply weathered rhyolitic flow with fluidal and autoclastic texture, irregularly vesciculated. Periods of intensive explosive activity were followed by the formation of about 300m of pyroclastic surge and fall deposits. They contain only juvenile vitreous clasts with different degrees of vesiculation. In the basal pumice fall deposits one finds lythic fragments, in the centimeter size range, derived mainly from the Crystalline Basement and subordinately from the Trap Series. Erosional surfaces and angular unconformities have been recognized in this pyroclastic succession. The last manifestation of the volcanic activity is represented by a 30m thick autoclastic rhyolitic obsidian flow with fluidal texture and irregularly vesciculated. The explosive crater south of Al Lisiis due to a phreatic eruption; no juvenile ejecta have been found. It has an irregular elliotical shape with axes of about 200 and 500m. Its bottom is flat and covered by soils. A low sill about 10m high surrounds the crater, with outer slopes gentler than the inner ones.

Basaltic Fissure Volcanism

Basaltic fissure volcanism includes widespread basaltic lava fields and numerous, scattered spatter cones. From the morphology, it appears they were formed over a considerable time span: deeply eroded surfaces together with nicely preserved or ropy pahoehoe surfaces and nice spatter or cinder cones have been observed. Some of these cones have given rise to small effusive activities. The basaltic lava flows are thin, wide spread and have been strongly controlled by the existing morphology because of their fluidity at the time of eruption. Shorter and thicker flows of more viscous lava have not been found. The volcanism was only of a fissural nature: according to the spatter cones alignments and flow directions of the lavas, the main feeding fractures trend NNE – SSW and E-W.

2.6 Structure of the first geothermal area (Al Lisi–Isbil Geothermal field)

The structural feature in the study area is controlled by the tensional tectonics. The Structural features were mapped in the study area. The main structural feature are trend (NNE-SSW), (NE-SW). Mostly of the large fault are located in the North and North East of Alisi Mountain. They are numerous large fault are located in south, east and south east of Alisi Mountain. In addition, they are numerous small fault are distepuation in the study area. Figure 5 shows structural fault in the study area.

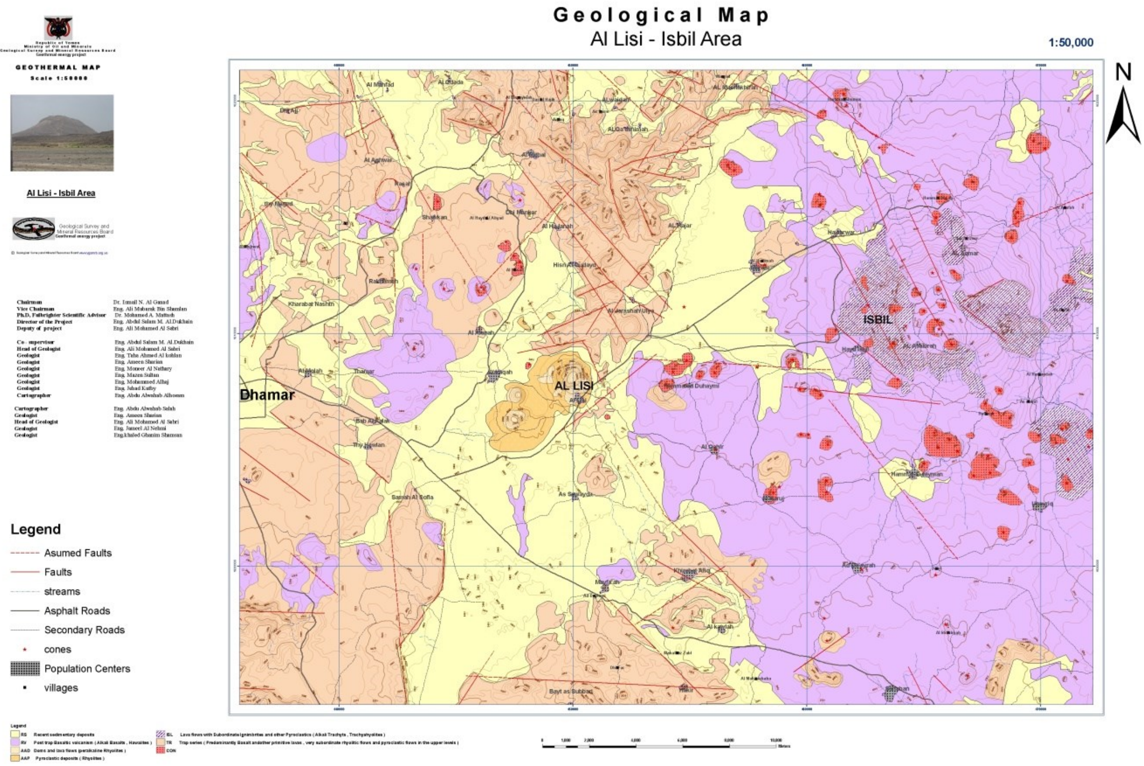

Figure 5: The Geological map of the first geothermal area (Al Lisi–Isbil Geothermal field)

2.7 Geothermal mapping work in the first geothermal area (Al Lisi–Isbil Geothermal field)

Hydrothermal alteration is a general term embracing the mineralogical, textural, and chemical response of rocks to a changing thermal and chemical environment in the presence of hot water, steam, or gas (Henley and Ellis, 1983).

The Hot spring, femoral Travertine deposits and hydrothermal alteration zones an extremely important element in geothermal exploration. Although springs are the most obvious surface manifestations of the hydrothermal system, alteration zones supply additional information that points out the areas of greatest temperature and permeability. Alteration zones can also guide exploration geologists to hidden systems or to ancient spring activity. The mapping process involves systematic sampling across the study area and analysis of mineral phases by x-ray diffraction and petrography. Study area can range from a map, which will often show the relationship of geothermal manifestation to Geological features. Figure 6 shows a Map of geothermal manifestation in the area they are to site of geothermal activity in the area. The first one is located in Al Lisi volcanic mountain the temperature 89^{o}C, and the second site of fumarole is located in Isbil volcanic mountain the temperature 43^{o}C and they are 118 wells in the area the temperature between 21^{o}C to 59^{o}C and the depth between 40 m to 350 m. The rocks show hydrothermal alteration from low intensity (slight alteration), to clayish alteration witness formerly active fumaroles, where the volcanic rocks have been completely replaced by secondary minerals.

2.7.1 Geothermal manifestations

The geothermal manifestations are common in Al Lisi volcanic mountain, West and North West of the Al Lisi Mountain, Isbil volcanic mountain and South and east of the Isbil Mountain. Two types of alteration zones are dislinguished slight alteration mostly characterized by slight color change of the Brownish, redish, yellowish to white colors and involving some calcite veins and the altered rocks assume a whitish color due to the presence of opline silica, clay minerals and iron oxides. The clayish alteration witness formerly active fumaroles where the hot rock has been completely replaced by clay. Hydrothermal surface alteration, hot or cold, indicates the presence of a hydrothermal systems beneath at some time therefore, mapping the surface alteration is useful in delineating a hydrothermal. The alteration intensity increases with increasing activity. By distinguishing between unaltered rocks (fresh or weathered) and slightly hydrothermally altered rocks, one can make destination. Intensive hydrothermal circulation has produced vapor phase crystallization and has induced deep alteration in the vitreous mass.

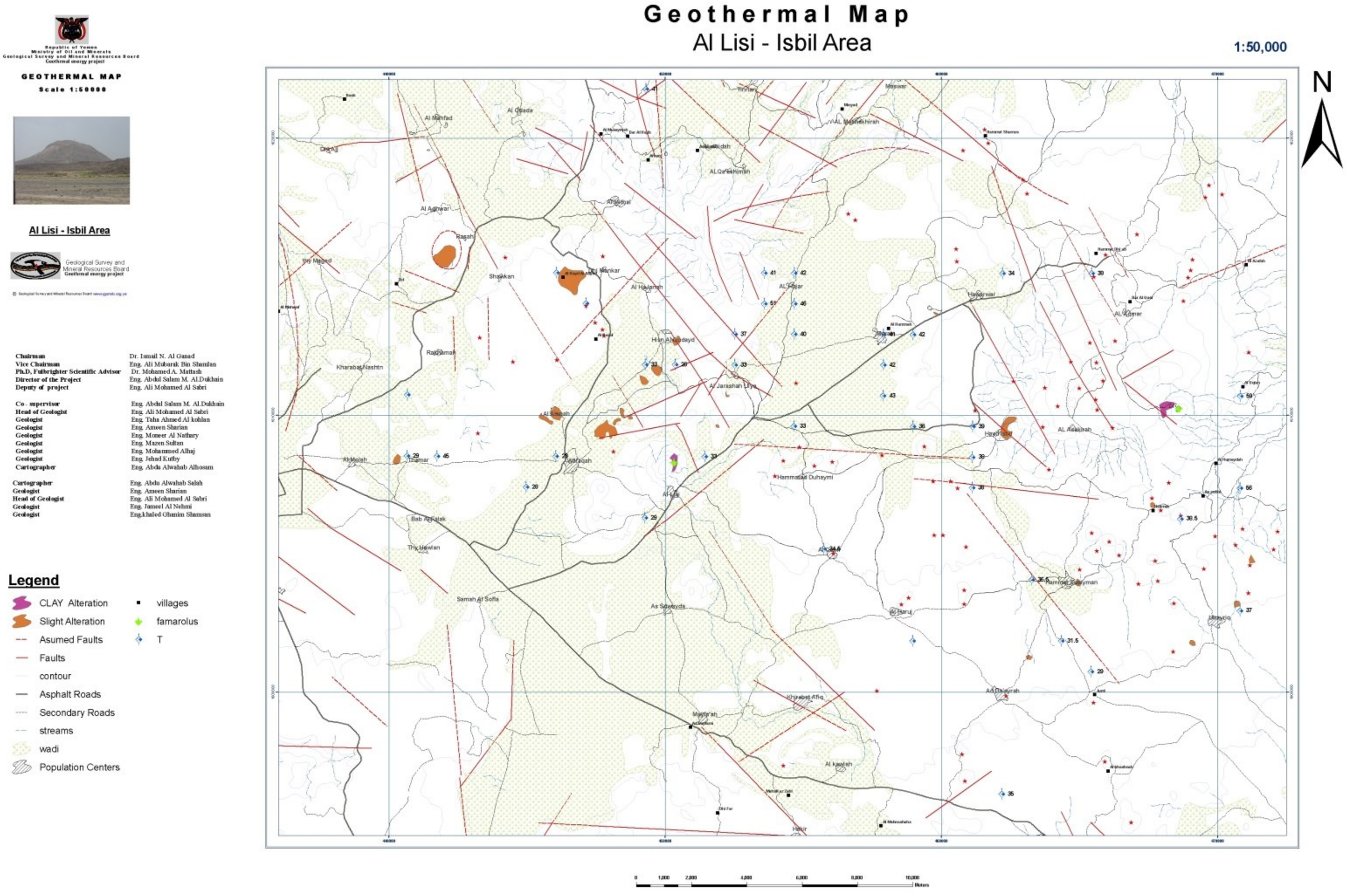

Figure 6: The Geothermal map of the first geothermal area (Al Lisi–Isbil Geothermal field)

Slight alteration

As the hydrothermal activity widespread in the mapped area, a considerable part of the rocks in the field area is slightly altered or visibly affected by some thermal alteration.

Clay alteration

Extinct clay alteration is less common than the slight alteration Figure 7 shows clay alteration.

Figure 7: The Clay alteration in the first geothermal area (Al Lisi–Isbil Geothermal field)

2.8 Mineralization

Thin calcite veins are found in the east and south of Isbil Mountain. The basalts rock shows extensive calcite veining Figure (8). Very small occurrences of cinnabar and reaglar have also been found (ELC, 1982). The silica minerals (opal) are found in the west of Al Lisi Mountain. The presence and distribution of such indicate the existence of wide fossil geothermal filed north – west of the

Al Lisi volcanic complex (ELC, 1982) .The, most common epithermal alteration styles are origillization reilaed to rhyolite domes in other areas, the predominant alteration styles are orgillization and pyritization relaled to quartz veins. Advanced orillic alteration as well as potassic alteration in the form of secondary biotite is identified at wavagaha area. (Mattash et al, 2010). Sulfide mineralization observed was almost all pyritic or limonitic Gangue minerals were quartz (veins, stock works, or epithermal breccia matrices), calcite or clay (vein selvages or argillic zones). (Mattash et al, 2010). Nevertheless, as along the thamar – waragah – Jabal Al Lisi trend, opalitic alteration can be the uppermost expression of a preserved epithermal vent, and thus provide valid targets for upithermal exploration. (Mattash et al, 2010).

Figure 8: Example of calcite veins in the first geothermal area (Al Lisi–Isbil Geothermal field)

3. THE SECOND GEOTHERMAL AREA (ALSYANI – ALGANDEAH GEOTHERMAL FIELD)

3.1 Study area

Alsyani – Algandeah Geothermal field is located in southern part of the west area of Yemen about (250) km from Sana'a capital city of Republic of Yemen

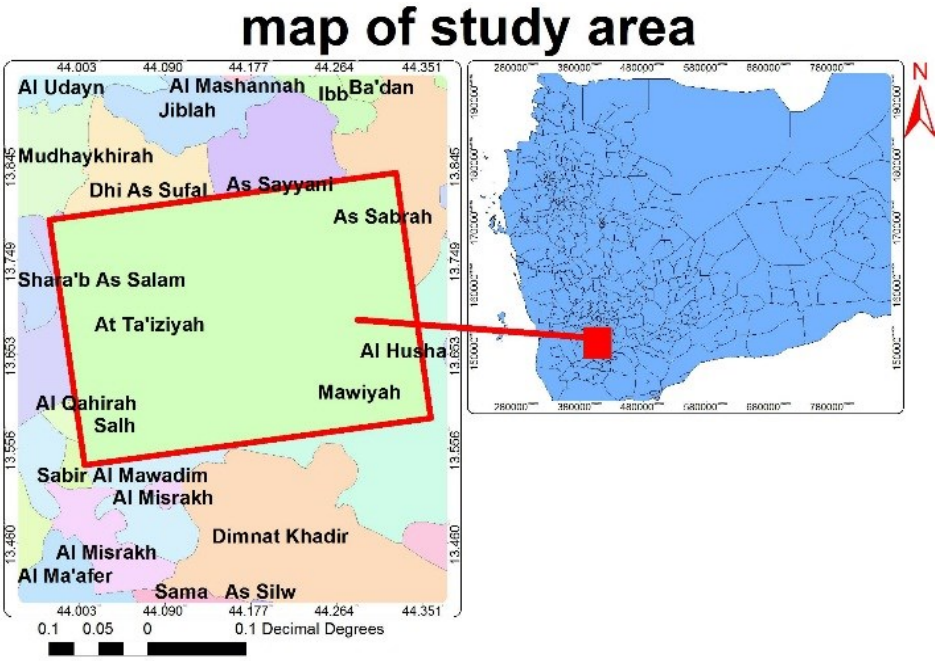

Figure 9: The map of the second geothermal area (Alsyani – Algandeah Geothermal field)

3.2 The rock type in the second geothermal area (Alsyani – Algandeah Geothermal field)

Figure 10 shows a map of rock type in the area it classified to four groups, Tertiary Volcanic (Basalt, Rhyolite, and Tertiary intrusive rocks), Tawilah Sandstone Group, Medj- Zir Sandstone and Quaternary Deposits.

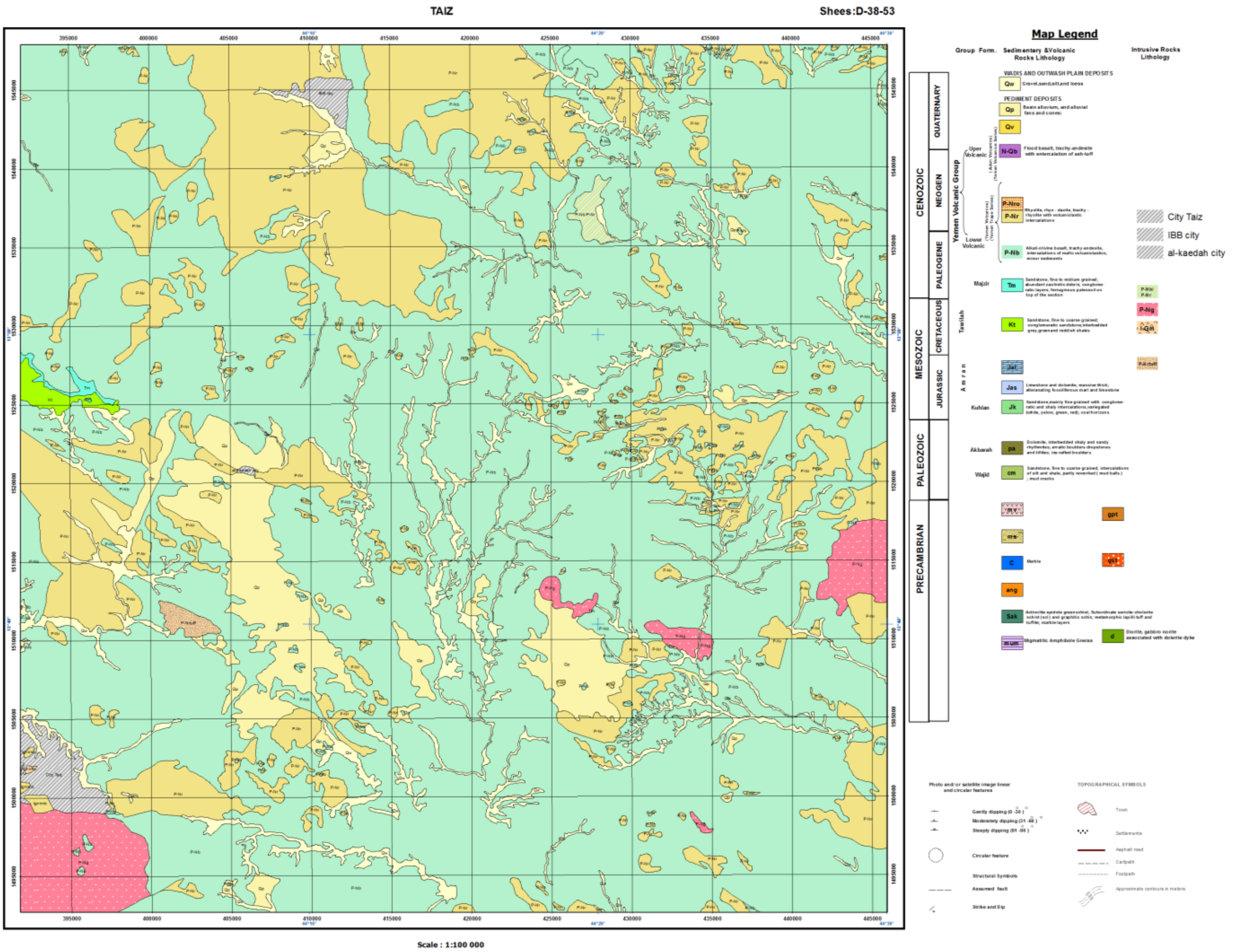

Figure 10: The lithology map of second geothermal area (Alsyani – Algandeah Geothermal field)

3.3 Structural of the second geothermal area (Alsyani – Algandeah Geothermal field)

The structural feature in the study area is controlled by the tensional tectonics. The Structural feature was mapped in the study area. The main structural feature is trend (NE-SW).

3.4 geothermal mapping work in the second geothermal area (Alsyani – Algandeah Geothermal field)

3.4.1 Geothermal Manifestations

Figure 11 shows a Map of geothermal manifestation in the area The geothermal manifestations are common in many different site in the Geothermal field , one types of alteration zones are dislinguished slight alteration, mostly characterized by slight color change of the Brownish, redish, yellowish to white colors and also involving some silica minerals (opal) and calcite veins and the some altered rocks assume a whitish color due to the presence of opline silica, clay minerals and iron oxides. They are (42) hot wells in the area the temperature from 27^{o}C to 75^{o}C and the depth from 200 m to 600 m.

3.4.2 Slight alteration

As the hydrothermal activity widespread in the mapped area, a considerable part of the rocks in the field area is slightly altered or visibly affected by some thermal alteration Figure 12 shows slight alteration.

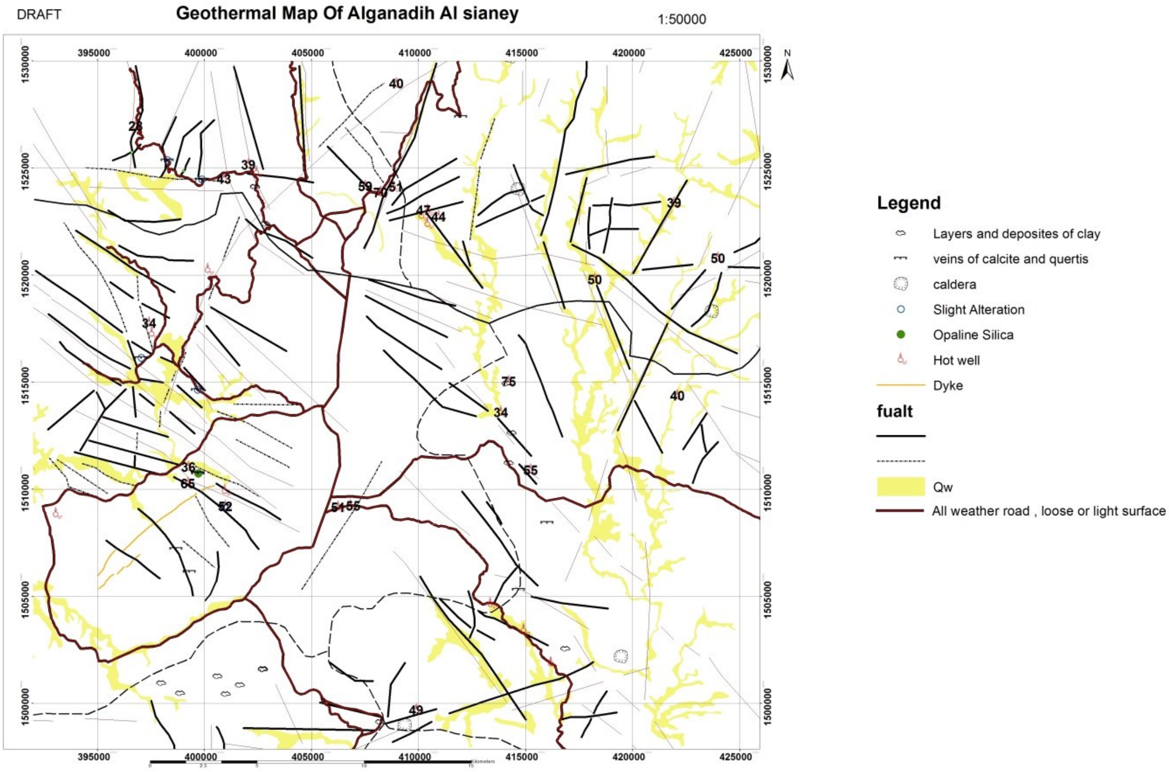

Figure 11: The Geothermal map of the second geothermal area (Alsyani – Algandeah Geothermal field)

Figure 12: Slight alteration in the second geothermal area (Alsyani – Algandeah Geothermal field)

3.5 Mineralization

Thin silica minerals (opal) and calcite veins are found in many different sites in the study area. The basalts rock shows extensive silica minerals (opal) and calcite veining (Figure 13). The siolite minerals are found in the southern part of the study area.

Figure 13: Example of calcite veins for the second geothermal area (Alsyani – Algandeah Geothermal field)

4 THE THIRD GEOTHERMAL AREA (RED SEA GEOTHERMAL AREA)

4.1 Study area

The third geothermal area (Red Sea geothermal area) is located about 290 km from Sana'a capital city of Republic of Yemen.

4.2 Geological features of the third geothermal area (Red Sea geothermal area)

The Red Sea area covered by drilling which is not exceed 3000 km^2, but data from several areas throughout the world, including neighboring countries such as Ethiopia yielded similar temperatures and geothermal gradients. In addition, the physical convective anomaly beneath Yemen (volcanic province) that is detected by space imagery (USGS, 1994) still is one of the most important in the whole region of the Afro-Arabian rift system. Such heat flow values have more or less been affected by 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, particularly throughout the Yemen Cenozoic volcanic areas and the occurrence of geothermal fields (Mattes et al., 2001). Figure 14 shows the Example of the Geological column of the third geothermal area (Red Sea geothermal area).

4.3 Heat flow in the third geothermal area (Red Sea geothermal area)

The present geothermal gradient in the Red Sea region ranges from 49 to 77 °C/km, and the present heat flow varies from 94 to 154 mW/ m^2. In support of this claim, data are obtained from several oil and gas wells drilled to 2458 meters deep. In the Present, the temperature logs from the boreholes show temperatures of 190°C at 2458 m depth in the Red Sea geothermal area, Figure 15.

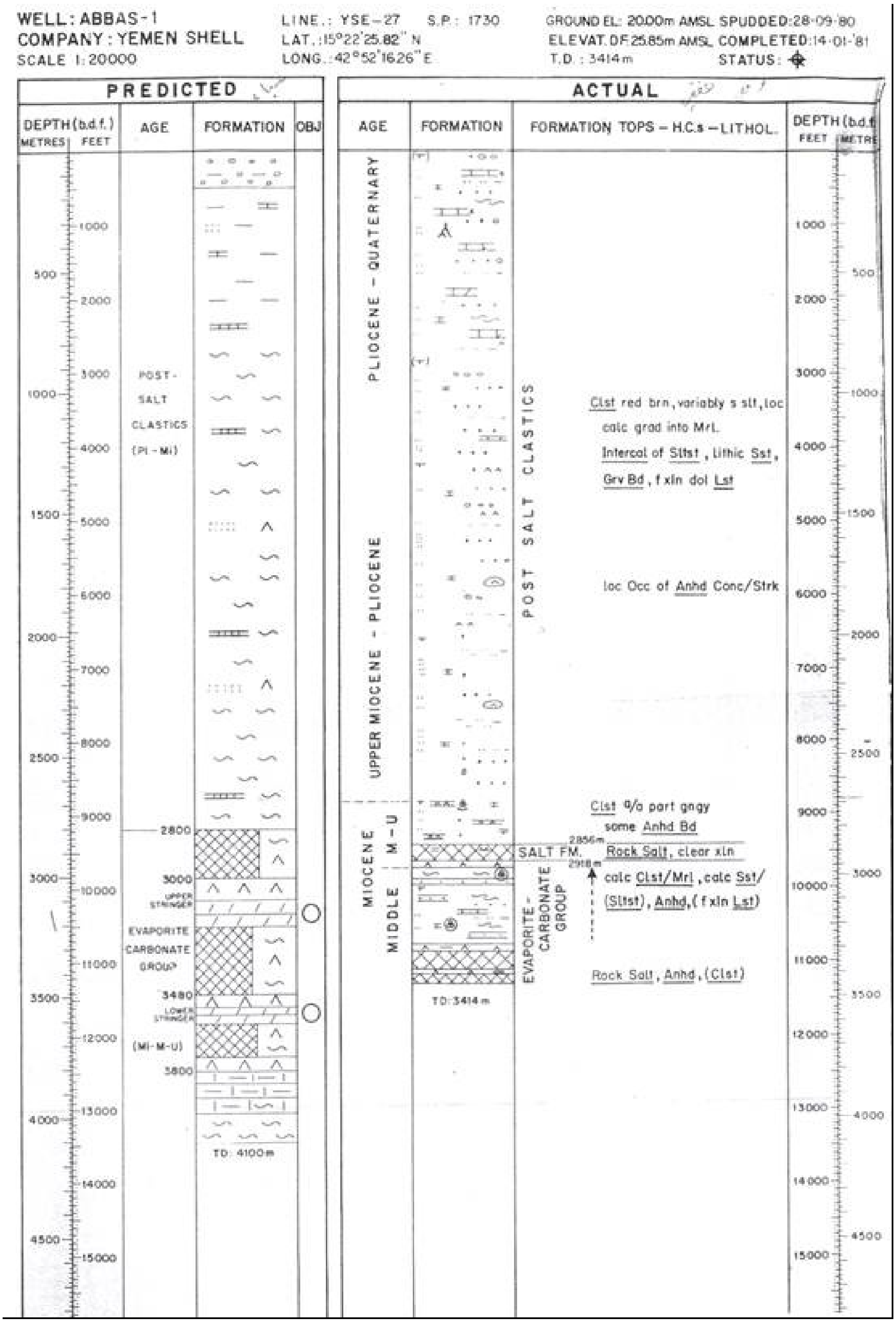

Figure 14: Example of the Geological column of the third geothermal area (Red Sea geothermal area)

Table 1 Temperature 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

Table 2 Temperature Data

Well	Depth (m)	Temperature (°C)	Heat Flow Wm^{-2}
ABBAS-1	0	20	
	1200	83	0.0829
	2870	170	0.1014
	2990	172	0.1029
	3290	182	0.0983

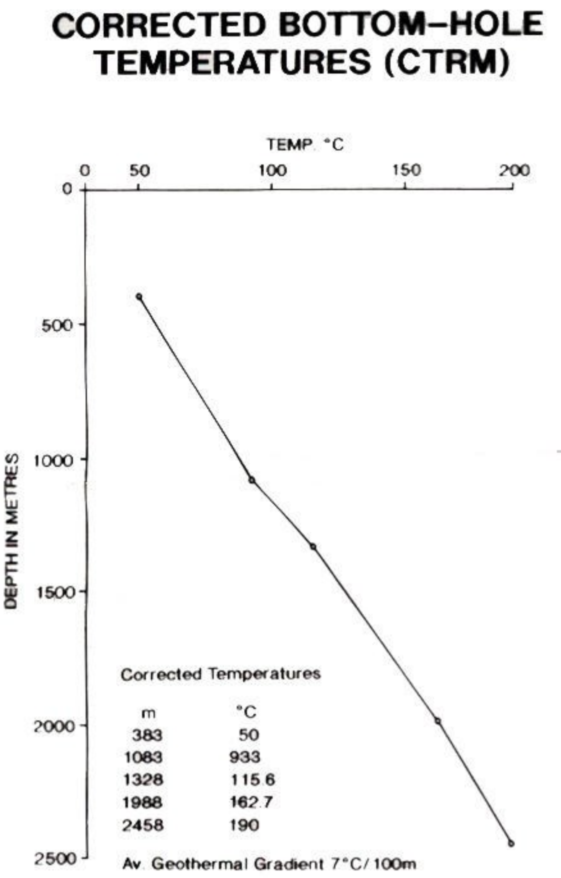

Figure 15: Example of the geothermal gradient of the third geothermal area (Red Sea geothermal area)

5. CONCLUSIONS

The first geothermal area (Al Lisi and Isbil Geothermal field) is located in the western Yemen volcanic part. It is particularly not a stable continental zone. It is characterized by some indications of elevated crustal magmas and thermal phenomena related to deep crustal fracture systems. The rocks in the study area were classified to 6 groups, trap series, post trappic volcanic activity, Isbil volcanic complex, Basaltic fissure volcanism and recently active sedimentary deposits. The main structural feature is NNE-SSW, NE-SW trend. The geothermal manifestations in Al Lisi and Isbil Geothermal fields are common in 4 areas in the study area. Two types of alteration zones are distinguished. Slight alteration was mostly characterized by slight color change of the brownish, reddish, yellowish to white colors and also involving some silica minerals (opal) and calcite veins. Some altered rocks assume a whitish color due to the presence of opline silica, clay minerals and iron oxides. The temperature of steam exceeds 92ºC and there are 118 hot wells in the area in which the temperature is between 25 to 59 ºC. And the geothermal manifestations (slight alteration) in Alsyani – Algandeah Geothermal area are common in many different sites in the geothermal field. There are 42 hot wells in the area where the temperature ranges from 27 ºC to 75 ºC. The thermal wells at 340 meters deep had a temperature of 75 ºC in the area. Two types of alteration zones are distinguished on the geothermal map, slightly alteration, and extinct clay alteration. In addition, the second geothermal area (Alsyani – Algandeah Geothermal field) is located in southern western Yemen volcanic part. The rocks in the study were classified to 4 types of rocks: - Tertiary Volcanic (Basalt, Rhyolite and Tertiary intrusive rocks), Tawilah Sandstone Group, Medj- Zir Sandstone and Quaternary Deposits. The main structural feature is NE-SW trend. The Geothermal Manifestations in Alsyani – Algandeah Geothermal field are common in many different sites in the study area. One types of alteration are zones are distinguished on the geothermal map, slightly alteration. The Red Sea geothermal area is located in west area of western Yemen volcanic part and was not more than 3000 km^2, but data from several areas throughout the world, including neighboring countries such as Ethiopia, yielded similar temperatures and geothermal gradients. In the present, the temperature logs from the boreholes show a temperature of 190°C at 2458 m depth in the Red Sea geothermal area.

6. REFERENCES

ELC-Electroconsult Dhamar-Rada geothermal prospect-geology and volcanology.: ELC-Electro consult, Internal Report, Milan (Italy), (1982).

YGSMRB-Yemen Geological Survey and Mineral Resources Board Exxon Exploration Production Mideast Inc.: Risabah-1 well, Final well Report W14A.170.L20, Sana'a Yemen, (1989).

Vaselli, O., Mattash, M. A., and Minnisali, A.: Geothermometry and geochemicalcharacteristics of the Yemeni thermal waters, (2002).

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.KThermal springs, fumaroles and gas vents of continental Yemen: their relation with active tectonics, regional hydrology and country's geothermal potential, (2007)

Angelo M., Orlando V., Mohamed M., Giordano M., Franco Tassi(2), Ad-Dukhain A., Al-Sabri., Al-Kohlani A., Geothermal prospecting by geochemical methods in the Quaternary volcanic province of Dhamar (central Yemen), (2009)

Saif W., Re-Interpretation of the previous geophysical field surveys in Al-Lisi - Isbil area for geothermal exploration Final Drafat Report Sana'a Yemen, (2010)