Proceedings, 7th African Rift Geothermal Conference
Kigali, Rwanda 31st October – 2nd November 2018

GEOLOGICAL SURVEY OF AMBADO-PK20, DJIBOUTI

Ayan Ahmed Suge, Moussa Hassanleh Hassan and Amin Mohamed Idriss

Djiboutian Office for Development of Geothermal Energy (ODDEG)

Under Presidency Office

P.O. Box 2025, Djibouti

ayan.suge24@gmail.com, moussahassanleh@hotmail.fr and amin.mohamed.idriss@gmail.com

Key words: Geothermal development, Ambado-PK 20, Republic of Djibouti

ABSTRACT

The geology of the Republic of Djibouti is marked by the triple joint between 3 different plates that created the Afar depression. The convergence which created rifts are those of the Red Sea, the Gulf of Aden and the East African rift. The rock formation of Djibouti is mainly characterized by Miocene, Pliocene and Pleistocene volcanic rocks.

The geothermal prospect of the PK20 region has been identified using the temperature anomalies observed on the water wells used for drinking water in the city of Djibouti. The Ambado-PK 20 exploration site is considered as a small site that is capable of producing electricity. Based on the high temperatures of the water from the wells, a prefeasibility study plan for this area was developed. The targeted area presents several types of geological formation: the basalt of the gulf bound with the opening of Tadjourah, the basalt of Dalha in the south in the massive "BourOugoul" and the basalt of Somali in the south-east and the Rhyolite of Mabla. On the whole, the study area is structured by normal faults that follow the direction of extension of the Gulf of Tadjourah. The tectonic structure is expressed by 3 families of faults which are the N80 ° faults at 120 ° almost E-W, the N10 ° almost N-S faults and the N60 ° and N150 ° faults. The contact between these geological formations and tectonic fabrics is related to the opening of the Gulf of Tadjourah.

These anomalies are, particularly, more observed on the northern part of the aquifer in the borehole region of PK20 and Awrofoul with temperatures ranging between 40 ° C and 61.4 ° C. The intersection of the major N-S and E-W trending faults can explain the anomalous temperatures recorded inside these water wells. The wells that are present higher temperatures are located closer to the junction of these faults.

1. INTRODUCTION

As part of the geothermal research program in the Republic of Djibouti, the OfficeDevelopment of Geothermal Energy (ODDEG) conducted a surface study on the geothermal prospect of Ambado-PK20. This site is part of 13 geothermal prospects listed across the country recently made by JICA with colaboration of the government of Djibouti in 2014. In terms of the presence index of this resource, the water well that it is carried out in this area revealed a thermal anomaly (around 66.7 ° C), including the Awrolafol drilling that supplies the city of Djibouti.

The Ambado-PK20 is located at about 20km from the capital of Djibouti and presented different geological structures, but also very active zone. The last campaign was carried out by CERD in 2010 as part of the research program entitled "Geophysics Application for Groundwater in Djibouti" funded by UNESCO.

This site is located at 20km from Djibouti town and there is water well which it supplies the town . Recently, mofette-like emanations (fumaroles with a temperature close to ambient temperature) have been observed on the ridge of Hayabley volcano.

This area have been studies in the past a large number of scientific works (geology, hydrogeology, geochemistry and geophysics) have been realized to understand the geometry of the brackish water underlying the freshwater aquifer.

The geophysical studies of the area has been the subject of several surface campaigns carried out by the BRGM (1960, 1963, 1965, 1972, 1987), University of Clermont-Ferrand and the University of Western Brittany (2003). The last campaign was carried out by CERD in 2010 as part of the research program entitled "Geophysics Application for Groundwater in Djibouti" funded by UNESCO. During this campaign, MT / TDEM survey was carried out due to the interruption of the campaign for the benefit of the geothermal program on the prospect Nord-Ghoubbet.

2. GEOLOGY OF DJIBOUTI

The geology of the Republic of Djibouti is marked by the meeting between 3 different plates that created the Afar depression. The convergence of these plates generated a deep chink in the earth's crust called rift, giving escarpments and normal faults along the axes. During this activities, 3 rifts are created the geodynamic plates in different directions: Red Sea, the Gulf of Aden and the East African Rift. They are currently home to significant volcanic and seismic activity, observable in the Afar Depression and the Rift Valley (McKenzie et al., 1970, Acton et al., 1991, Manighetti et al., 1998, Manighetti et al. Beyene and Abdelsalam, 2005).

The formation of Djibouti is mainly characterized by volcanic rocks of Miocene, Pliocene and Pleistocene (Figure). The Ali Sabieh basalt, dated Miocene, is a marker of the first movement of the Arabo-Nubian block (Figure 1). The rhyolite Mabla, located in the north of the country, shaped the Oligocene-Miocene bedrock. The Stratoïde series and the Gulf basalt are the recent formation and issued during the opening of the Gulf of Tadjourah. Lacustrine sedimentary formations, both detrital and evolutionary, have developed sedimentary formations in the grabben (Pleistocene to present). The geological map of the Republic of

Djibouti shows the different formations present in the region, ranging from older to more recent layers. The black square shows the Ambado-PK20 study area.

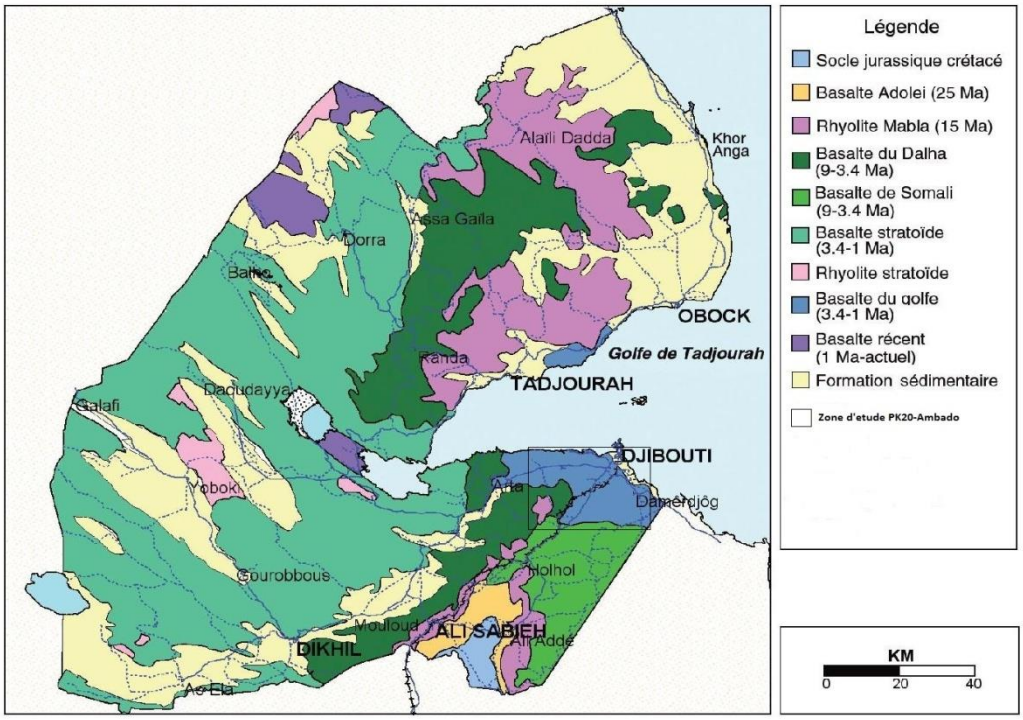

Figure 1: Geology of Republique of Djibouti (blake square prospect zone)

3. GEODYNAMIC CONTEXT

Due to an exceptional geodynamic situation, the Republic of Djibouti is located at the southeastern of the Great Afar depression. The separation of two plates Africa and Arabia involved that the crust is getting more thin in the depression of Afar. to. This separation is caused by the rift activity that created a new oceanic type crust in the Red Sea and Gulf of Aden. The Gulf of Aden is the divergent to south-east boundary of the Arabian Plate and was formed by oceanic accretion. In addition, the identification of magnetic anomalies indicates that the ages of the oceanic crust are becoming younger as they move to the west. Thus the junction of the triple point of the Afar depression is called "rift-rift-rift" types (Meckenize et al, 1970).

The East African continental rift or Ethiopian rift: the northern make an incision the African continent following the direction of N.NE-S.SW. The oceanic rift of the Red Sea: the direction of the Red Sea aligned N.NW-S.SE which corresponds to the separation between the plate Arabia and Africa. Finaly, the oceanic rift of the Gulf of Aden have the direction of East-West extends towards the west in the Gulf of Tadjourah. The Aden ridge is torn apart and changes in south-west direction to Assal and across Makarassou to Manda Inakir. The movement of these different tectonic plates is represented by the following figure.

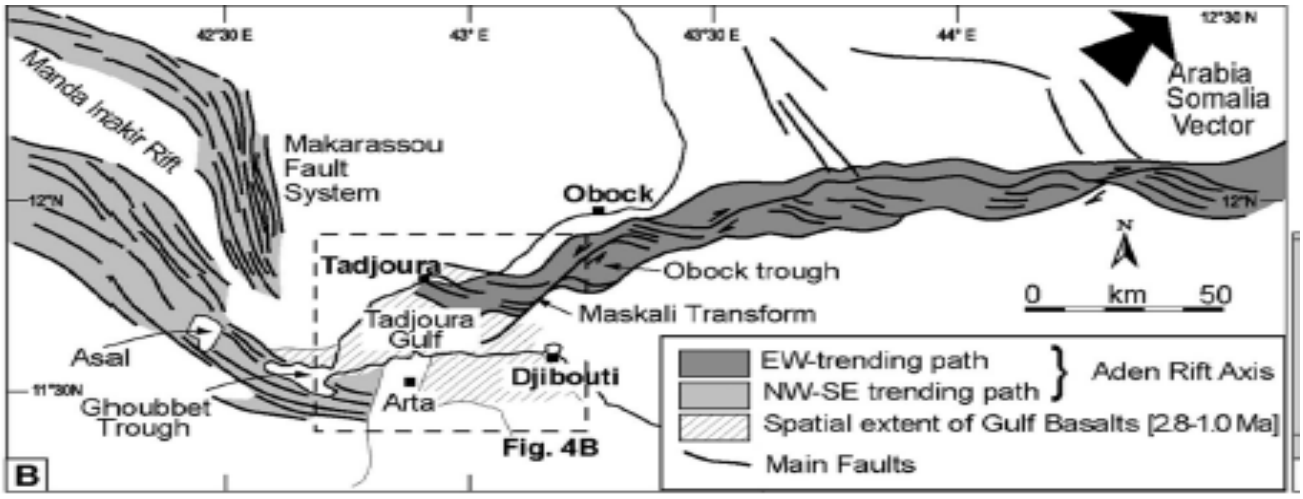

Figure 2: Structural map of Gulf of Tadjourah andrift Asal-Ghoubet (M. Daoud et al., 2008).

3.1.MORPHOLOGY AND STRUCTURAL GEOLOGY

The distribution of the general morphology of the Ambado-PK20 zone is studied by the use of 3D images and predefined topographic sections as well as collected GPS data. The topographic average varies from 0 to 400 meters altitude where the maximum altitude is at Arta region with an altitude of 700 meters. Going to the west, the difference of the topography is between 500-700 meters above sea level because the basalt of the Gulf is superimposed on the Stratoïde series, hence the characteristic of this bulging (Bernard Robineau 1979). The study area extends from the east to Ambado and south to the massif of Ougoul (Chebelley-Ghoubetto area). The structural observations are made from the pre-existing structural maps and Landsat images were completed by the field study. The important deformations are observed on the basalt of the Gulf in general, more precisely on the southern flank of the Gulf of Tadjourah. According to field observations, the basalt of the Gulf is fractured by a NW-SE fault system and E-W and we also note that the Ambado Graben collapses to the North.

The Chebelley-Ghoubetto zone is almost stable, no dense fraction has been observed. It results less tectonic movement. On the other hand, the kinematics of the Ambado-PK20 zone is located on the southern flank of the Gulf of Tadjourah where the tectonic activities related to the opening of the Gulf of Tadjourah are important. The central part is affected by dense fault networks mainly of EW direction which disappear to the east in the Hayabley volcano side, where the latter is posterior to the faults by covering the basalt of the gulf, and to the west these faults as we approach the Arta mountain range (Med Daoud et al.). Over the entire study area is structured by normal faults that follow the direction of spread of the Gulf of Tadjourah. The tectonic structure is expressed by several families of faults:

- The N80 ° faults at 120 ° EW most recent also affecting the posterior series (Gulf Basalt). There are normal faults with large vertical discharges (several hundred meters), the percentage of these faults increases with the approach of Tadjourah Gulf (Figure 3) and the contact zone with Somali basalt. This geological structure is linked to the axis of the ridge at the opening of the Gulf.

- The N10 ° almost N-S fault is observed in the Chebelley zone, crosses the volcanic cones (the best known Goumarré) and also the ancient formations (Dalha, Somali and Mabla Rhyolite).

- The N60 ° and N150 ° faults, According to the geological map (Figure 1), these faults are mainly located in the South towards the Boulé region and near Wea.
  The following map shows the fault networks described above with the drill points of the PK20 study area.

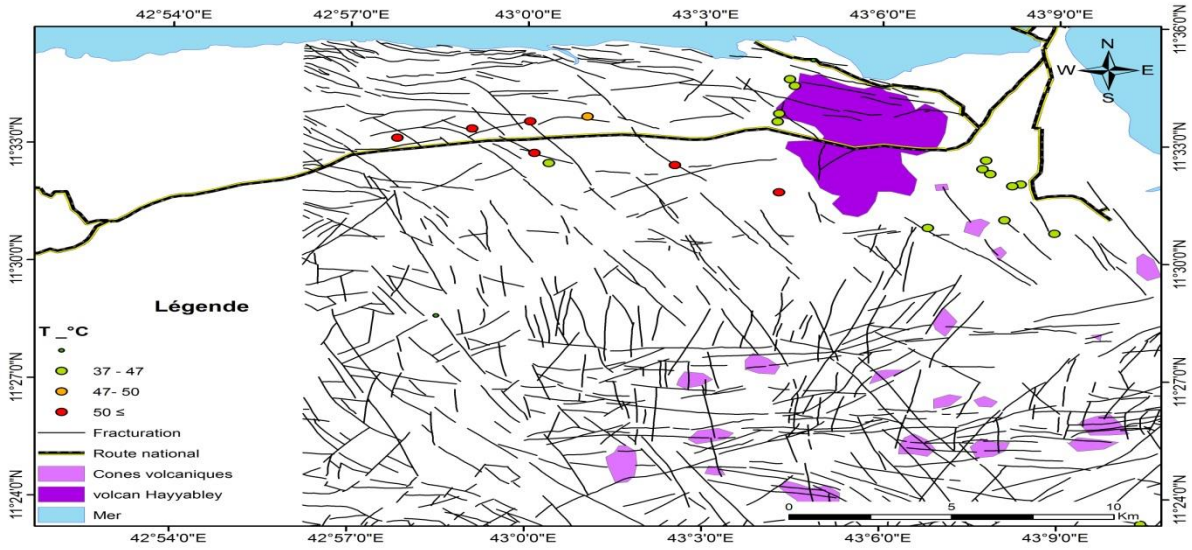

Figure 3: Structural map of Ambado-PK20 with intrusion (Vincent, 1990)

We made 3 crossings as shown on the following map (Figure). We observed the NW-SE, E-W faults and moving further south the Rhyolite formations are oriented North-South. The sections show the geological units as well as the fault network (Figure).

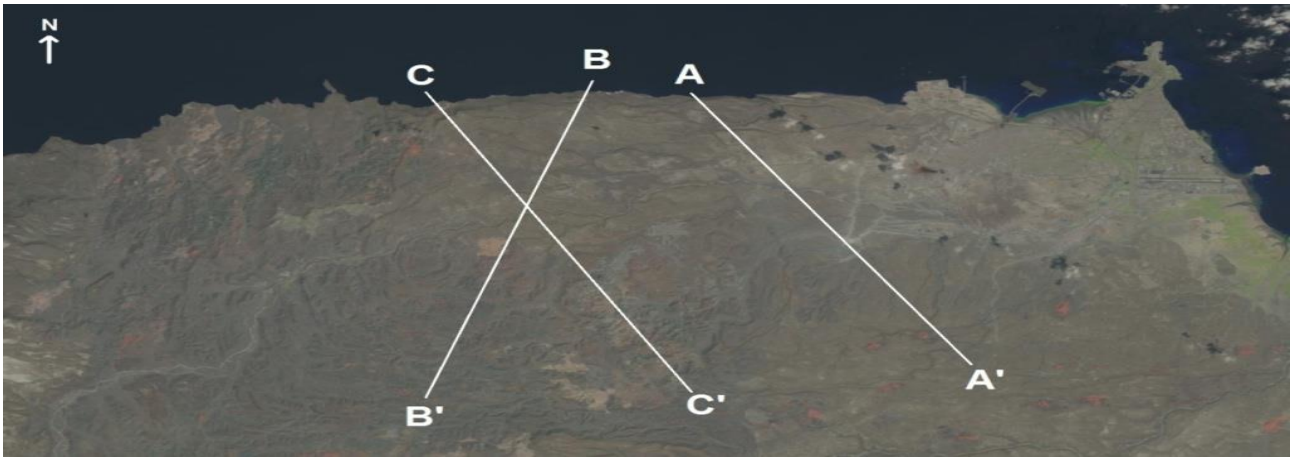

Figure 4 : Landsat image of the Ambado-PK20 study area. The lines A'-A, B'-B and C'-C show the location of the cross sections illustrated in FIG.

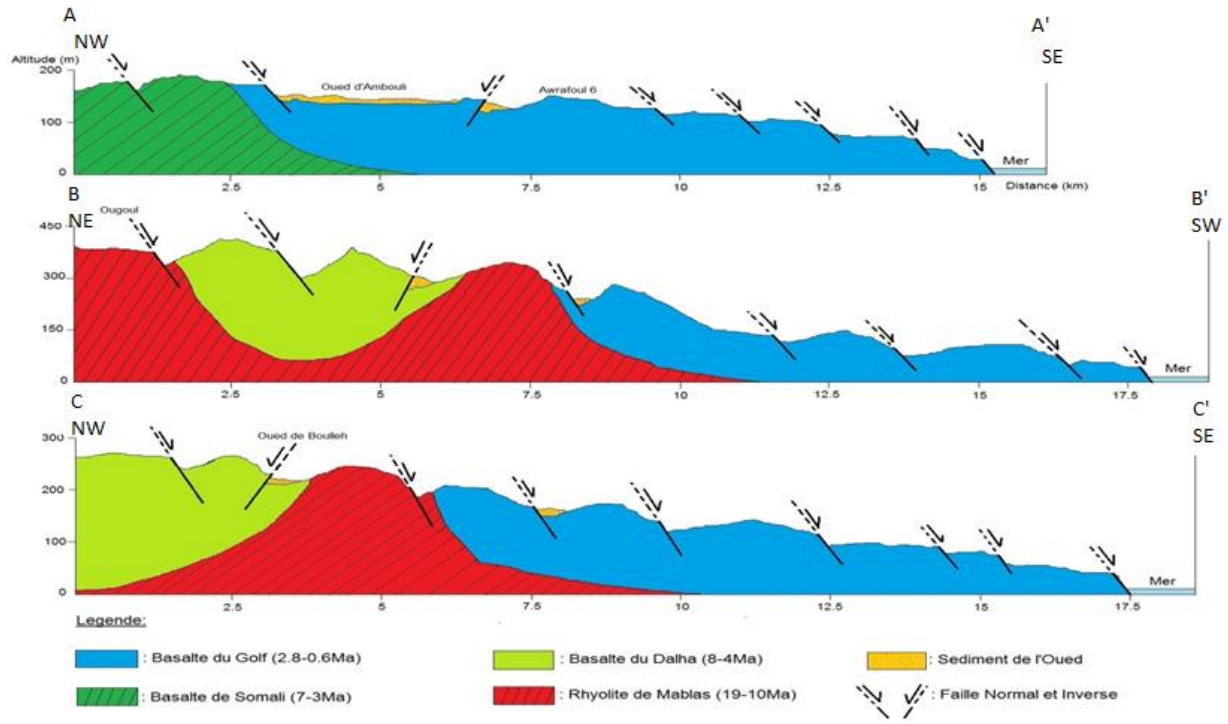

Figure 5: Cross sections of the Ambado-PK20 study area, the location of these three sections is shown in Figure 4.

4. GEOLOGICAL FORMATIONS

4.1The volcanic formations

The Ambado-PK20 study area presents several types of formations; the Gulf basalt linked with the Tadjourah opening, the Dalha basalt to the south in the "Bour Ougoul" massif and the Somali basalt to the south-east and the Mabla rhyolite. The contact between these geological formations and tectonics is related to the opening of the Gulf of Tadjourah.

Gulf basalt dating from 3.4 to 1.4Ma is the most expended formation in the Ambado-PK20 study area. The basalt of the Gulf, which dates from 3.4 to 1.4Ma, occupies a geographical position, around the Tadjourah Gulf course. All of the basalt of the Gulf is emitted on top of Dalha's basalt and the Rhyolite of Mabla which forms the relief of the "Bour Ougoul" massif. The Gulf series consists mainly a basaltic intrusions with sedimentary formation intercalations (red clays and conglomerates). The thickness of this formation reaches at least 70 meters (Jalludin et al. 1990), reach the Somali basalt and Dalha basalt in the west.

The Dalha basalt, which dates from about 9 to 3.4Ma, is outcropping to the southwest of the study area. A more or less pronounced angular discordance is found on the highly eroded Mabla rhyolites. There is also intercalation between ignimbrites and detritics formations. Normal fautls with direction of N160 and N40 are marked the old rock Mabla Rhyolite (Figure 6). This series narrows northward as the Gulf approaches, this would locate the emissive fissures at the current location of the Aden Gulf.

Somali basalt is only found in the southeastern part of the Republic of Djibouti (Figure 6). This series is dated 7.2 to 3.4 Ma and their emplacement seems to be along emissive fissures direction N160 ° (Red Sea). The Somali basalt would be the last emissions of the system in extension in the same direction of the Red Sea, before the abrupt change due of the opening

of the Gulf of Tadjourah about 3.5 Ma following direction E-O (Chessex and al.1975). This basalt is unconformably outcropping on the Dalha basalt stack and in places on the also tilted Mabla rhyolite.

The rhyolite of Mabla is the oldest formation of the study area that was set up at the Miocene in the southwest. Some rhyolitic flows cover the basalts of Dalha. The ryolite is more light than the basalt, it is seem light redish and very altered.

4.2 Sedimentary formations

Sedimentary formations are less expented than volcanic rocks. They are found along the main wadis and in areas of alteration on the basaltic plateaus. In the Chebelley area, the wadis "Waan-cadle, cago-dheree and chebelley" are drained into Somali basalt formations (Figure 6). These basalts cover the plain of south Djibouti of the regional flexure of Ambouli; farther north, they are covered by the basalt of the Gulf. The wadis (Sarrey, bicidle) seen in the Ambado sector are drained in the basalt formations of the Gulf. Subsequently, we find that the wadi "Boulé Bialé" meets two types of formations the basalts of Dalha and rhyolites of Mabla. The conglomerates are older than the initial basalts and are found in the Arta area. The old valley is filled by 25 m conglomerate. The very coarse conglomerate are at the base ad showsa typically fluviatile stratification. The red clays outcropping around the Gulf basalt come from the precipitation of weathering and this red color is due to the presence of iron oxide.

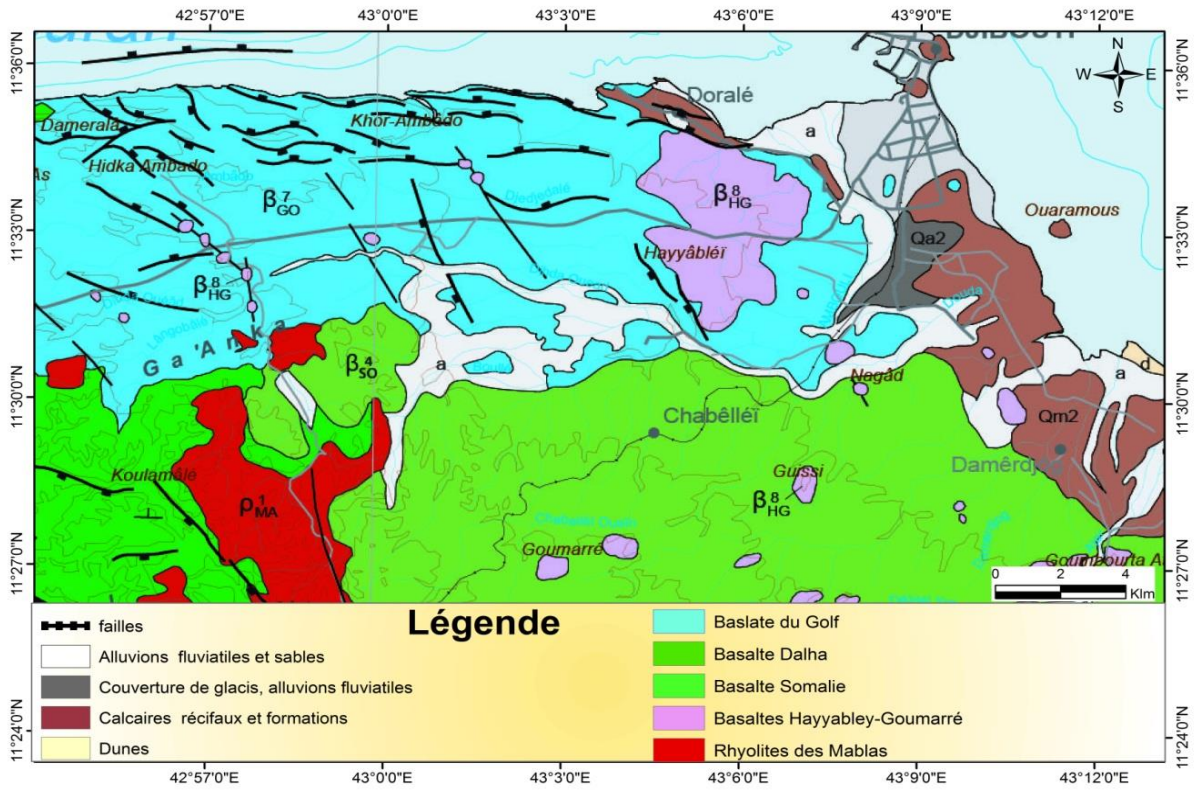

Figure 6: Geological Formation of the Ambado-PK20.

5. Correlation of Awrofoul water wells 2, 5 and 6.

The water wells of Awroful 2,5 and 6 are based on the basalt of the Gulf. The respective altitude is 118 m, 85 m and 135 m above sea level. These boreholes allowed the recovery and analysis of the cuttings obtained. The interpretation of the cuttings made it possible to

recognize the experimental site's geology and to carry out logs and litho-stratigraphic sections. For Awrofoul 2, with final depth of 128 m, there is 0 to 40 m of highly altered Gulf basalts. On the other side, the lithological section of Awrofoul 5, which has a depth of 160 m, shows a superficial sedimentary level between 0 and 6 m thick, formed by alluvium sediments. At Awrofoul 6, we observed the presence of cracked basalt from 0 to 63 m. The basalts begins at 6 m with some grains of clay and become altered from 70 m until the end of the drilling at 160 m for Awrofoul 5. As shows forAwrofoul 6, we observed sands of the wadi from 63 to 80 m (Figure 6). In Awrofoul 2, alternating cracked and altered basalts and sedimentary deposits in: 90 to 100 m, 100 to 110 m, 110 to 120 m and 120 to 128 m are observed. On the other hand, in the Awrofoul 6 well we found the cracked basalt from 80 to 88 m and then deteriorated to 100 m and at the end the slags take the relay from 100 to 106 m and a the end at 190 m. Then we have altered basalts which recover from 106 to 180 m. The cut is finished with the altered basalts. The static water table level at Awrofoul 6 is 114.43 m. On the other hand it is 70 m for Awrofoul 5. Their respective distance from each other is 4.72 km.

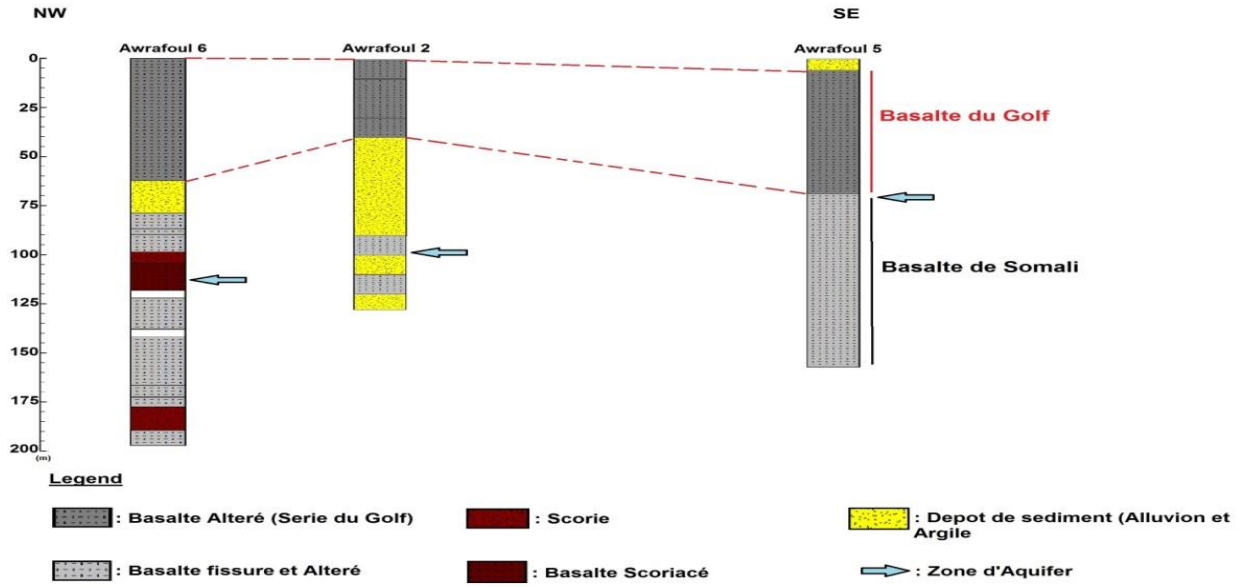

Figure 7: Correlation of Awrofoul boreholes 2, 5 and 6, (ODDEG and al.2017)

6. RESULTS

During this field study, 4 different geological units were observed: Mabla rhyolites, Somali basalts, Dalha basalts and Gulf basalts. Field observations have shown that Gulf Basalt is the most recent formation by its very black color and the size of the minerals that is aphanitic. The latter has very little hydrothermal alteration. There is an NW-SE fault network that is responsible for the formation of the Ambado graben in the direction of the Tadjourah rift and an E-W fault parallel to it. The blocks remain nevertheless very fractured and permeable.

In the figure above (Fig.7), the Awrofoul 2, 5 and 6 boreholes cut the GulfGulf basalt in the near surface and the Dalha would be deeper. Drilling has high temperatures ranging from 37.3 to 61.4 ° C in the 200m depth and, as shown in Figure 8 below, they are found at the intersection of NW-SE faults with WSW-ENE. These faults pass near the boreholes or they tend to join the initial direction of the Tadjourah rift (E-W). Similarly, the water level drops from 72m Awrofoul 5 to 118 m Awrofoul 6 it tells us that drilling crosses indeed a fault deep.

In short, as the topography decreases we have assumed that the static water level of Awrofoul 2 is about 100m.

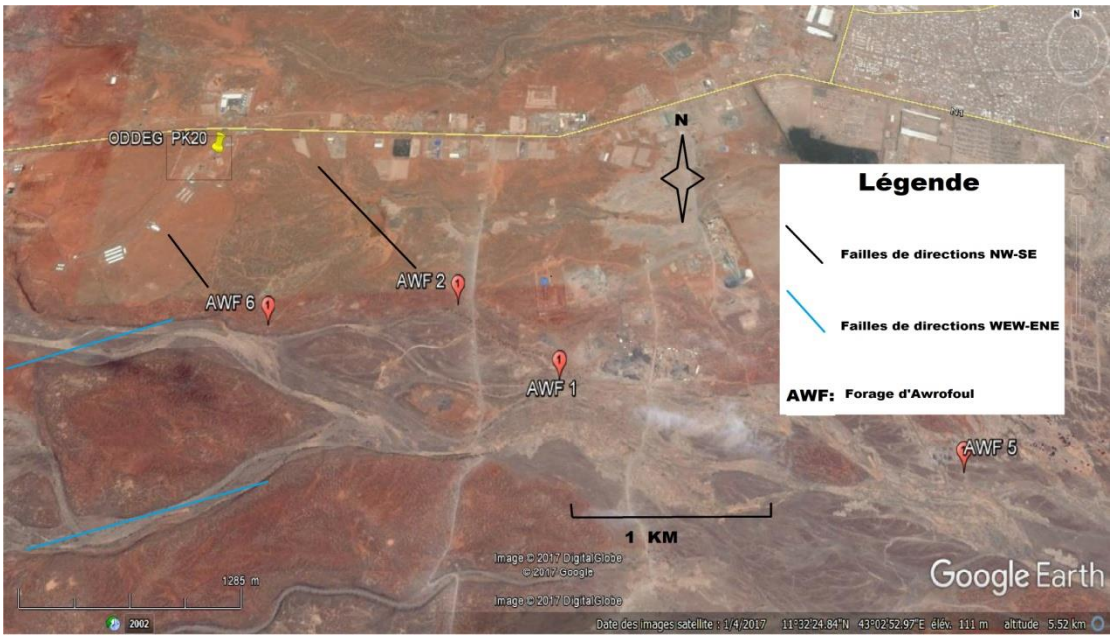

Figure 2: Location Awrofoul wells in the faults zones.

The fault networks intersept in several places where there should be hydrothermal manifests on the surface which could explain the high temperatures but no alteration is observed on the geological formations. It can be deduced that drilling intercepts faults where the water level is detected by the probe, ie between 72m and 118m. For example, the drilling of Awrofoul 6 notes a higher temperature compared to others.

Finally, the harvested samples are altered by approaching the beds of the wadis because we find crystals of calcite. According to the following table, the samples analyzed with XRD mainly have calcite, little montmorillonite as alteration minerals. These analyzes are therefore consistent with the hypothesis that in the Ambado-PK20 study area, we are not in the presence of surface manifestations and the rocks show very little alteration.

7.HYDROGEOLOGY

7.1.The aquifer of the study area

What constitutes the aquifer of the study area is the basaltic entity. It is the mixture of scoriaceous basalt and fractured basalt that serves as a reservoir of water in the region. There is a natural boundary between the basalt aquifer of the Gulf and Somali basalt aquifer. This limit is the bed of Ambouli wadi. South of the bed, the aquifer is the Somali basalt and to the north of this bed, the basalt of the Gulf course plays the role of the reservoir. On the other hand, at a depth of 223m on the PK20-2 borehole, we fall back on the Somali basalts. For these two geological entities that serve as aquifers, the continuity of the hydraulic gradient from basalt Gulf to Somali, shows that there is a relationship between these two entities.

The slags with greater porosity contain more water than fractured basalts and have higher transmissivity than the rest of the system. Alteration and hydrothermalism are factors that contribute to reducing the transmissivity of the aquifer. The existence of trace hydrothermal in this system is proven by the calcite vein seen on a core sample of the piezometric

boreholes of the Atar hydrogeological study site. Older Dalha basalts have much lower transmissivity than Gulf basalts. By comparison, Adolei basalts aged 25 Ma have an average transmissivity of 0.001m² / s while those in the Gulf have an average transmissivity of 0.1m² / s. The high fracturing density at the study site tends to increase the reservoir capacity of the aquifer. The dominant fracturing network is the N80 and N140 network and is due to the opening of the Gulf. This dense fracture network thus ensures a good flow of water throughout the aquifer. That said, the heterogeneity remains important and the percentage of 50% of successful drilling is there to confirm it.

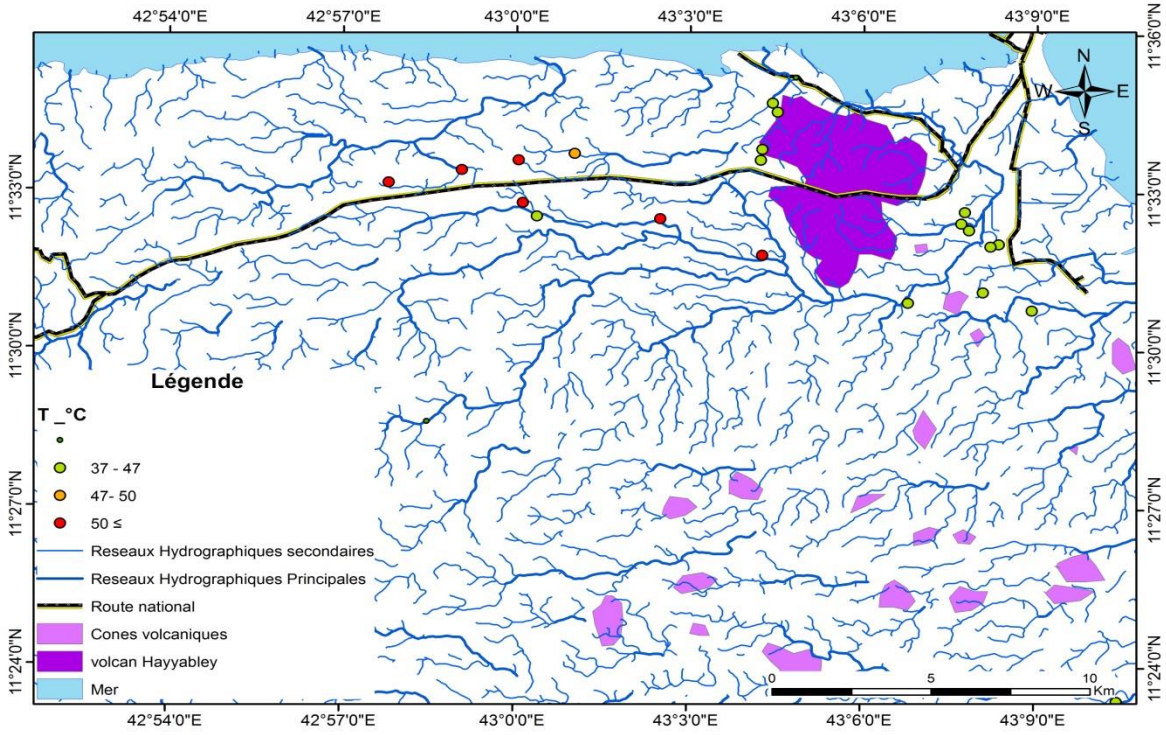

Figure 3: Hydrographic of PK-20-Ambado.

The water table holds its main resource by the infiltrations at the wadi beds and by the inferoflux aquifer found in the sedimentary layer of the wadi beds. During the floods in the wadis, the waters take advantage of it to infiltrate and recharge the deep aquifer. In a study of the Atar hydrogeological site, a rise in the piezometric level was observed after the flood days. According to simulations made in thesis work, it has been shown that the waters of the aquifer flow towards the shores of the sea from the west of the study area.

The quality of the waters is very varied. The waters of the top of the aquifer are quite heavy but going deep, it is possible to encounter brackish water. These waters are pocket-shaped and are randomly dispatched to the aquifer. Brackish waters are much more present near the coast. A positive geothermal anomaly on the Awrofoul, FU2B, FU3, FU4 and PK20-9 boreholes was found in PK20. On the PK20-9 borehole, the thermal profile shows a temperature increase of approximately 12 ° C over 100m while the normal is 3 ° C over 100m.

8.CONCLUSION

During this field study, 4 different geological units were observed: Mabla rhyolites, Somali basalts, Dalha basalts and Gulf basalts. Field observations have shown that Gulf Basalt is the most recent formation by its very black color and the size of the minerals that is aphanitic. The latter has very little hydrothermal alteration. There is an NW-SE fault network that is responsible for the formation of the Ambado graben in the direction of the Tadjourah rift and an E-W fault parallel to it. The blocks remain nevertheless very fractured and permeable.

REFERENCES

Abdourahman., Houmed and Gaba. "Hydrogeology of volcanic environments under arid climate. Experimental site characterization and numerical modeling of the basaltic aquifer of Djibouti(Horn of Africa).", thesis, University of Poitiers, France (2009).

Daoud. M. A.,"Dynamic continental rifting from 30 Ma to the present in the southern part of the Afar Triangle. Tectonics and magmatism of the Tadjourah rift and the Danakil and Ali Sabieh domains.", thesis, University of Brest, France (2008) Western Brittany

Jalludin,M., "Properties Geometric and hydrodynamic aquifers in volcanic environments cracked in arid climate, REPUBLIC OF DJIBOUTI (1993).