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# Exploration of the Heat Source and Geothermal Possibilities of the Aksaray Region, Central Anatolia, Turkey

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## ABSTRACT

The studied area is located at eastern part of Aksaray province in Central Anatolia. The basement rocks of studied area is Paleozoic aged Bozçaldag formation composed of marble, schist and gneiss. These rock units are overlain uncomfortably by Tertiary to Quaternary aged volcanic rocks of Cappadocian volcanic belt interlayer sediments. The compositions of these units are mainly represented by tuff, ignimbrite, reworked tuff interlayer sediments, basalt lavas, ash fall deposits, pumice and dasite to rhyodasitic lava domes.

The study area contains Ziga and Acıgöl (Narköy) thermal area, which they have similar geologic environments with in the Cappadocian volcanic belt of the Tertiary to Quaternary age. Existence of surface manifestation like that high regional heat flow, the presence of expanding acidic to weakly acidic hydrothermal alteration surrounding the geothermal area, hot springs which have a temperature of 44-65 $^{o}$C indicating the important of geothermal possibilities in the area. Initial studies such as field geology, geophysical investigations (gravity-magnetic survey and local electrical resistivity studies); have been completed in the studied area. As well as four gradients well and three shallow production well have been drilled in the study area in 1980’s.

Reassessment gravity and magnetic studies indicated that four important anomalous exists with respect to geothermal heat source exploration. Magnetotelluric (MT) and Transient-electromagnetic (TEM) methods have been carried out where the anomalous in the study area, for this aim the MT soundings have carried out along the four profiles on 38 points of measurements. Besides MT studies also remote sensing, aerial photo studies, detail geology, surface hydrothermal alteration, water chemistry has been carried out in the studied area. On the basis of the MT measurement low resistivity anomalous are interpreted to be hot, solid and / or partly molten magma bodies which can be considered the heat source of the geothermal system in the study area. It has been found that the average depths of the heat sources are about 5-8 km. A good correlation has been found high gravity - low magnetic, high heat flow and low resistivity body measured with MT exploration in the studied area.

On the basis of the MT studies, low resistivity zone exists from the surface to 1500m depth considered with to hydrothermally altered tuff and ignimbrite as a cap rocks, and high resistivity below the low resistivity zone considered with the deep reservoir rocks.

On the basis of water chemistry studies show that the hot waters can be classified as Na, Cl, $HCO_3$ and Na, Ca, $HCO_3$, Cl, As and B bearing hot and mineralized water. On the basis of silica and Na/Li geothermometre of the reservoir rocks are 90-153 $^{o}$C and 135-197 $^{o}$C respectively.

## 1. INTRODUCTION

Studied area is located at the eastern part of the Aksaray within Cappadocian Region in central Anatolia (figure 1). Central Anatolia is situated in the middle of the Anatolian block bounded by ‘the NAF-North Anatolian Fault’ and ‘EAF-East Anatolian Fault’. After the continental collision between Arabian Plate and Anatolian, Two main fault (NAF, EAF) have occurred and Anatolian plate have begun to move through the west (figure 1) (McKenzie 1972, Yılmaz, 1991). This motion played a major role in the deformation of the block (Mc Kenzi and Yılmaz, 1991; Lyberis et al., 1995). Volcanic activity most pronounced in Central Anatolia is related directly to this deformation(McKenzie and Yılmaz ,1991; Ayder et al., 1995).Cappadoccian Volcanic Provens comprise ignimbrites and two strato-volcanoes(Karacadag and Melendiz) of Miocene-Pliocene age, plus a number monogenetic vents(basaltic maars, cinder cones, lava domas) and Quaternary age two stratovolcanoes (Mont Erciyes, Mount Hasan)(Ayder et al 1995). This volcanic province is known as The Cappadoccian Volcanic Province (CVP) is located within depression surrounded by basement rocks referred to as the central Anatolian Crystalline (Göncüoğlu et al, 1992). These basement rocks represented by gneiss schist and marble which referred as Tamadag and Bozçaldag formation in the area (Seymen, 1981). This Province consists of Neogene –Quaternary aged volcanic rocks and interlayer some sediments (Toprak, 1998 and 2000). The volcanism activity has begun during Miocene but main activity occurred during Quaternary period. The volcanism activity in Central Anatolia has been studied many researchers whose studies petrographical, chronological, emplacement of ignimbrite and geochemical characteristics(Pasquare, 1968; Keller, 1974; Innocent et al.,1975; Batum, 1978a,b; Beekman, 1966; Pasquare et al., 1988; Schmaher et al., 1990; Ercan et al., 1990, 1992; Bigazzi et al., 1993; Aydar et al., 1994; Le Pennec et al., 1994; Druit et al., 1995; Dhont, et al., 1998; Toprak, 1998, 2000 ).

Water chemistry (Göçmez, 2000) and isotop studies have been carried out (Time, 1993) in region and stressed the importance of the area for geothermal exploration.

As young volcanic activity has effected from Miocene to Quaternary, this region has important geothermal potential There are two main Geothermal field in this region as Ziga and Acigöl(Narköy) geothermal fields has temperature range between 44-65°C. Field geology, gravity, magnetic surveys have been completed in 1980-1990's (Öktü and Kalkan, 1984; Akdoğan, 1989; Kaynak, 1989; Kaya, 1991) and four gradient well and three shallow well have been drilled (Ölmez and Gevrek, 1991) in the areas. Gravity and magnetic studies have been reassessed and some anomalous defined which can indicate heat source in the study area (Akdoğan et al, 2000a, b, c).

The aim of this study is to explore the heat source and geothermal possibilities of the area. Remote Sensing, fotogeology, detail geology, hydrothermal alteration, water chemistry, isotope studies and Magnetotelluric(MT) and Transient-electromagnetic surveys(TEM) have been carried out and gravity, magnetic data's have used for this purpose(Burçak et al, 2003). A magnetotelluric survey was chosen to explore the anomalous which defined from gravity and magnetic surveys and to investigate the deep reservoir under the thick volcanic rocks. Before MT survey, on the result of reassessment of gravity and magnetic data's in the area, four main anomalous have been found. Low magnetic and high gravity anomalous have been considered that being a heat source for the geothermal systems in the area (Akdoğan et al, 2002). Two of these anomalous are close to the Ziga and Acigöl geothermal area but the others several km far from the known geothermal area, an other words, and two anomalous encountered to the area having no geothermal manifestation at the surface (Figure 9, 10, 11, and 12).

In this paper we shall define the heat source opportunities and geothermal importance on the base of MT, TEM surveys and hydrothermal alteration in Aksaray region.

MT soundings have carried out along the four profiles on 38 points of measurements. The data obtained from MT sounds on the Central Anatolia may be divided into three groups. The low resistivity section from the surface to 1000-1500m depth has been interpreted hydrothermaly altered volcanic rocks such as tuff and ignimbrite. The high resistivity below the low resistivity zone has been interpreted reservoir rocks. The low resistivity body has average depth of between 5000-8000m intruded within high resistivity crust lithosphere interpreted as hot and solid and/or partly molten magma bodies which can be considered heat source of the geothermal systems.

Surface hydrothermal alterations studies have shown that the fluids which caused the hydrothermal alteration on the young volcanic rocks belong to Cappadocian Volcanic Belts have a temperature about 100 °C and acidic to neutral pH conditions. MT surveys indicated that this hydrothermaly altered rocks has 1000-1500m thick. These rocks can be considered that the cap rocks of the geothermal system in Aksaray region, Central Anatolia.

## 2. GEOLOGY

The basement rocks of studied area is Paleozoic aged Bozçaldag formation composed of marble, schist and gneiss and intruded Cretaceous Baronetage granitic intrusion (Seymen, 1981; Ayhan and Papak 1988) This basement rock units are referred as Central Anatolian Crystalline Complex(Göncüoğlu et al., 1992). These rock units are overlain unconformably by Early Eosen aged Çayraz formation which consist of sandstone, limestone and marl, Late Eocene-Early Miocene aged terrestrial clastic sedimentary rocks are called as Mezgit Group(Ayhan et al., 1988) which composed of conglomerate and gypsum, Middle Miocene to Quaternary aged sedimentary and volcanic rocks of Cappadocian Volcanic belt interlayer sediments. The Units of CVP are classified by Beekman, 1966 and Innocenti, 1975. Composition of these units are mainly represented by tuff, ignimbrite, reworked tuff interlayer sediments, basalt lavas, ash fall deposits, pumice and dacite to rhyodasitic lava domes(Figure 2). Rock units of the Cappadoccian Volcanic Belt were defined by Beekman From older through the younger like below, middle-upper Miocene age Göstük tuffite, Göstük ignimbrite, Karakaya tuffite, Pliocene-Pleistocene aged Selime tuff, Gelveri ignimbrite, Kızılkaya ignimbrite, Hasandag ash formation, Göllüdag ash flow and tuff, Holocene aged Göllüdag rhyolite and rhyodacite lavas, pyroclastic cones(scoria, volcanic bombs,lapilli ), basalt-andesite lavas, ignimbrite, Acıgöl pyroclastics and basalt lavas.


**Figure 1: Location map of the studied area**

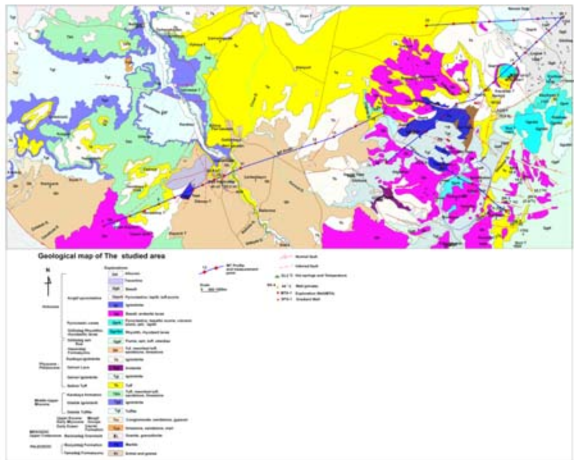

**Figure 2: The geological map of studied area**

## 3. GEOTHERMAL FIELDS IN AKSARAY REGION

The studied area consist Two main geothermal fields have temperature(surface and subsurface) range between 52-65 °C as Ziga and Acıgöl(Narköy) and Şahinkalesi 44 °C subsurface temperature without no surface manifestation. Maximum temperature of hot springs in Ziga geothermal field 52 °C (figure 2). Two gradient well (ZBG 1 and ZBG 2) and one shallow (240m) production well (48 °C temp and 100 l/sec output) have been drilled in the area. High grade geothermal gradient (almost two time of normal gradient) have been measured from the gradient wells (0, 62 °C/10m and 0, 53 °C/10m respectively).

There is hot springs with range of temperature between 43-57 °C in the Acıgöl geothermal field. Two gradient well(SFG 1 and 2) have been drilled in the area (Figure 2) and too high grade geothermal gradient have been measured from SFG 1 well (3 °C/10m) and high gradient from SFG 2 (0,5 °C/10m) wells(Ölmez and Gevrek, 1991). Three shallow (90-180m) production well have been drilled in

Acigöl field, and hot water has 65 $^oC$ temperature been produced from these wells.

There is almost no surface manifestation in Şahinkalesi geothermal field. Only indicator is a well drilled by a farmer for irrigation purposes. Geothermal fluid has temperature 44 $^oC$ been produced and used irrigation (SK-2 in, figure 2.)

## 4. HYDROGEOCHEMISTRY STUDIES

Water chemistry studies have been carried out in the area. The variation temperature and chemical composition of hot and cold water from the studied area are shown in table 1 and figure 3. According to the IAH standards, the hot waters in Ziga field classified as Na-Cl-$HCO_3$ type and As and B bearing mineralized hot water. Geothermal fluids in Acigöl field, classified as Ca-Na-$HCO_3$-Cl type and B bearing mineralized hot water, and Şahinkalesi hot water(from well) has been classified as Ca- Na-$HCO_3$ type non mineralized thermal water. According to Giggenbacch 1988(figure 4) the hot waters are immature in the Aksaray region so silica thermometers have been carried out in the area. On the basis of silica thermometer (Fournier 1977) 119-145$^o$C, 160-181 $^o$C and 135-159$^o$C reservoir temperature have been calculated in Ziga, Acıgöl and Şahinkalesi geothermal fields respectively.

**Table1: Major anions and cations of thermal and cold water in Aksaray geothermal fields**

| Smp | Temp°C | pH | Ca | Mg | Na | K | Cl | SO4 | HCO3 | H2SiO3 | H3BO3 | TDS(mg/lt) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SDJ1 | 24.4 | 6.85 | 43 | 7.7 | 18.1 | 10.6 | 8.52 | 5.3 | 232 | 130 | 4 | 459.19 |
| SK1 | 10.9 | 7.33 | 22 | 1.82 | 3.5 | 6.6 | 2.84 | 7.69 | 81 | 67.5 | | 192.95 |
| SK2 | 44.1 | 7.39 | 44 | 7.9 | 21.5 | 16.5 | 3.55 | 2.46 | 261 | 189 | | 545.91 |
| SK3 | 26.8 | 6.7 | 52 | 13.2 | 17.1 | 12.2 | 4.62 | 4.81 | 296 | 130 | | 529.93 |
| SK5 | 23.7 | 7.54 | 22 | 8.3 | 17.8 | 12.9 | 3.2 | 1.92 | 162 | 153 | | 381.12 |
| ACG3 | 43.3 | 6.69 | 327 | 13.9 | 175 | 60.5 | 247 | 80.2 | 1275 | 138 | 80 | 2396.6 |
| ACG4 | 22.4 | 6.78 | 351 | 53 | 138 | 73.1 | 255 | 98.9 | 1681 | 191 | 79 | 2920 |
| MT1 | 53 | 7 | 224 | 44 | 190 | 64 | 300 | 156 | 970 | 263 | 48.5 | 2259.5 |
| MT2 | 65 | 7 | 92 | 49 | 195 | 66 | 299 | 160 | 537 | 222 | 48.5 | 1668.5 |
| AZ1 | 39 | 6.5 | 276 | 46 | 1175 | 150 | 1889 | 72 | 1165 | 61 | 182 | 5016 |
| AZ2 | 37 | 6.5 | 300 | 41 | 1225 | 156 | 1907 | 78 | 1208 | 61 | 188 | 5164 |
| AZ3 | 51 | 6.9 | 309 | 49 | 1160 | 158 | 1900 | 65 | 1244 | 61 | 182 | 5128 |
| AZ4 | 46 | 6 | 300 | 36 | 1180 | 162 | 1880 | 71 | 1208 | 97 | 182 | 5116 |
| ZG1 | 50 | 7.13 | 270 | 75.6 | 946 | 124 | 1294 | 42.6 | 1722 | 58.5 | 148 | 4680.7 |
| ZG3 | 32.9 | 6.53 | 212 | 162 | 830 | 118 | 1220 | 39.9 | 2087 | 62 | 131 | 4861.9 |
| ZG7 | 16.8 | 7.66 | 65.9 | 19.4 | 12.7 | 8.67 | 7.46 | 6.73 | 336 | 74 | 4 | 534.86 |
| HB 1 | 31 | 6.6 | 660 | 170 | 5200 | 160 | 8230 | 300 | 1994 | 51.4 | 285 | 17050.4 |

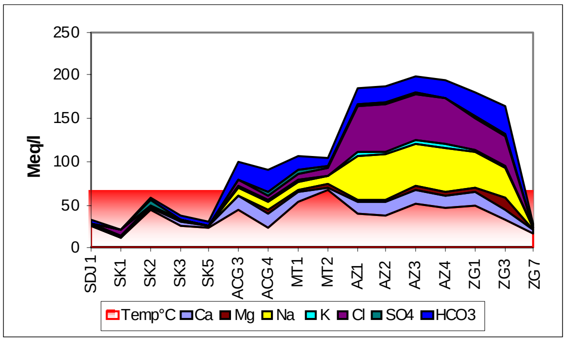


**Figure 3: Variation of temperature and chemical composition of hot and cold water in studied area**

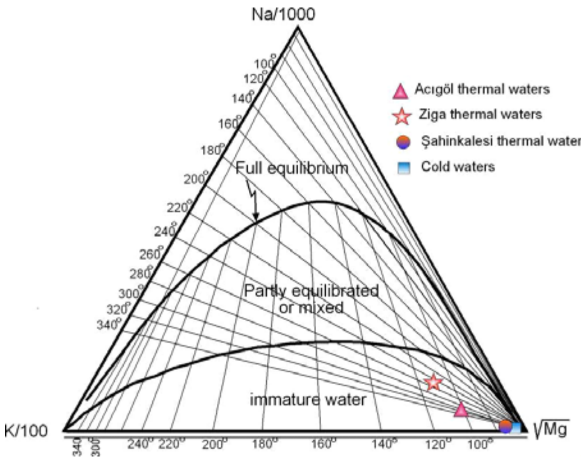


**Figure 4: Equilibrium diagram (for Na/K and $K^2$/Mg temperatures) of thermal and cold waters in Aksaray geothermal fields (Giggenbach 1988).**

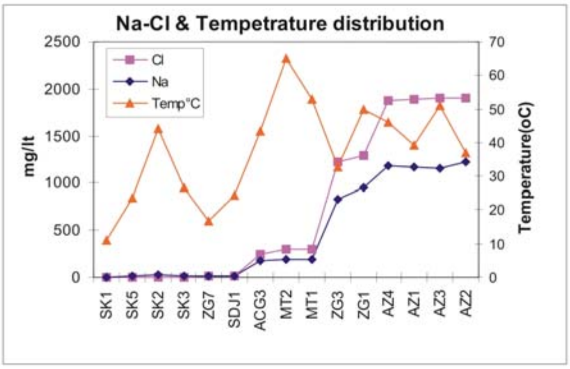


**Figure 5: Na, Cl & temperature distribution of the waters in Aksaray geothermal fields.**

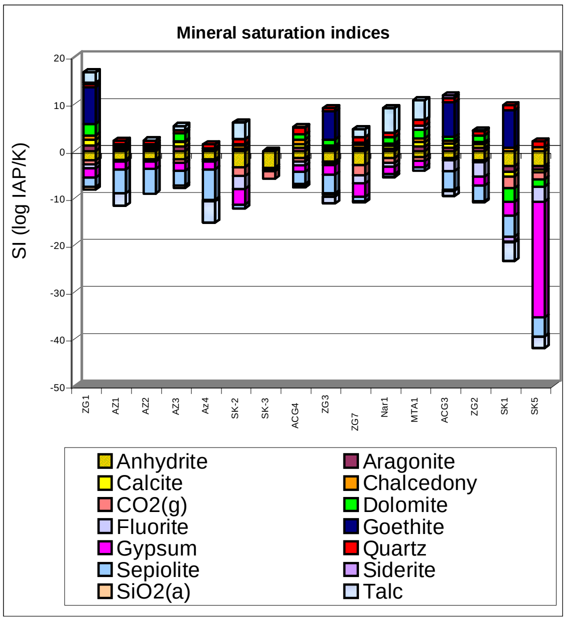


**Figure 6 : Mineral saturation indices of hot and cold waters in Aksaray geothermal fields.**

According to diagram (figure 3), It has been considered that the highest temperature samples (MT1 and 2) doesn't have highest dissolved minerals so, another words, despite the samples have highest Cl concentration doesn't have highest temperature (figure 5). Generally it can be considered that some anion and cation such as Na and Cl has deep origin in geothermal systems. Contrary the origin of high Na and Cl concentration in hot waters maybe evaporitic sediments in the Ziga area (figure 5). By reason of hot water mixturing with high NaCl cold water in shallow reservoir, temperature decreasing has been expected by the way temperature increasing could be expected in deep reservoir under the shallow reservoir. MT studies have shown that the deep reservoir has 800-100m depth in the areas. According to the silica thermometers (Fournier, 1971) 119-145 $^{o}$C reservoir temperatures have been expected. According to the silica mixing model(Fournier, 1971) reservoir temperature have been estimated as 210 $^{o}$C and cold water mixing calculated theoretically about (Göçmez, 2000).

According to mineral saturation indices diagram (figure 6) almost all waters have saturated with quartz, calcite, dolomite, goethite and chalcedony and under saturated of gypsum, anhydrite fluorite and sepiolite.

## 5. HYDROTHERMAL ALTERATION STUDIES

Surface hydrothermal alteration have existed through the large area in Pliocene aged tuff and ignimbrite in Acıgöl and Ziga thermal area Forty two samples have been collected for XRD and XRF (X-ray diffractometer and X-Ray fluorescence) analyses. These analyses are supported by twenty petrographical samples to determine primer mineral association. The primer mineral assemblages are feldspar, amphibole, biotite, volcanic glass and quartz. On the base of the XRD analyses hydrothermal mineral assemblages are smectite, kaolinite, opal, zeolite, calcite, alunite and gypsum (Table 2). According to hydrothermal mineral assemblages, the hydrothermal fluids which caused the alteration had temperature of about 100 $^{o}$C and neutral to weakly acidic conditions (Elders, W.A. et al 1979). On the base of XRF results (Table 3) $SiO_2$ composition of the fresh rocks has a range between 70-73 % on weight and decrease with intensity of the alteration which indicated by increasing LOI (loss on ignition) (Figure 7 and 8). $SiO_2$ composition of weakly altered rocks is about 60-65% on weight and %55-46 in altered rocks. Decreasing $SiO_2$ with respect to increasing intensity of the alteration have been interpreted leaching $SiO_2$ during the alteration, similarly the composition of alkali oxides($Na_20$ and $K_20$) have decreased from fresh through the altered rocks(table 2,3, and figure 7). $Al_2O_3$ composition is about 16-17% in fresh rocks, increasingly with alteration intensity, reached %34 's in altered rocks, decreasing alkali's and increasing $Al_20_3$ concentration from fresh to weakly altered and through the altered rocks can be considered occurring clay minerals such as smectite, kaolinite and zeolite. Some samples has high $SiO_2$ (85-95%w) and low $Al_20_3$ low alkali concentration is characterized by opal veins. Hydrothermal alteration studies have been carried out on the samples which collected from the surface and although there are no information about subsurface alteration, The experiments show that interface conductivity of the rocks depends more on the magnitude of the internal surface (porosity) and on its nature(surface condition) than on the original chemical composition of water and rock. The main reason for interface conductivity is the presence of clay minerals (alteration) and surface double-layer conduction (Rink and Schopper, 1976). Low resistivity zone (<20 Ohm-m) exist from the surface through the 1000-1500m depth which defined by MT studies (figure13, 15, 17) compared with conductive clay minerals (which formed by hydrothermally altered tuff and ignimbrite) interpreted as a cap rock of geothermal system. Although no information (well data) about the high resistivity(20-40 Ohm-m) under the low resistivity zone, it can be compare with transition zone(smectite, illite) and high resistive alteration minerals such as illite and chlorite that indicate the temperature between 140-200 $^{o}$C.

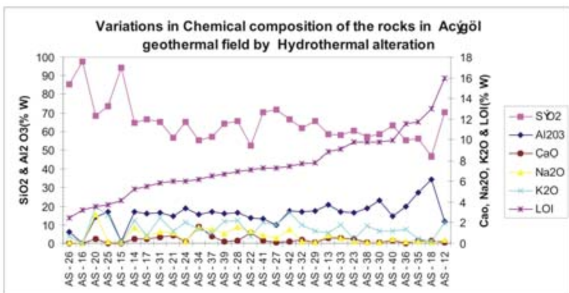


**Figure 7: Variation in chemical composition of the rocks in Acigöl geothermal fields by hydrothermal alteration**

**Table 2: XRD results of the samples in Aksaray geothermal fields**

| Sp. No | Def. | Fel | biot | Opal | Qtz | Sm | Kao | Amr | Zeo | Cal | Alu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AS-1 | Alt r | xx | | | | xxx | | | | xxxx | |
| AS-2 | Alt r | | | xxx | | xx | | xxxx | | | |
| AS-3 | Alt r | xxx | | | | xxx | | xx | | | |
| AS-4 | Alt r | xxxx | | | xx | x | | xxx | | | |
| AS-5 | Fr r | xxx | | xxxx | | xx | | x | | | |
| AS-6 | W lt | xxx | | xxxx | xx | xx | | | | | |
| AS-7 | Fr r | xxx | | | xx | | | xxxx | | | |
| AS-8 | Alt r | x | | xxxx | xx | | | | | xxx | |
| AS-9 | Alt r | xxx | | xxxx | | | xx | | | | |
| AS-10 | Alt r | | | xxxx | xx | | | | | | xxx |
| AS-11 | W lt | xxx | | xxxx | | | xx | | | | |
| AS-12 | Alt r | | | xx | x | | xxx | | | | xxxx |
| AS-13 | Alt r | | | | xxx | xxxx | | xx | | | |
| AS-14 | Fr r | xxxx | | | | xxxx | | xx | | | |
| AS-15 | Alt r | | | xxxx | xxx | | | xx | | | |
| AS-16 | Alt r | | | xxxx | xxx | | | xx | | | |
| AS-17 | Alt r | xx | xx | xx | xxxx | xxx | | x | | | |
| AS-18 | Alt r | | | | xxx | | xxxx | | | | |
| AS-19 | Alt r | | | | | | xxx | | | xxxx | |
| AS-20 | Fr r | xxx | | | xxxx | | | xx | | | |
| AS-21 | Walt | xxxx | xx | | xxx | xx | | x | | | |
| AS-22 | Walt | xxxx | | | | xxx | | x | | | |
| AS-23 | Alt r | xxx | | | | xxxx | | x | | | |
| AS-24 | Alt r | | x | | xxxx | xx | xxx | | | | |
| AS-25 | W lt | | xxx | | xxxx | | xx | | | | |
| AS-26 | Alt r | | | | xxxx | xxx | xx | | | | |
| AS-27 | Alt r | xxx | | | xxxx | | | | | | xx |
| AS-28 | Alt r | xxx | xx | | xxxx | | xx | | | | |
| AS-29 | Alt r | xx | x | | xxxx | | xxx | | | | |
| AS-30 | Alt r | | | | xxx | x | xxxx | | | | xx |
| AS-31 | Walt | xxxx | | xxx | | xxx | | x | xx | | |
| AS-32 | Alt r | | | | | xxxx | | xxx | | | |
| AS-33 | Alt r | xxx | | | xx | xxxx | | x | | | |
| AS-34 | Fr r | xxxx | | | xx | xxx | | | | | |
| AS-35 | Alt r | | | | xxx | | | xx | xxxx | | |
| AS-36 | Alt r | xxx | | | | xxxx | | xx | | | |
| AS-37 | Walt | xxx | | | | xxxx | | xx | | | |
| AS-38 | Alt r | | | | | xxxx | | xx | | | |
| AS-39 | Alt r | | | | xxxx | xxx | | | | | |
| AS-40 | Alt r | xxx | | | xxxx | | xx | | | | |
| AS-41 | Alt r | | | | xxx | | | xxxx | | | |
| AS-42 | W lt | | | | xxxx | | | xxx | | | |

Alt r : altered rock, W alt : Weakly altered rock Fr r : Fresh rock

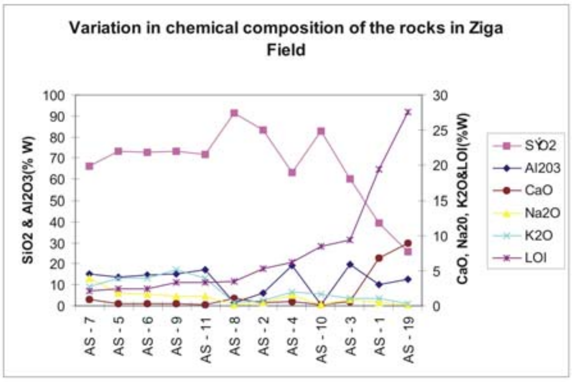


**Figure 8: Variation in chemical composition of the rocks in Ziga geothermal fields by hydrothermal alteration**

## 6. DEFINING HIGH GRAVITY-LOW MAGNETIC ANOMALOUS ON THE BASE OF GRAVITY, MAGNETIC SURVEYS

Residual Bouguer gravity anomaly and total magnetic anomaly maps have been used for this purpose, on the base of gravity and magnetic explorations four anomalous have been found to be worth to exploration for heat source. Four MT profile have been planned a crossed with these anomalous (Figure 9, 10 and 11, 12).

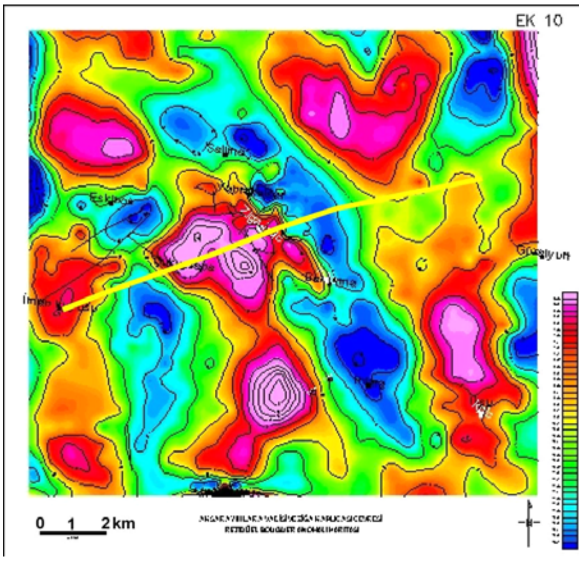


**Figure 9: The Bouguer anomaly map of studied area (Ziga area). Yellow line MT profile which crossed defining high gravity anomaly**

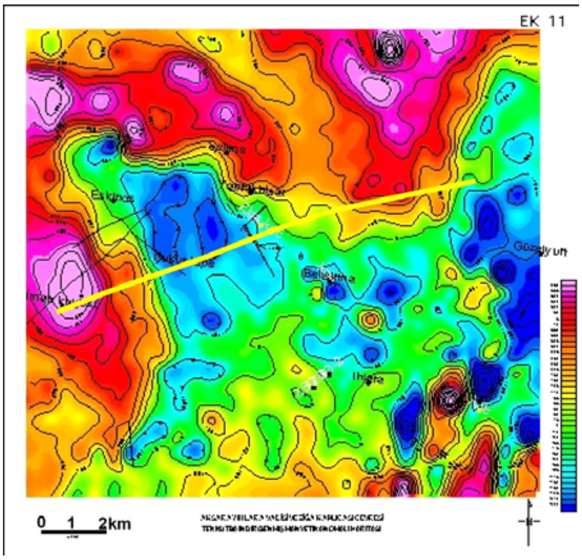


**Figure 10: The magnetic anomaly map of studied area (Ziga area). Yellow line MT profile which crossed defining low magnetic anomaly**

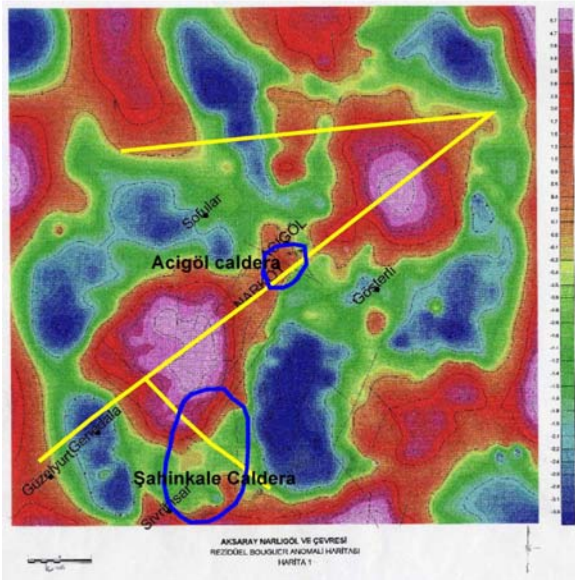


**Figure 11: The Bouguer anomaly map of studied area (Acigöl area). Yellow line MT profile which crossed defining high gravity anomalous**

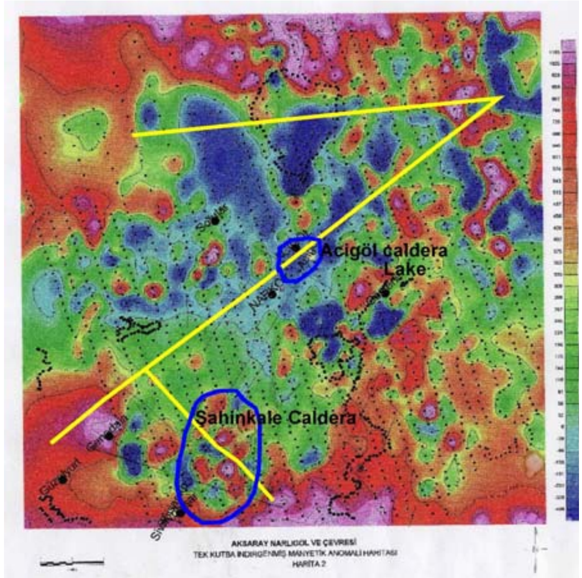


**Figure 12: The magnetic anomaly map of studied area (Acigöl area). Yellow line MT profile which crossed defining low magnetic anomalous, blue ellipse is the rim of Şahinkalesi Caldera.**

**Table 3: XRF results of the samples in Aksaray geothermal fields**

| Sample | SiO2 | TiO2 | Al203 | Fe203 | MgO | CaO | Na2O | K2O | LOI | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| AS - 1 | 39.5 | 0.3 | 10 | 4.5 | 1.3 | 22.5 | 0.4 | 1.1 | 19.35 | 98.95 |
| AS - 2 | 83.4 | 0.1 | 6.1 | 1.7 | 0.9 | 1.3 | 0.4 | 0.7 | 5.35 | 99.95 |
| AS - 3 | 60.2 | 0.3 | 19.7 | 3.2 | 2.9 | 2.1 | 0.9 | 1 | 9.35 | 99.65 |
| AS - 4 | 63.2 | 0.3 | 19 | 3.1 | 2.2 | 2 | 1.5 | 1.9 | 6.25 | 99.45 |
| AS - 5 | 73 | 0.3 | 13.5 | 1.7 | 1.2 | 1.2 | 1.8 | 4 | 2.45 | 99.15 |
| AS - 6 | 72.5 | 0.3 | 14.5 | 2 | 1 | 1.2 | 1.7 | 4 | 2.5 | 99.7 |
| AS - 7 | 66.3 | 0.4 | 15.4 | 4.2 | 1.1 | 3.1 | 4 | 2.7 | 2.1 | 99.3 |
| AS - 8 | 91.5 | 0.3 | 1.3 | 0.5 | ud | 3.4 | 0.2 | 0.4 | 3.55 | 101.15 |
| AS - 9 | 73 | 0.4 | 15.2 | 0.5 | 0.1 | 1 | 1.4 | 5.1 | 3.3 | 100 |
| AS -10 | 83 | 0.3 | 0.7 | 7 | ud | 0.3 | 0.1 | 1.6 | 8.55 | 101.55 |
| AS -11 | 71.8 | 0.3 | 17 | 1.5 | 0.3 | 0.4 | 1.3 | 3.9 | 3.4 | 99.9 |
| AS -12 | 70.5 | 0.1 | 12 | 0.3 | ud | 0.3 | 0.3 | 2 | 16 | 101.5 |
| AS -13 | 58.3 | 0.6 | 20.8 | 4.5 | 2.2 | 2.6 | 0.8 | 1 | 8.85 | 99.65 |
| AS- 14 | 64.5 | 0.4 | 17 | 4.6 | 1.6 | 2.3 | 1.5 | 2.2 | 5.3 | 99.4 |
| AS- 15 | 94.5 | 1.6 | 0.8 | 0.1 | ud | 0.1 | 0.1 | 0.1 | 4.2 | 99.4 |
| AS -16 | 97.5 | 0.3 | 0.2 | 0.1 | ud | 0.1 | 0 | 0 | 3.2 | 101.4 |
| AS -17 | 66.4 | 0.5 | 16.1 | 4.6 | 97.7 | 2.3 | 0.7 | 0.8 | 5.55 | 98.75 |
| AS -18 | 46.8 | 0.1 | 34.3 | 2.9 | 0.2 | 1.6 | 0.1 | 0.2 | 13 | 99.2 |
| AS -19 | 26 | 0.3 | 12.8 | 1.4 | 1 | 30 | 0.1 | 0.3 | 27.6 | 99.5 |
| AS -20 | 68.3 | 0.3 | 14.2 | 3.5 | 1 | 2.3 | 2.8 | 3.6 | 3.55 | 99.55 |
| AS -21 | 56.6 | 0.8 | 14.7 | 11 | 2.2 | 4.2 | 1 | 1.2 | 6 | 99.7 |
| AS -22 | 52.4 | 0.8 | 13.5 | 15.2 | 1.7 | 5.5 | 1.2 | 0.7 | 7.1 | 99.75 |
| AS -23 | 60.5 | 0.6 | 16.7 | 5.7 | 3.4 | 2.5 | 0.2 | 0.4 | 9.75 | 98.6 |
| AS -24 | 65 | 0.7 | 18.8 | 3.1 | 1.9 | 0.9 | 0.2 | 2 | 6 | 98.6 |
| AS -25 | 73.4 | 0.6 | 16.8 | 1.7 | 0.3 | 0.1 | 0.2 | 2.7 | 3.7 | 99.5 |
| AS -26 | 85.5 | 0.4 | 6.3 | 2 | 1 | 0.2 | 0.1 | 0.7 | 2.45 | 98.65 |
| AS -27 | 71.5 | 0.4 | 9.8 | 6.2 | 0.7 | 0.4 | 0.5 | 1.8 | 7.3 | 98.6 |
| AS -28 | 65.5 | 0.5 | 16.5 | 3.1 | 1.5 | 1.2 | 1.6 | 2.2 | 7 | 99.1 |
| AS -29 | 65.4 | 0.8 | 17.5 | 5 | 0.7 | 0.5 | 0.1 | 1.2 | 7.8 | 99 |
| AS -30 | 58.4 | 1.1 | 23.3 | 4.4 | 0.7 | 0.7 | 0.1 | 1.2 | 9.75 | 99.65 |
| AS -31 | 65.1 | 0.4 | 16.5 | 3.1 | 2 | 3.1 | 1.1 | 2.5 | 5.9 | 99.7 |
| AS -32 | 61.6 | 0.8 | 16.9 | 5.5 | 3.2 | 1.8 | 0.2 | 1.8 | 7.7 | 99.5 |
| AS -33 | 58 | 0.7 | 17.2 | 5.8 | 3.7 | 3 | 0.5 | 1.8 | 9.1 | 99.8 |
| AS -34 | 55 | 0.6 | 15.7 | 6 | 2.7 | 8.8 | 1.5 | 1.4 | 6.2 | 97.9 |
| AS -35 | 56.2 | 0.3 | 27.2 | 1.9 | 0.7 | 1.3 | 0.2 | 0.4 | 11.75 | 99.95 |
| AS -36 | 55.1 | 0.8 | 19.8 | 7.5 | 2.5 | 0.1 | 0.2 | 1.4 | 11.55 | 98.95 |
| AS -37 | 57 | 1 | 17 | 7.8 | 2 | 4 | 1.4 | 1 | 6.5 | 97.7 |
| AS -38 | 57.1 | 0.8 | 18.8 | 7.8 | 2.8 | 0.5 | 0.1 | 1.7 | 9.75 | 99.35 |
| AS -39 | 64 | 0.9 | 15.9 | 5.5 | 2 | 0.9 | 0.9 | 2.1 | 6.75 | 98.95 |
| AS -40 | 63.2 | 1.3 | 14.7 | 7 | 0.5 | 1.6 | 0.4 | 1.2 | 9.9 | 99.8 |
| AS -41 | 70.3 | 0.4 | 13.3 | 3 | 0.7 | 1.5 | 0.8 | 2 | 7.3 | 99.3 |
| AS -42 | 66.5 | 0.5 | 17.4 | 2.5 | 0.3 | 0.8 | 1.4 | 3 | 7.45 | 99.85 |

## 7. MAGNETOTELLURIC METHOD

In the magnetotelluric (MT) method the orthogonal components of the horizontal electric and magnetic fields induced by natural primary sources are measured simultaneously as a function of frequency. The natural time –varying EM-field can be observed as variations in the Earth's magnetic field. They are called micropulsations having frequencies of less than 1 Hz. used as source for magnetotelluric method. MT methods have been used to investigate deep structure, heat source exploration by Beblo et al., 1983. MT studies have been considered to investigate deep structure, upper mantle and crustal thickness, heat source exploration (Vozof, 1972, Jupp and Vozof, 1977, Beblo et al., 1999 Hersir, and Björnssonn 1991).

The predominant origin of the micropulsation is interaction of Earth's magnetopause with charged particles ejected from the sun.

### 7.1. Data Acquisition

Phoenix V5 MT equipment has been employed in order to record three orthogonal magnetic (**H**) fields and two orthogonal electrical (**E**) fields' components. 100 m. dipoles extending N-S and E-W geomagnetic directions and Pb-PbCl electrodes were used for **E** field. Horizontal components of **H** field were measured with induction coil. Vertical component of the **H** was recorded with an air loop on the ground.

The V5 system is calculated all sounding parameters in real-time. In this system, data acquisition is divided into two frequencies levels. High frequencies level is 320-7.5 Hz. These were processed using Fourier transform techniques in a frequency band. Every band is contains two frequencies. Low frequency level is 6- 0.00055 Hz, were processed using cascade decimation (Wight and Bostick, 1980).

Electric and electromagnetic waves are measured with horizontal pairs of orthogonal electric dipoles and magnetic sensors.

$$\begin{aligned} E_x &= Z_{xx}H_x + Z_{xy}H_y \\ E_y &= Z_{yx}H_x + Z_{yy}H_y \end{aligned} \quad (1)$$

The notation $Z_{ij}$ in equation (1) are the transfer function called impedances. They are a measure of Earth's response to magnetic fields in x and y directions. If the subsurface is homogeneous or horizontally stratified (one dimensional), the impedances $Z_{xx}$ and $Z_{yy}$ are equal to zero and $Z_{xy}$ and $Z_{yx}$ impedances will be equal as below (2).

$$Z_{xy}(f) = \frac{E_x(f)}{H_y(f)} \quad (2)$$

If the direction of electric field(E) parallel to geological strata, vertical magnetic field is polarized linearly and called Transverse Electric mode or E-polarization. In this situation the direction of electric field, related to two orthogonal axis, if the direction is x,

$$Z_{xy} = \frac{E_x}{H_y}$$

If the electric field perpendicular along the strike, magnetic field will be polarized as linear. If 'y' is perpendicular to strike Transverse Magnetic mode or H polarization is defined as,

$$Z_{yx} = \frac{E_y}{H_x}$$

And the components of Zxx and $Z_{yy}$ are zero. As not knowing the direction of axis, MT measurements are recorded in geographically as being a direction of North-South and East-West. In data process to calculate the impedances belonging to the mode of TE and TM, tensor components ($Z_{xx}$ and $Z_{yy}$) as to be minimum level, impedances tensor is rotated using least square method. In two orthogonal directions the orthogonal magnetic (H) and electric components (E) of natural fields can be related at each frequency by tensor impedance (Z). The impedance tensor and impedance are given in equations (1) and (2) respectively.

For a homogeneous earth, it is easy to calculate the resistivity from the elements of immedance tensor, the formula for apparent resistivity is (Cagniard 1953);

$$\rho_{aC}(f) = \frac{|Z|^2}{w\mu} \quad \textbf{(3).}$$

Central loop TEM measurements have been completed at each MT station in order to remove the static shift effect from the MT data and to get near surface information. Static shift corrections have been made by the use of transient electromagnetic (TEM) data (Pellerin and Hohman 1990). All TEM data inverted and 1D model are obtained. MT and high frequency responds of 1D TEM models are plotted together. Both TE and TM apparent resistivity data shift towards to the responds obtained from model based on TEM method. One point should be emphasis that the shifting process using 1D model may cause information loss in case of existence of shallow 2D - 3D structure that departs the TE and TM mode apparent resistivities from each other even in very high frequencies. This fact is accepted as a sacrifice for the methodology followed.

### 7.2. Two Dimensional Inversion Interpretation

Two dimensional inversion plots are generated in the field. 40 MT data were observed along the four profiles, on measurement stations. To calculate the true subsurface resistivity 2D inverse interpretation give information related to direction as well as depth. The models presented here are obtained by the use of WinGLink™ interpretation package, which uses 2D inversion code of d2inv_nlcg2_fast (Mackie et al. 1997). Initial models for each profile have been taken as a homogeneous half space of 100 ohm-m. To justify the models, all sections were inverted with starting models of homogeneous half space of 1 ohm-m (results not presented). Comparison of both result for each section delineate the depth of investigation (e.g. Oldenburg and Li, 1999) and confirm the existences of some small size features. 2D inverse model is interpreted by way of the electrical section formed by a software program called finite difference method by using 'Network analogy' (Madden, 1972; Jupp and Vozoff, 1977). Infinite Difference Network the thick and width of the cells are chosen with respect to used frequencies, measured resistivity and accepted average resistivity. The 2D MT modeling and conceptual modeling of geothermal areas are shown in Figure 13,15,17,19.

7.2.1. Ziga Geothermal Field

A NW-SE directional profile was chosen by reassessment of gravity and magnetic surveys to measure MT data. .MT surveys have carried out 15 point of measurement along the profile (yellow line in figure 9 and 10; blue line figure 2). On the base of the MT data modeled (two dimensional inversions), low resistivity zones (ρ<16 Ωm) from the surface through the 1000-1500m depth have been interpreted with tuff, and ignimbrite and hydro thermally altered varieties of these rocks (figure 13 and 14). Presence of the clay minerals let to decrease resistivity, so it can be considered that the cap rocks of geothermal system. Under the covered rocks the resistivity have increased obviously, the range between 20-70Ωm have been thought to be Eocene - Miocene aged reservoir rocks made of sand stone, limestone and gypsum(figure 2) in the upper part as a shallow reservoir and Paleozoic aged marble and gneiss as a deeper reservoir(figure, 13, 14). According to MT two dimensional inversion modeling, similarly high resistivity on APJ7-APJ8 locations is indicated by basement uplifting in this area (figure 13 and 14). Low resistivity body intruded high resistivity crust materials have been interpreted hot, solid and/ or partly molten magma body formed the heat source of geothermal system. The intrusive mass and may be heated surrounding rocks is clearly shown with low resistivity (under 20 Ωm) with contrast in high resistivity zone belongs to crustal rocks which can be relatively cold. The average depth of the conceptual heat source is about 8 km. It can be considered that a deep reservoir have been expected under the shallow reservoir. Water chemistry studies indicate that 119-145 $^{o}$C reservoir temperature in deep reservoir.

7.2.2.Acıgöl Geothermal Field

MT measurement have carried out along NE-SW directional profile on 13 location (figure 15) crossed the relatively low magnetic and high gravity anomaly zone (figure11, 12 yellow line).Very similar underground structure have been a crossed with Ziga field's. According to MT two dimensional inversion modeling, similarly high resistivity on APJ018-APJ020 locations is indicated by basement uplifting in this area (figure15). This basement rock uplifting zone have limited by the fault zone from two sides on NE and SW directions (figure 2). High resistivity (> 100 Ohm-m) have been measured on the basement rocks (marble and gneiss) in this field. Low resistivity (< 40 Ohm-m) from the surface through the range between 1000-1500m depth have been interpreted to be tuff, ignimbrite, and hydrothermaly altered varieties of tuff and ignimbrite as a cap rocks of the system(figure 16). High resistivity ( > 40 Ohm-m) zone under the low resistivity zone is interpreted as basement rocks within occurred reservoir. The heat source in this field is interpreted a low resistivity body intruded high resistivity crust which has depth 8-10km to the top of the body (figure 15). Since has it relatively low resistivity when compared with high resistive surrounding crustal rocks, Intrusive body can considered hot, solid and or partly molten conditions (figure 15 and 16). Two reservoir, shallow and deep, are expected geologically on base of the conceptual model (figure 15 and 16).

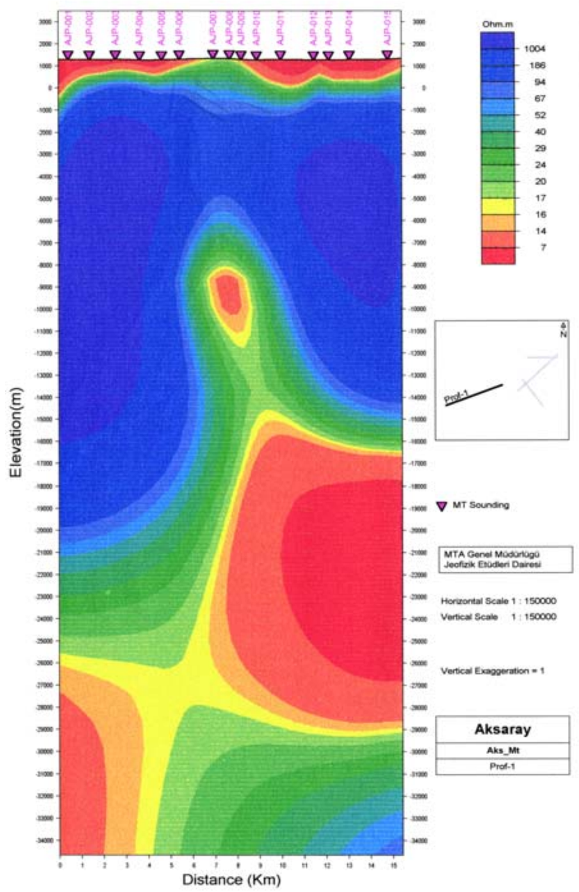


**Figure 13: Two dimensional MT modeling of Ziga geothermal area.**

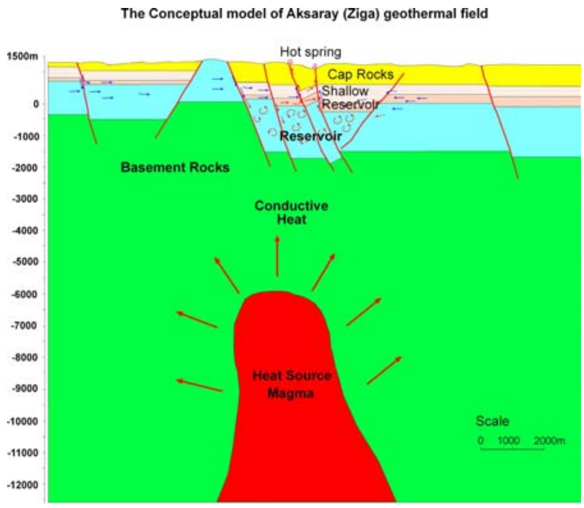


**Figure 14: The conceptual model of Ziga geothermal area**

7.2.3.Şahinkalesi Geothermal Field

MT measurements have carried out along NW-SE directional profile on 6 location (figure 17) crossed Şahinkalesi Caldera (figure 11, 12 yellow line). There is no surface manifestation as a hot water spring, any fumaroles like that. Only indicator is a well, drilled by a farmer for irrigation purposes. Ca-Na-$HCO_3$ and non mineralized type hot water has temperature 44 $^{o}$C been produced and used irrigation (SK-2 in Figure 2). The water type of this sample is non mineralized thermal water. Considerable heat source can be interpreted more than 10km depth under the caldera rim on the based of MT modeling (figure 17). It couldn't be defined the low resistivity in Şahinkalesi caldera caldron from surface to 5000m depth. It can be thought to be as a cap rock may be hydrothermaly altered or hot magmatic intrusion which connected with deep intruded body(30-35km)(Figure 17 and 18).

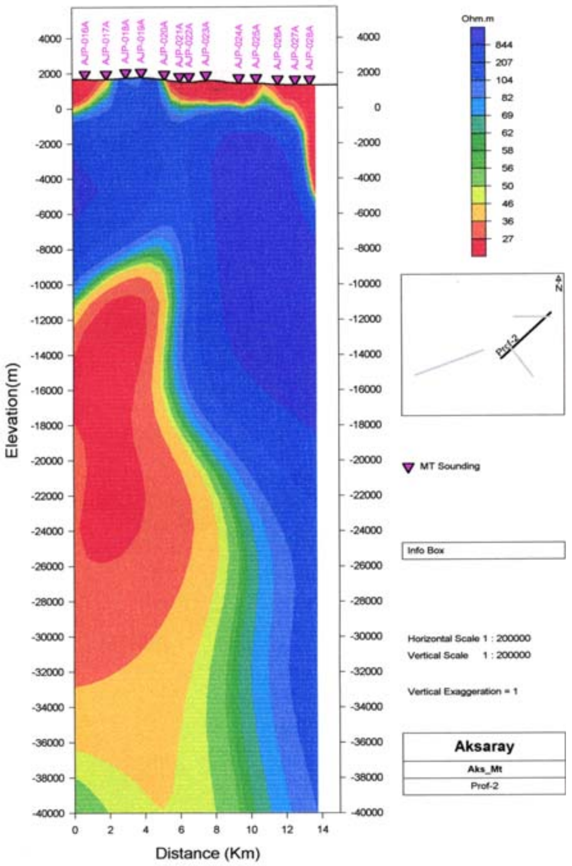


**Figure15: Two dimensional MT modeling of Acigöl geothermal area.**

7.2.4. Nenezi field

MT measurement have carried out along almost E-W directional profile on 7 location crossed the relatively low magnetic and high gravity anomaly zone (figure11, 12 yellow line). According to MT modeling (figure 19) low resistivity zone which intruded within high resistivity crust have interpreted hot and molten and/ or solid magmatic body. Because of the lock of data (having no well data, any hot spring etc) the conceptual model couldn't be prepared. But this area can be investigated for hot dry rock since the shallow heat source (5-6km) which considered by MT modeling.

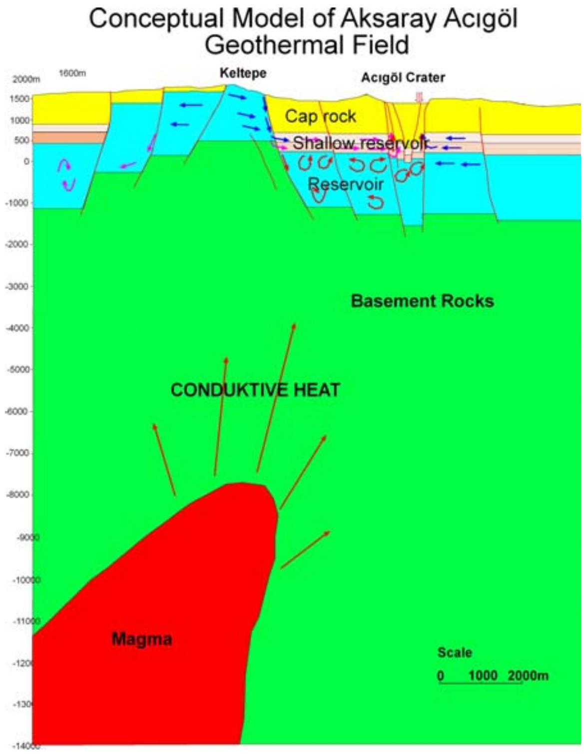


**Figure16: The conceptual model of Acigöl geothermal field**

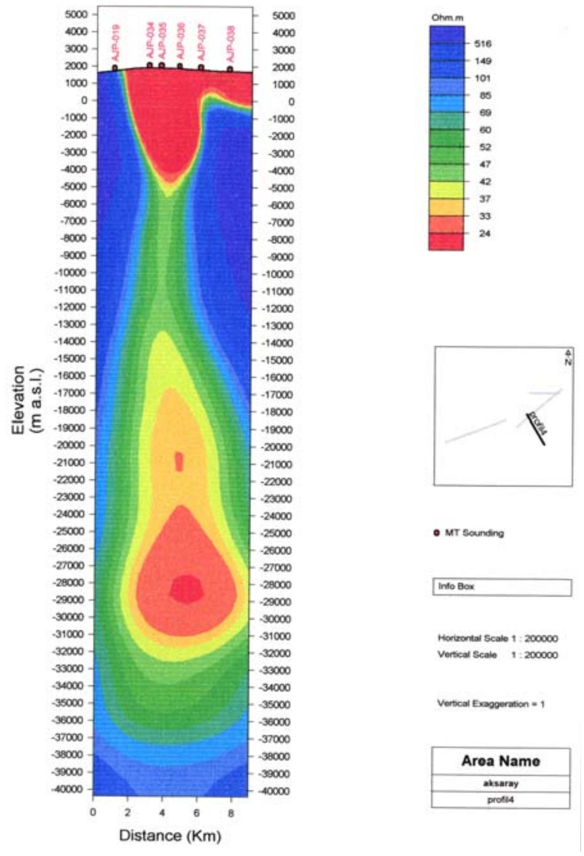


**Figure17: Two dimensional MT modeling of Şahinkalesi geothermal area.**

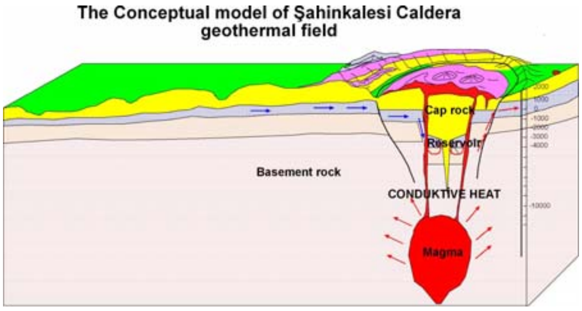


**Figure18: The conceptual model of the Şahinkalesi geothermal field**

## 8. CONCLUSION

Aksaray region have consist of two geothermal fields as known Ziga and Acıgöl besides two potential geothermal region Şahinkalesi and Nenezi fields. There has been hot springs at temperature range between 44-65$^{o}$C. Based on the water chemistry studies, geothermal fluids were classified as Na-Cl-$HCO_3$ type and As and B bearing mineralized hot water, in Ziga, Ca-Na-$HCO_3$-Cl type and B bearing mineralized hot water, in Acigöl field, as Ca- Na-$HCO_3$ type non mineralized thermal water Şahinkalesi hot water(from well) According to the IAH standards. On the basis of silica thermometer (Fournier 1977) 119-145$^{o}$C, 160-181 $^{o}$C and 135-159$^{o}$C reservoir temperature have been calculated in Ziga, Acıgöl and Şahinkalesi geothermal fields respectively.

The study of surface hydrothermal alteration of Pliocene aged tuff and ignimbrite belong to Cappadocian Volcanic Belt, indicate that the geothermal fluids caused the alteration were about 100 $^{o}$C temperature and had neutral weakly acidic condition when alteration have occurred. MT data were evaluated by Two Dimensional Inversion Interpretation method by using WinGlink$^{TM}$ software program. According to MT studies It has been found out hydrothermally altered tuff and ignimbrite are formed cap rock of the geothermal system and has 1000 1500m depth, the reservoir of the systems is Paleozoic aged Bozçaldağ formation consist marble, schist and gneiss and Early Eocene to Early Miocene aged sedimentary rocks, consist limestone, sandstone, marl, conglomerate and gypsum. Low resistivity bodies which located within high resistivity crustal rocks were interpreted as a heat source which can be hot and partly molten and/or solid magma intrusions. Location and depth of the heat sources are defined, so average depth of the heat source of geothermal systems 5-8km. The conceptual models were prepared using water chemistry, hydrothermal alteration, and MT data. It has been expected that important geothermal potential in Aksaray region, two deep exploration wells have been planned in the area. Also it can be possible to explore hot dry rock facilities which can be planned in future.

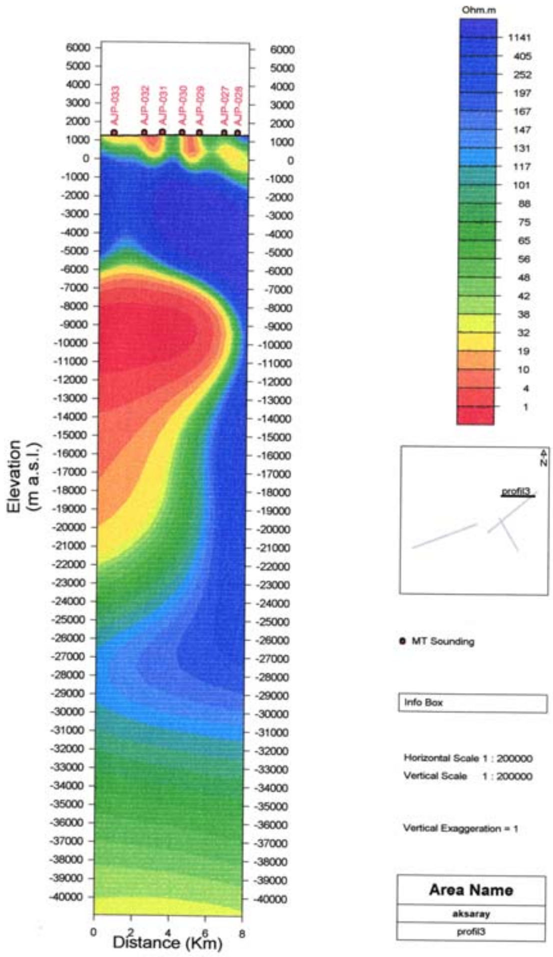


**Figure19**: **Two dimensional MT modeling of Nenezi geothermal area.**

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