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Geothermal Energy Studies and Evaluation the Potential of Sabalan Volcano in the NW of Iran

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ABSTRACT

Sabalan Mt (NW Iran) an isolated voluminous composite volcano, was erupted in two major cycles in Plio-Quaternary. Geothermal investigation on this volcano was started in 1978 and resumed since 1998. After identifying some geothermal prospects around the Mt Sabalan, this economical, environmentally benign energy source has been highly recommended for the geothermal energy developments. Here, we review and compile all the data and results of the geological-geophysical-well logging explorations since the first study in 1978 until now. Major investigations have been done on the geological (stratigraphy-tectonic), geophysical (Magnetotelluric-telluric-well logging), thermal (heat flow-conductivity), and geochemical (hot spring) aspects of volcano to reveal the high potential and promising zones for geothermal reservoir. It results in introducing the main hot spots located within an area (~100 squares Km) around Moil in north and west Sabalan. New structural measurements are combined to the current data base to unravel some new aspects of the structurally controlled geothermal reservoirs in the area.

1. INTRODUCTION

Iran Ministry of Energy has begun a series of investigations on exploring geothermal energy potentials in north and North West of Iran since 1975. These studies were commenced with the cooperation an Italian company (ENEL) in a region of 260,000 km$^{2.}$ The data obtained via geological, geophysical and geochemical studies showed that the areas mainly in NW Iran are suitable to carry out complementary studies and to exploit geothermal energy. In 1995 the geothermal region of Meshkinshahr (NW Sabalan volcano) was introduced as the first priority to continue exploration studies. Mt. Sabalan is a young volcanic complex that rises to a height of 4811 masl. The geothermal resource has now been proven by the results a couple of deep exploration wells upon detailed geo- based survey conducted by the joint collaboration of Iran Ministry of Energy (SUNA branch) and Sinclari knight Mers Ltd. (SKM) of New Zealand. Up to now 11 wells have been drilled in Sabalan geothermal field and this study help to the field development.

2. SURFACE GEOTHERMAL EXPLORATION DATA

2.1 Surface Geology

Located in NW Iranian Plateau, the Mt. Sabalan volcano is a young Plio-Quaternary element of the Cenozoic Alborz Magmatic Arc (AMA), Alavi (1991, 1996b, 2007). The studied area is mainly located in the west of volcano within the Moil Valley that can be seen to be a major structural zone in Fig. 1 .Exposed at the surface in the valley are altered Pliocene and Quaternary terrace deposits, Bogie et al. (2000) volcanics, an unaltered Pleistocene trachydacite dome (Figure 1). These units have been divided into four major stratigraphic units which in order of increasing age are:

- Quaternary alluvium, fan and terrace deposits
- Pleistocene post-caldera trachyandesitic flows, domes and lahars
- Pleistocene syn-caldera trachydacitic to trachyandesitic domes, flows and lahars
- Pliocene pre-caldera trachyandesitic lavas, tuffs and pyroclastics

2.2 Geology of the Exploration Wells

Based on stratigraphy, alteration geothermometers and permeability Control results from the nine well exploration drilling program stratigraphy column (figure 2) are presented.

To investigate the altered minerals in exploration wells indicate a range of high temperature as much as 210-230ºC in 1300-1500 masl. The main permeability controlling structures are faults those are encountered in the depth 700-2077m. An estimation of thermal gradient along three exploration wells is shown a descending trend SE_NW (Figure 3).

2.3 Tectonic

A main WNW-ESE dextral strike-slip fault system is dominated the structural pattern of the studied area; N-S normal faults and NNE-SSW thrust faults are less in population. The structural survey of the main faults around Mt Sabalan shows that the compressional stress is oriented NNW-SSE. It follows the current stress field and GPS data. Elongation of the Sabalan caldera is estimated parallel to the regional extensional axis. The Sabalan caldera is associated with an extensive hydrothermal system and fracturing in the caldera can provided a readily available source of geothermal energy.

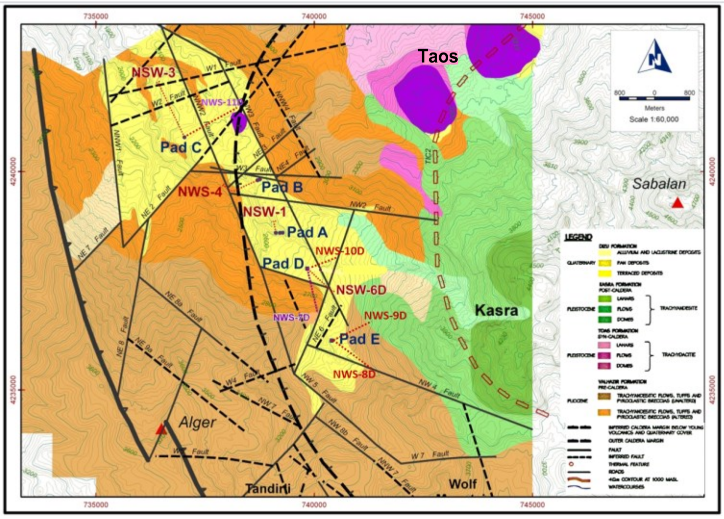

Figure 1: geology map of NW Sabalan overlaid by the location of exploration wells and main structural trends.

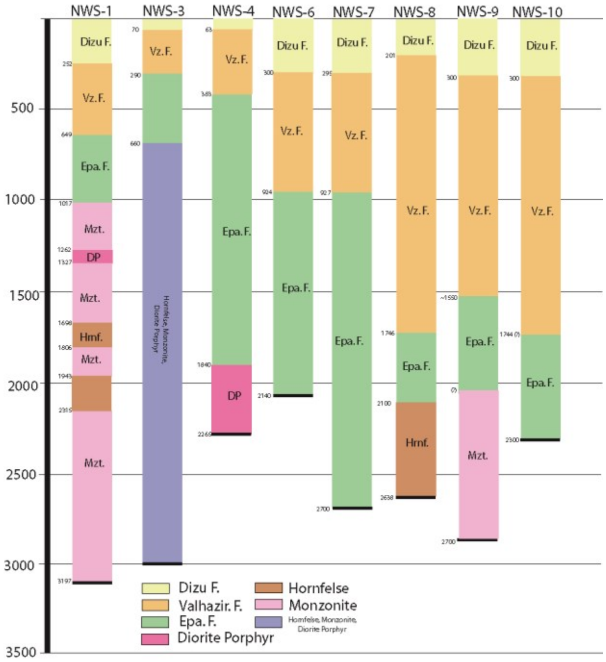

Figure 2: Schematic stratigraphy column in NW Sabalan, extracted from eight exploration wells.

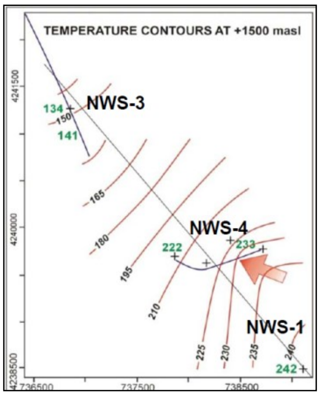

Figure 3: Estimated Temperature contours at of NWS1,NWS4 and NWS3 base on alteration(SKM 2005).

3. GEOCHEMISTRY STUDIES

Geochemistry analysis of fluid samples collected during discharge testing of two wells NWS1 and NWS4 suggests reservoir temperatures reaching as high as 260°C to 280°C based on cation geothermometry (SKM, 2005). The geochemistry of the Sabalan wells and surface springs suggests two different geothermal sources:

- The wells are associated with geothermal water originating at 270 to 280ºC
- The springs are associated with geothermal water originating at 240 ºC

High cation temperatures are evident on the trilinear plot of Giggenbach (1988) where the reservoir water lies close to the full equilibrium line at a temperature of about 280°C.

Using the relative amounts of major anions, namely Cl, HCO3 and SO4 Giggenbach (1989), the type of liquid produced in NWS6D is neutral pH-Cl water. Towards the vertex of HCO3 which affirms that the fluid is buffered by this species.

Sodium-Potassium geothermometer by Fournier predicted a subsurface temperature range of 271 to 278 ºC. Sodium-Potassium-Calcium geothermometer by Fournier and Truesdell gave temperature prediction range of 268 to 274 ºC while temperature based on the quartz solubility (TQtz, Fournier) showed a lower temperature range of 234 to 239 ºC. The TQuartz predicted downhole water temperature is comparatively lower than the predicted by both TNaK and TNa-K-Ca geothermometers. However, the measured down-hole temperature during shut-in survey indicated a range of 237 to 247 ºC which is comparable to the temperature range predicted by silica geothermometer. The higher temperature values given by TNaK and TNa-K-Ca reflect the initial liquid condition since the periods for re-equilibration of the minerals (albite, feldspar) controlling these geothermometers are longer compared to quartz. It can be deduced that a much higher temperature “source” can be found in the Sabalan geothermal system. The liquid obtained in NWS6D plotted in the partial equilibrium section of Na-K-Mg ternary plot. This partial equilibration is attributed to higher level of magnesium concentrations in the water samples. Since the well is not acidic, wherein high amount of magnesium is expected, there is a possibility of inflow of cold diluting water in the reservoir. Cold surface waters contain considerable amount of Mg relative to Na and K due to increased leaching of Mg from rocks at low temperature condition. Partial equilibration may also result from steam addition due to the dilution of Na+ and K+ ions by steam condensation shifting the data points towards the Mg vertex. As noted, the well has excess enthalpy in the discharge.

4. GEOPHYSICS STUDIES

The first resistivity surveys such as MT were conducted at Mt. Sabalan as early as 1998. Several conductive anomalies were identified, the largest of which is located at Moil Valley Bromley et al.(2000). Reanalysis of the MT data defined an up flow region southeast of NWS-1D and the potential resource area is confined within the present well pads and is estimated to have an area of about 19 km2 (SKM, 2005). It is however noted that the MT survey did not achieve the depth penetration it was originally planned (SKM, 2003).

In 2007, EDC conducted a deeper-penetrating MT survey to determine the possible center of the resource and identify possible drilling targets for the development of a 55 MWe geothermal power plant (EDC, 2008). 28 stations were measured during the 1 month survey and analysis of the data mapped a shallow resistivity anomaly believed to be the center of the Sabalan geothermal system, located west of the young lava domes of the Post-Caldera Volcanic Formation. Still, a complete interpretation of the geophysical structure was not achieved because of insufficient station coverage particularly in the east,that the east-southeastern boundary of the anomaly was not established.

The recent MT survey conducted at Mt. Sabalan Geothermal Project was a continuation of the MT survey conducted by EDC last 2007. Its main objective was to map out thoroughly the resistivity structures around Mt. Sabalan and refine the postulated resource area delineated by the earlier surveys specifically east-southeast of the Moil Valley. A total of 50 new and 10 retested stations were occupied during one month in 2009 (Fig 4.). This brings the total MT stations measured EDC in Mt. Sabalan to 78. The new MT stations covered the areas of the present drill pads within Moil Valley, Alvares in the south and Houshang-Toas-Shabil in the north.

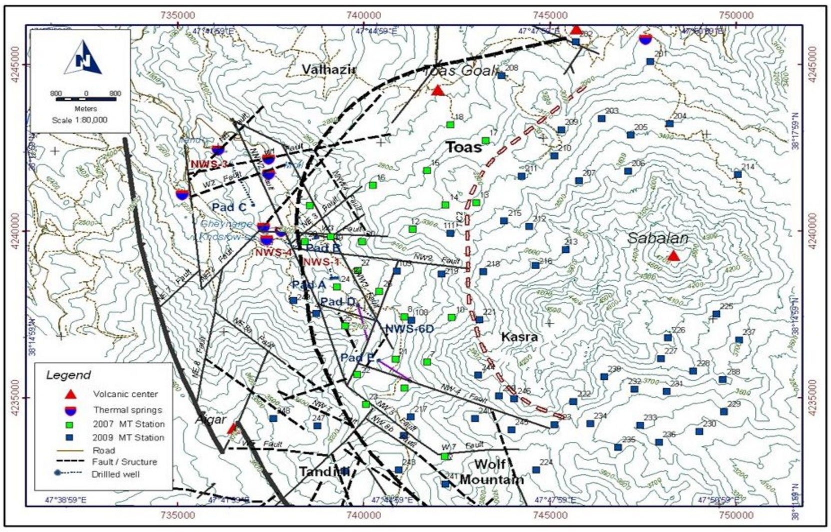

Figure 4: MT stations location map. The locations of stations are shown by blue and green rectangles.

Figure 5 displays the results of 2D inversion along line P01. Resistivity of the top layer varies from 50 to >250 Ω-m. An anomalous conductive layer extending from Moil Valley to pads D and E was observed beneath MT stations 25 and 217 from the surface to about 1000 masl.

This conductive layer has thickness of about 500-1000 m and is underlain by a moderate to highly resistive layer with resistivity values >50 to 250 Ω-m.

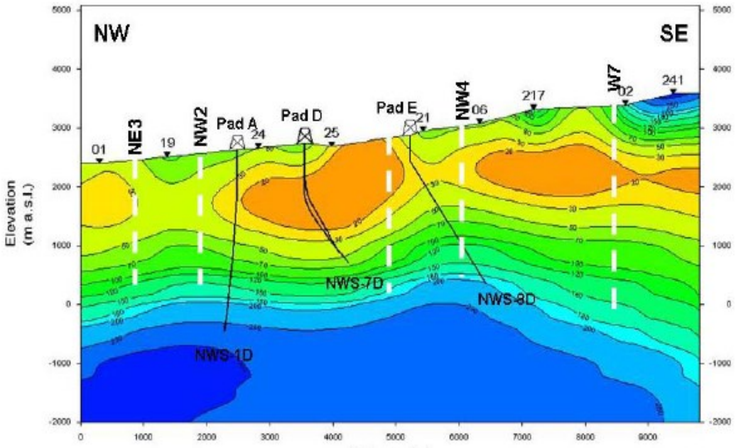

Figure 5: 2D model along.

The results of the 2D inversion along line P02 shows two conductive zones (<30 Ω-m) are detected, A high resistivity block (>100 Ω-m) is modeled separating the conductive zones, its boundaries marked by steep resistivity gradients.

The resistivity structure resulting from 2D inversion of line P03 shows a highly resistive (>200 Ω-m) cap layers were detected in the north (Toas) and in the south. This is underlain by two (2) conductive anomaly zones (<30 Ω-m).

The 2D resistivity model along line P04 is shown in Figure6. Notable features in this profile are the three low resistivity anomalies (>30 Ω-m) found beneath stations 18, 209 and 204, between elevations of 2800 m and 1200 m. This is underlain by increasing resistivity values >70 Ω-m which was detected to be shallowest beneath station 203 at elevations of about 2700 masl.

The 2D resistivity model along P05 shows a highly resistive cap layer (>100 Ω-m) overlying two slightly conductive anomalies (<30 Ω-m) located beneath station 201 and station 206 in the southern portion. A resistive layer underlies this conductive layer, and is shallowest beneath station 205 at elevation of about 2500 masl.

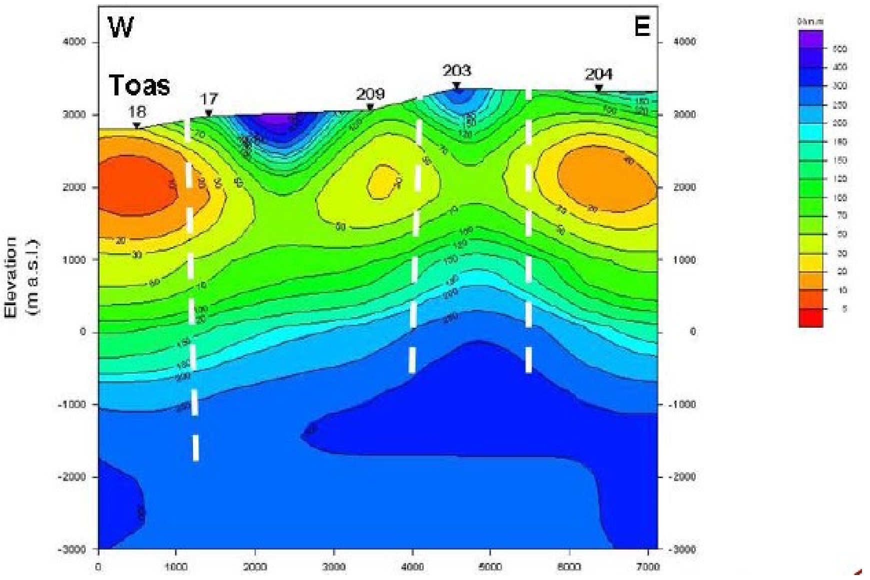

Figure 6: 2D model along p04.

2D resistivity structure along P06 shows a distinct feature in this profile is the almost continuous conductive anomaly (<30 Ω-m) found between elevations of 3000 to 1000 masl, except on the eastern side of Alvares where a resistive block is found from the surface down to lower elevations.

The 2D model along P07 shows a highly resistive body is detected beneath stations 226 and 227 which extend at lower elevations. This is the same resistive body identified in P06 which terminated the conductive layer in that profile. A small patch of a conductive body (<30 Ω-m) is revealed in between stations 231 and 233 at elevations of about 3000 to 2000 masl. Underlying this body starting at elevations of about 1700 m asl and persisting to deeper levels is a highly resistive (>200 Ω-m) slab

5. CONCEPTUAL MODELLING

Sabalan area consistent with the study made by Johnston et al. (1992), wherein the thickest conductive layers are usually found in the outflow regions, the interpreted major outflow directions in Mt. Sabalan are towards the west (Moil Valley) and the north (Shabil) as indicated by the presence of the conductive zones that persist at deeper elevations. These conductive zones are about 600 to 1000 m thick beneath Pad D based from profiles P01 and P02. Furthermore, correlation with well data from NWS-7 shows that the conductive layer coincides with Sm, Il-Sm, zones while the epidote zone coincides with the increasing resistivity values (>30 Ω-m) (Fig. 7). Again, this is consistent with the conceptual model by Johnson et al. (1992) wherein by correlating the different alteration mineral assemblages with resistivity, it was found out that the higher temperature minerals like pure illite and epidote have resistivity values >20 Ω-m. This is also consistent with the results of the previous surveys wherein the conductive layer coincides with the Sm (smectite) zone Bromley et al (2000). Additional correlation shows that the Paleozoic metamorphics lie within the >70 Ω-m layer (Fig. 7).

The broad <20 Ω-m conductive resistivity anomaly mapped in the west (Moil) at elevations starting from 2400 m down to 2000 m was also mapped by the previous MT surveys and was interpreted to correspond to relict hydrothermal alteration rocks formed by a decollement Talebi et al (2005).

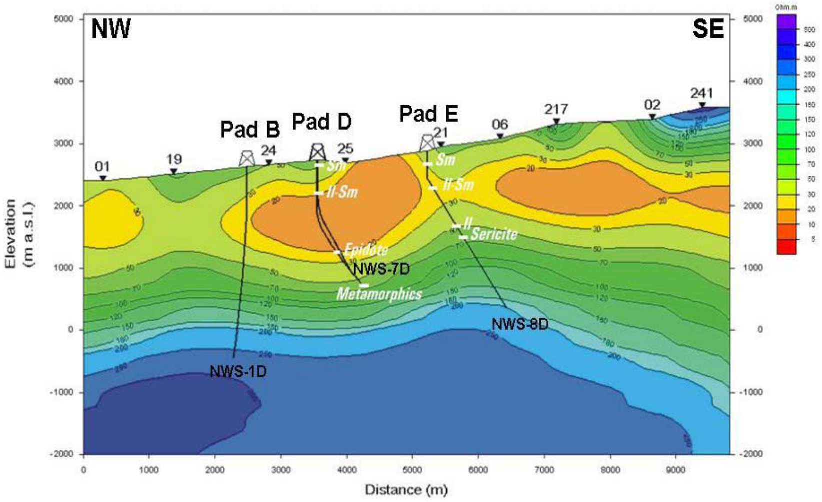

Figure 7: Correlation of resistivity with alteration minerals.

6. CONCLUSION AND RECOMMENDATIONS

MT survey conducted in Mt. Sabalan further confirmed the existence of a geothermal resource in Mt. Sabalan. This is located west of Mt. Sabalan, bounded by mapped and delineated faults such as NNW2, NW5 and W7 and has an area of about 55 km2 this is more than twice the size defined by the earlier surveys (SKM, 2005).

Projecting the mapped major faults shows that most of these structures coincide with the discontinuity or the change in resistivity layers. These may be the permeable zones in the area but should be verified by carrying out structural mapping in the future.

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