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Borehole Geology and Alteration Mineralogy of Well NWS-4, Mt.Sabalan Geothermal Field, NW-Iran

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ABSTRACT

Drilling of well NWS-4 was finished in 29 March 2004 during 98 day at western side of Sabalan Volcano in Northwest of Iran. Refer to MT results, there is <4Ωm anomaly beneath the western side of Moil valley with about 500m thickness. Lithology of the well consists of Lava flows and volcanic ash and hypabyssal rocks in the lower parts of the well. Surface deposits are unaltered and in lower parts, secondary hydrothermal minerals mainly consist of clays, Silica, Pyrite and in lower parts and quartz, clay, magnetite and epidote in high temperature zone. Heat up test in 4rth day survey shows the maximum temperature at T.D (211^{o}C) and also behind of production casing there is high enough (about 205^{o}C). After 1612 m depth there is tectonized permeable zone due to encountered faults. At 1220m depth and 1620m there are 2 cooler zones created by faults. At 950m depth there is a clear increase in high temperature hydrothermal minerals as epidote that 4th heat up test emphasized it. Correlation between measured temperature and alteration temperature indicates that alteration temperature is close to measured temperature at maximum of about 230oC in interval 950-1170m depth.

FIGURE 1: Location map of well NWS-4

1. INTRODUCTION

Well NWS-4 is located in western part of Mt.Sabalan volcano at a distance of about 20km Meshginshahr city in Ardebil province in northwestern parts of Iran (Figure 1). This field is named Meshginshahr geothermal field that is second geothermal field drilled deeply. Well NWS-4 is 3rd deep geothermal exploration well in the field drilled by Renewable Energy Organization of Iran (SUNA) in 2003-2004 after 98 days. NIDC (National Iranian drilling company) was drilling contractor of the project.

2. GENERAL GEOLOGICAL INFORMATION

According to global tectonic the area is effected by some phenomena's as subduction of Arabian plate under central Iranian plate also two trust that have made southern Caspian sea depression and two trust fault in north of Iran and Caucasian range as well as. Northwest of Iran is located in boundary of these plates. Mt. Sabalan and Mt.Sahand are two quaternary volcano in the area.

Sabalan is a large stratovolcano consists of 3 summit named Soltan (4811), Heram (4612m) and Kasra (4573m). The stratovolcano is created on a possible horst trending northeast-southwest erupted possibly in Holocene in latest time. Caldera collapsing has caused a depression about 400 m height and 12 km diameter. The lava flows consists of trachyandesite, andesite and dacite and pyroclastic deposits.

There are 9 hot springs with a temperature in the range of 25-85^{o}C as Ghotursui in southern parts of Moil valley (29^{o}C, pH= 3), Moil at Moil Village (45^{o}C, pH=5) and Gheynarjeh at north of Dizu village (84^{o}C, pH= 7). Gheynarjeh is hottest spring in Iran. Hot springs in the area have neutral, Cl-SO4 and SO4 composition. (SKM, 2003,1).

Hydrothermal alteration outcropped in some parts indicating secondary alteration minerals as Iron oxides, Kaolinite, Limonite, silica and clays.

Well NWS-4 is located on Dizu formation consists of uncemented Quaternary terrace deposits, These deposits has lied on Valhazir formation that is belong to Precaldera consist of Trachyandesite, Tuff, Pyroclastic breccia belong to Pliocene that are altered in lower unit and unaltered in upper lava flows except some parts that are fracture controlled altered (Figure 2). In northern parts of the site there is a syn-caldera trachydacite dome belong to Pleistocene and is remarked as Toas formation.

3. GEOPHYSICAL STUDIES:

Results of MT geophysical survey around the area shows that there is a low resistivity area under western sides of Moil valley that indicates a <4Ωm anomaly with a thickness > 500m that top of it is located in 2700 masl (Figure 3)

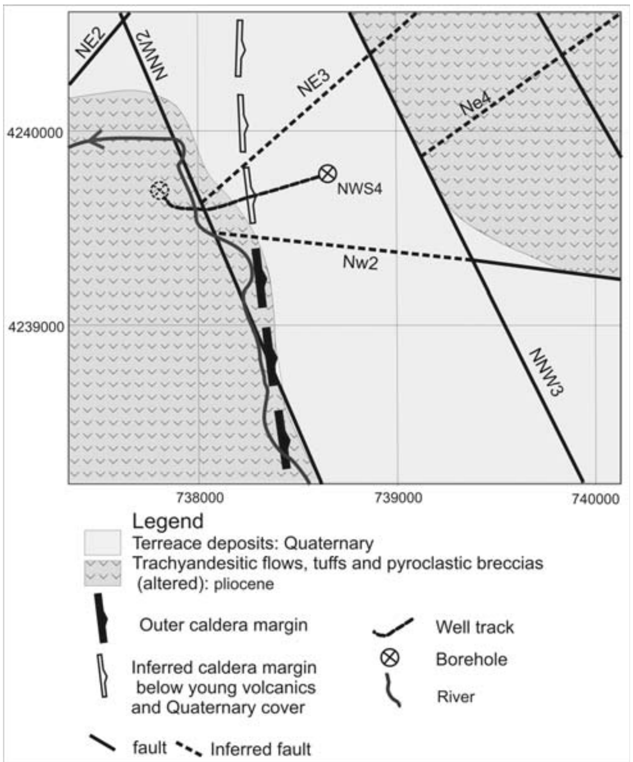

FIGURE 2: Geological map of the area and well track of well NWS-4.

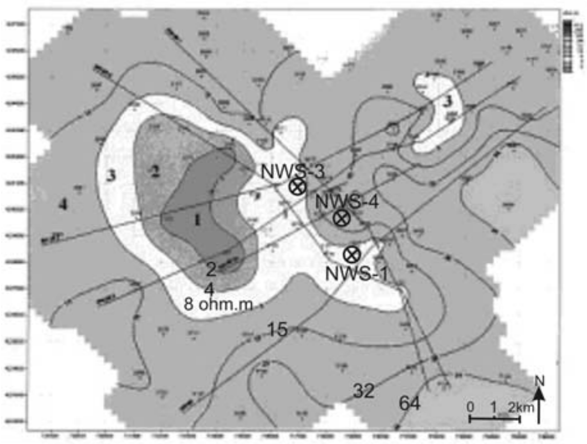

Figure 3: Results of MT survey in depth 500m from 2D models (Modified after SKM, 2003).

4. BOREHOLE GEOLOGY

4.1 Materials and methods

From Surface down to 2262 m depth in each 3 interval cuttings were picked during the drilling of the well NWS-4. The samples were analyzed and are the foundation of the subsurface geology, distribution of alteration minerals and foundation of subsurface geology. After sampling, the samples are studied under a binocular microscope. Petrographic microscope on the borehole was used for studding thin sections. XRD and Fluid inclusions samples sent to New Zealand to study by consultant (SKM).

4.2 Drilling

Wells NWS-1, NWS-3 and NWS-4 are exploration wells and NWS-2 and NWS-5 are reinjection wells in the area drilled down to 650 and 550m depth respectively. There is no reinjection well for NWS-3 because the water table is too high. Drilling of well NWS4 was finished after 98 days after spud (18 December 03) down to 2226.5 m. Specifications of well NWS-4 and two another wells is shown in table Appendix I.

The aim of drilling was both exploration and exploitation of steam for a geothermal power plant in the area. The reason for directional drilling of NWS-4 was to drill toward low resistivity anomaly (less than 8 ohm.m) in western sides of moil valley (Figure 2) also to intersect fault NW2 (Figure 2) in the lower parts of the well. Totally there are three reasons for directional wells: Topographically, it is difficult to access the target zone; Encountering faults and fractures may be done with more assurance; to minimize the environmental impacts on the disturbed area (Eshaghpour, 2003)

4.3 Faults

There are 3 faults: NNW2, NW2 and NE2 that is shown in geological map of the area (Figure 2). It was a goal for drilling to crosscutting the faults to study them as well as alteration and geophysical anomaly. Well encountered NNW2 at 1380m and NW2 at 1478m. After encountering NW2 there was good permeability resulted walking along the fault as there was total loss of circulation at most parts of the well after 1612m down to 2025m (Appendix II).

4.4 Stratigraphy

- Dizu: 0-60m

Equivalent with Qt1 and Qt2 in geological map of geological survey of Iran carried out by Amini creates all surface deposits in both 3 wells. Grain size is variable from sand to boulder. There is an unconformity between 2 deposits (Qt1, Qt2) (Amini, 1988). Deposit is unconsolidated and unaltered except some rare extinct secondary alteration minerals. Grain composed of: Trahyandesite with Plagioclause, Hornblade and Potasic Feldspars in red groundmass; Andesite with Plagioclause and Hornblande phenocrysts in grey groundmass; Trachydacite with Sanidin phenocrysts that is accomodated along plagioclases and hornblandes with grey, vesicular groundmass.

- Valhazir: 60-383

Formation is equivalent with Qpad in Amini geological map of geological Organization of Iran. Consist of andesite, porphyri dacite that underlies Dizu formation. Lithology consist of consolidate rocks as andesite flow, trachyandesite and volcanic breccia with porphyritic texture. Samples from this well in Valhazir formation is totally altered to clay, silica and pyrite with less amounts of chlorite and Fe-oxides hence primary lithology is not too clear and Volcanic altered is the Term that uses for it.

- Epa:383-1840m

Composed of Microlitic porphyri andesite, most of the rocks are hardly epidotized and carbonitized due to contact with hypabbysals. Formation is characterized by iron oxide rich in the top.

- Hypabbusal rocks: 1840-26255m

Fine grained altered diorite. Boundaries of this unit with strutigraphy of two another wells is not too clear.

4.5 Distribution of hydrothermal alteration minerals

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 (Heneley and Ellis, 1983). Due to water –rock interaction and chemical transport by the geothermal fluids, the primary minerals in the host rock matrix are transformed, or altered, into different minerals. The alteration process and the resulting type of alteration minerals are dependant on the type of primary minerals, chemical composition of the geothermal fluid and temperature. On the other hand intensity of alteration is dependant on the temperature, but also on time and texture of the host rocks. Overall, hydrothermal alteration is affected bye temperature, permeability (related to gas content and hydrology of a system), fluid composition of rocks, duration of activity (immature, mature), number of superimposed hydrothermal regimes (overprinting of alteration), and hydrology (Reyes, 2000). Four alteration zone is distinguished in the well (SKM, 2004):

- Argillic: Characterized by low temperature clays as Kaolinite, Smectite and interlayerd of Smectite-Illite. This zone indicates alteration Temperature <230^{o}C created by acid or neutral fluids with brine or neutral specifications.

- Phyllic: characterized by existence of Sericite or Illite and Quartz and Pyrite and possibly Anhydrite. It is possible to find fewer amounts of Calcite, Chlorite Titanite and Rutile. Indicating Temperature about 230-400 ^{o}C and creates by both acid and neutral with variable salinity. Mostly in permeable zone close to veins creates.

- Propylitic: characterized by existence of Illite, Sericite, Quartz, Epidote, Albite, Calcite and Anhydrite. Indicating moderate temperatures about 200-300 ^{o}C and creates in near-neutral pH with variable salinity. Mostly in low permeable areas.

- Potassic: creates near-intrusive hot fluids (>300 ^{o}C) with a strong magmatic character and high salinity

Well NWS-4 is characterized by too much silica in most parts of the well. Hexagonal quartz found at depths 750-800m indicating alteration temperature more than 180^{o}C. Clay minerals (especially Smectite) are dominant in upper parts of the well and bottom and they found less from11150m depth (where production casing run in the hole) down to 1612m depth smectite created plugging problem during drilling because of swelling situation. Illite that distinguished according XRD results generally acts as filler material and stable at temperature between 200-300^{o}C (Thompson and Thompson, 1996). .High amounts of Silica and smectite made abrasion problem during drilling of the well. Magnetite is starting at depth about 1150m down to total depth. Magnetite during drilling seemed to be fresh but according to measured temperature it will ignored. Magnetite occurs as disseminations or vein-fills within early quartz-amphibole alteration in some porphyry deposits and is a common constituent of biotite-rich potassic alteration in many porphyry deposits. High concentrations of magnetite are particularly common in gold-rich porphyry deposits (Thompson and Thompson, 1996). Epidote is a calcium silicate that is general secondary alteration mineral from 780m down to bottom of the hole with moderate range of abundance as anhedral fine crystals both as replacement and open-space filling in veins. In high temperature parts of the well where calcite was more abundant epidote was increase as well. Epidote also is susceptible to replacement by calcite in precence of CO2-rich fluids (Thompson and Thompson, 1996). Sustainability of calcite in temperatures between 50-270^{o}C (Reyes et al, 1994), and high amount of calcite even in high temperature zone, makes possibility of replacement of epidote to calcite at high temperature zones. Distribution of hydrothermal alteration minerals and amounts of loss of circulation and measured temperature of well NWS-4 is shown in Appendix II.

In well NWS-4 case,Quartz, Cacite and anhydrite readily from veins and fill vugs, but cholorite, illite, pyrite, hematite and epidote have also been observed to occur in places where they could only have deposited directly from a fluid as mentioned in another places (Arnarsson, 1981).

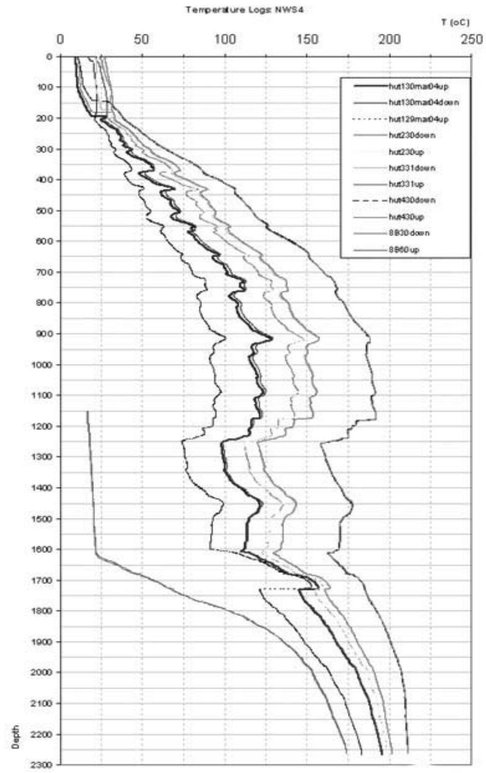

Figure 4: Temperature logs of well NWS-4 all depth is according to measured depth.

5.DISCUSSION

Temperature logs of completion test with 8bbl and heat up tests is shown in Figure 4. According to spinner log water table is located at 145m depth at 4th heat up test. It seems that temperature at depth 1200m is maximum but there is no sufficient permeability at depths upper than 1612m this impermeable zone is correspond with high amounts of smectite, hence it can not be determine as a production parts of the well. It seems that there are two flow zones at depths about 1220m and 1612m decreasing temperature of formation correspond to fault zone.

At case that we consider alteration temperature between 220-280^{o}C for epidote (Reyes et al., 1994), Correlation between measured temperature and alteration temperature indicates that alteration temperature is close to measured temperature hence system is on boundary of cooling and heating. It needs more research on alteration temperature of epidote and other high temperature secondary minerals in the field to comparing them with reservoir temperature to discuss more clearly about temperature of this geothermal system vs. time. A correlation between this well and two another wells indicates that high temperature zone is located upper than well NWS-3 and lower than well NWS-1 indicating a possible up flow zone toward south in higher elevation parts.

6. RESULTS:

- Lithology of the well consists of lava flows and pyroclastics that are affected by intrusions in lower parts.
- Existence of fresh Epidote in 750m depth down to T.D indicates alteration temperature >230oC in this intervals.
- After 700m depth we have high enough temperature but permeability is very low down to 1612m to product.
- Comparison between alteration temperature and measured temperature indicate is approximately corresponding with each other.
- The maximum temperature measured at T.D but for more information it needs to study following heat up tests.
- After 1612m depth there was total loss of circulation created by cross cutting of the faults specially walking along fault NW2.

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Appendix I: Drilling specification of well NWS-4,NWS-1 and NWS-3

NWS-4	Conductor pipe	Surface Casing	Anchore Casing	Production Casing	Liner
bit (")	26	20	17 1/2	12 1/4	8 1/2
drilled depth(m)	47	105	547	1195	2266
Casing (")	30	20	13 3/8	9 5/8	7
Casing shoe (m)	39.5	99.24	541	1176	2265.5

Top of cellar elevation (masl): 2487 Total depth:2265.5

Cellar Coordination: 738 712 mE UTM, 4 239 733 mN UTM planned Orientation: Deviated

kick of point: 600m Buil up rate: 3°/30 m End of Build up rate: 950 m Drift angle: 38° Throw: 835.3 m

Azimuth (to 1558 m): 249° Azimuth (bottm hole): 301.5° Actual time taken from Spud: 98 days

*all depths are m MD ex RKB (RKB= 9.5m) from: 17 Dec 03

NWS-1	Conductor pipe	Surface Casing	Anchore Casing	Production Casing	Liner
bit (")	26	20	17 1/2	12 1/4	8 1/2
drilled depth(m)	47	105	547	1195	3197
Casing (")	30	20	13 3/8	9 5/8	7
Casing shoe (m)	27	110	380	1587	

Top of cellar elevation (masl): 2630 Total depth:3197 *all depths are m MD ex RKB

Cellar Coordination: 739002 mE UTM, 4 238398 mN UTM planned Orientation: Vertical

NWS-3	Conductor pipe	Surface Casing	Anchore Casing	Production Casing	Liner 1st	Liner 2nd
bit (")	26	26	17 1/2	12 1/4	8 1/2	6 1/8
drilled depth(m)	47	103	362		2649	3176
Casing (")	30	20	13 3/8	9 5/8	7	5
Casing shoe (m)	39.5	99.26	358	1599	2648	3170

Top of cellar elevation (masl): 2276.5 Total depth:3176 *all depths are m MD ex RKB

Cellar Coordination: 737 028 mE UTM, 4 240 784 mN UTM planned Orientation: Deviated

Actual time taken from Spud: 118 days kick up point: 390 m Buil up rate: 2.99 o/30 End of build up rate:740

Throw: 1623 m Azimuth: 337.3 o Drift angle: 35.3o (to 2636m) and 48o (after 2636 to T.D)

Appendix II: Distribution of hydrothermal alteration minerals and amounts of loss of circulation and measured temperature of well NWS-4