Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geochemical Characteristics of Reservoir Fluid from NW-Sabalan Geothermal Field, Iran

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Keywords: Sabalan geothermal field, geochemistry, thermal fluid, stable isotope, Iran

ABSTRACT

The first geothermal exploration activities in Iran were carried out in the Mt. Sabalan field. The discharge test measurements show that wells NWS-1and NWS- 4 produce predominantly from a single-phase, reservoir (liquid) with a temperature of 225°C and 223 ^{o}C. The chemical composition of the reservoir water was analyzed by standard methods and subsequently classified using Cl-SO_4-HCO_3 and Cl-Li-B triangular diagrams. A Na-K-Mg triangular diagram was used to classify waters according to the state of equilibrium at given temperatures. The geothermal waters are of sodium-chloride type and from a relatively old hydrothermal system. Thermal fluid is in equilibrium with reservoir rocks. The isotopic composition of the Well NWS-4 presents enrichment in ∂^{18}O, typical characteristics of geothermal origin. The chemical geothermometers were used to predict subsurface temperature. Silica geothermometers give temperature more close to measured temperature whereas cation geothermometers show significantly higher temperatures than measured temperatures.

1. INTRODUCTION

The Mt. Sabalan geothermal field is one of the prospective areas in NW-Iran for geothermal exploration which was initiated by SUNA (Renewable Energy organization of Iran) is 1978. NWS-1 and NWS-4 are the first and third deep exploration geothermal wells which were drilled in Iran. The map location is shown in Figure 1. Vertical geothermal well NWS-1 with general capacity of about 2.2 MWe is located in the northwest of Sabalan volcano and produces from a major zone at 2500 m with a temperature of 226°C. Maximum mass flow is 30 kg/s and total discharge enthalpy is about 980-1000 kJ/kg (SKM, 2005). Directional geothermal wells NWS-4 are located about 1.2 km north of NWS-1. Generating capacity is 3.9 MWe. The well produces from a single-phase reservoir with liquid at 1400m at a temperature of 223°C (SKM, 2004).

2. CHEMICAL COMPOSITIONS OF THE WATERS

The geochemical study is based on discharge water samples collected from the discharge brine line of two production wells (NWS-1 and NWS-4). These samples were collected in May and June 2004 for well NWS-1 and in September 2004 for well NWS-4. Samples were untreated and included acidified water. Chemical analyses of pH, Cl, HCO_3, SO_4, Ca, B and CO_2 were carried out in the site laboratory of SUNA and Li, Na, K, Ca, Mg and SiO_2 in laboratory of GNS Wairakei (New Zealand). Stable isotope analyses (σ^{18}O and σ^{2}H) were carried out in the laboratory of GNS Welligton.

2.1 Classification of the thermal fluids

The average chemical compositions of the geothermal water from the production wells (NWS-1 and NWS-4) are presented in Table 1. The composition of thermal fluid from geothermal wells (W-51 and W-65) in Baransky volcano (Russia) is presented for comparison. The discharge water from production wells NWS-1 and NWS-4 are of the sodium chlorate type with alkaline pH (8.1-8.5) and with total dissolved solids in range the of 4712-4995 mg/kg. A Cl and Na are predominate cations with concentration of 2460-2750 and 1413-1600 mg/l respectively, whereas Mg is present only in trace (0.1-0.23 mg/l). In contrast, hot waters discharged from wells W-51 and W-65 are neutral (pH-7,4-7,3) and concentration of sulfate and carbonate ions are lower while calcium and K concentration from W-51 are two times higher than that from wells NWS-1 and NWS-4. The chemical compositions of the waters were classified on the basis of major ions using the CI-SO_4-HCO_3 triangular diagram of Giggenbach (Figure 2). All samples plot to area of mature waters and can be classified as Cl-rich geothermal water which formed by the interaction of geothermal fluids with the host rock and dilution with low-salinity water at depth (White and Muffler, 1971).

Cl and B are conservative elements in the geothermal system. They are fixed in fluid phase and have not equilibrated. The conservative elements are the best geoindicators of the origin of the geothermal system. B/Cl ratio and Cl-Li-B ternary diagram were used to indicate the source of the fluid. A plot of the relative concentrations of Cl, Li and B is shown in Figure 3. All geothermal waters have high Cl content relative to Li and B, indicating that they are from an old hydrothermal system and that fluid migrated from the old basement rock.

The B/Cl ratio of the water from wells NSW-1 and NSW-4 is 34 and 36, respectively. A high ratio can be representative of andesitic reservoir and rhyolitic system or due to absorption into alteration clays along the geothermal flow (SKM, 2004: SKM, 2005).

The water composition from well NSW-1 and NWS-4 is similar to reservoir waters found in the Baranskiy geothermal field of Russia but somewhat lower in concentration of carbonate and sulphate (analyses from W-51 and -65) and higher calcium and potassium for Well-51.

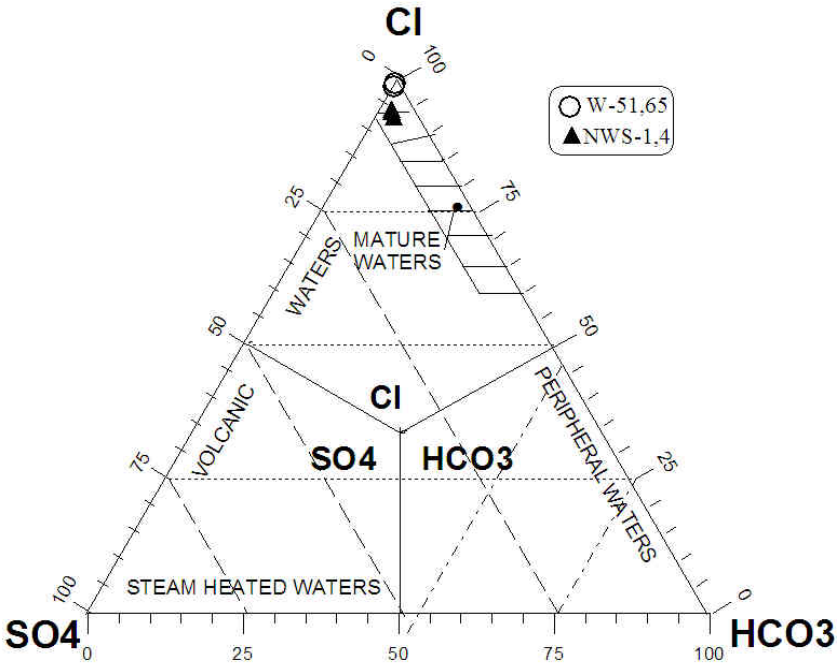

Figure 2: Cl-SO_4-HCO_3 classification diagram of Giggenbach (1991) for the studied fluids

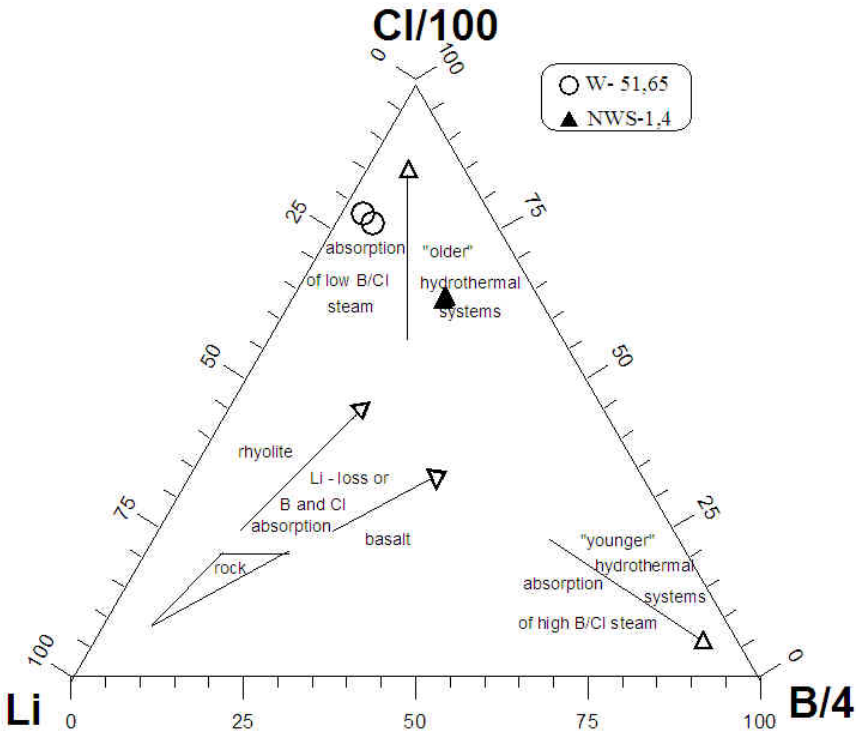

Figure 3: Cl-Li-B diagram of Giggenbach for the studied fluids

2.2 Isotopic characteristic

The relationship between $\sigma^{18}O$ and $\sigma^{2}H$ for the water from geothermal well NWS-4 is shown in Figure 4. Isotope data for hot springs and local cold surface waters were also plotted. As seen from the figure, the well presents a $\sigma^{18}O$ shift of about 3,0‰ from local meteoric water which can be indicative of the origin of geothermal fluid. The shift can be due to isotopic exchange at high temperature between reservoir water and the rock minerals which are richer in $\sigma^{18}O$ (Arno′rsson, 2000).

Most of the hot springs are located on the line of world meteoric waters but have a smaller shift due to mixing with local meteoric water.

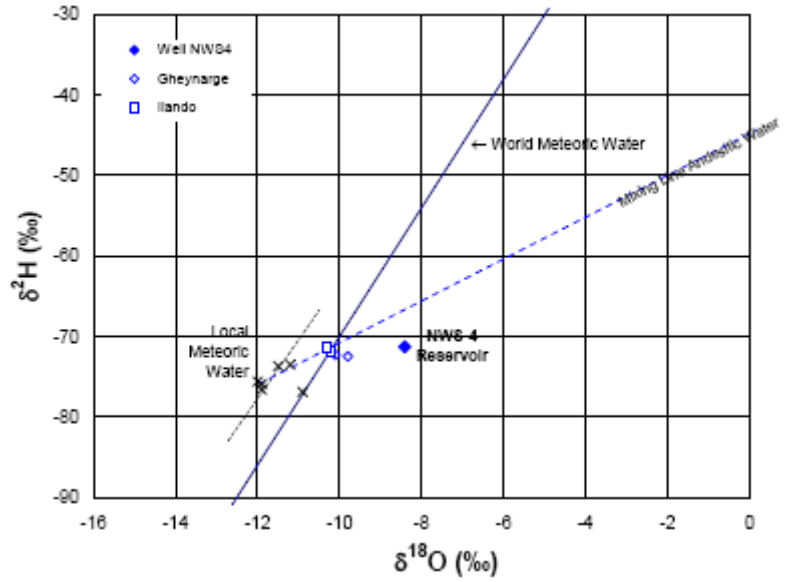

Figure 4: Relation of $\sigma^{18}O$ and $\sigma^{2}H$ stable isotope in the Sabalan geothermal field (SKM, 2005)

3. SUBSURFACE TEMPERATURE ESTIMATION

The silica and cation geothermometers were used for the evaluation of subsurface temperature for well discharges (Table 2). The chalcedony geothermometers of Fournier (1977) and Arnosson et al were used.

Table 2: Geothermometer temperature for the thermal water from NWS-1 and NWS-4 wells (^{o}C).

Geother.	T_{mea}	$T_{Na\text{-}K\text{-}Ca}$	$T^{1}_{Na\text{-}K}$	$T^{2}_{Na\text{-}K}$	T^{1}_{Ch}	T^{2}_{Ch}	T_{Q}
NWS-1	226	506	273	291	246	211	226
NWS-4	223	490	271	289	251	215	229

Source of temperature equations: T_{M} –measured temperature, $T_{Na\text{-}K\text{-}Ca}$ – Fournier and Truesdell (1973), $T^{1}_{Na\text{-}K}$ – Giggenbach (1988), $T^{2}_{Na\text{-}K}$ – Arnorsson et all. (1983), T^{1}_{Ch}- Fournier (1977), T^{2}_{Ch}- Arnorsson et all. (1983), T_{Q}- Fournier (1977).

These (1983) give reservoir temperatures ranging from 211 to 251 ^{o}C. In comparison with chalcedony geothermometer, the temperature calculated by the quarts geothermometer of Fournier (1977) is 226 and 229 ^{o}C almost the same as the measured reservoir temperature 226 ^{o}C and 223 ^{o}C, respectively. It may be inferred that quartz controls the dissolved silica concentration in the deep reservoir (D'Amore, 1991). The temperatures obtained from cation geothermometers are significantly higher than from silica geothermometers. The Na-K geothermometer of Giggenbach (1988) and Arnorsson et al. (1983) suggested reservoir temperature in the range of 271-289 ^{0}C which is higher than measured temperature. The Na-K-Ca geothermometers (Fournier and Truesdell (1973)) predict anomalously high reservoir temperature (490 and 506 ^{0}C). It can be due to loss of carbon dioxide due to boiling which causes calcite to precipitate.

The Na-K-Mg triangular diagram shows the equilibrium between the geothermal fluids and rock and reservoir temperature (Figure 5).

Figure 5 shows that samples from studied geothermal wells fall on the full equilibrium line, suggested attainment of the water rock equilibrium. The water attains to be in equilibrium at temperatures around 260-280 ^{o}C (NWS-1 and NWS-4) and 260-300 ^{o}C (W-51 and W-65).

CONCLUSION

The geothermal waters discharged from wells (NWS-1 and NWS-4) of the Mt. Sabalan geothermal field are of sodium-chlorate type with a high concentration of Cl. Chemical compositions of reservoir waters indicate that the reservoir is located in the liquid dominant zone and geothermal waters come from an old geothermal system. The water composition from well NSW-1 and NWS-4 is similar to reservoir waters found in the Baranskiy geothermal field of Russia but somewhat lower in concentration of carbonate and sulphate (analyses from W-51 and -65) and higher in concentration of calcium and potassium than Well-51. Thermal fluid is in equilibrium with reservoir rocks.

The isotope composition of the well NWS-4 presents enrichment in $\partial^{18}O$ which can be the product of water-rock interaction at high temperature.

Common geothermometers have been used for estimating the subsurface temperature. The results from silica geothermometers indicate that quartz can control silica concentration in the reservoir or quartz geothermometers better indicate the reservoir temperature. The calculated temperatures using quartz thermometer is 226 and 229 ^{o}C which that almost coincides with measured temperature (226 and 223 ^{o}C). Cation geothermometers give temperature significantly higher than quartz geothermometers and higher than measured temperatures.

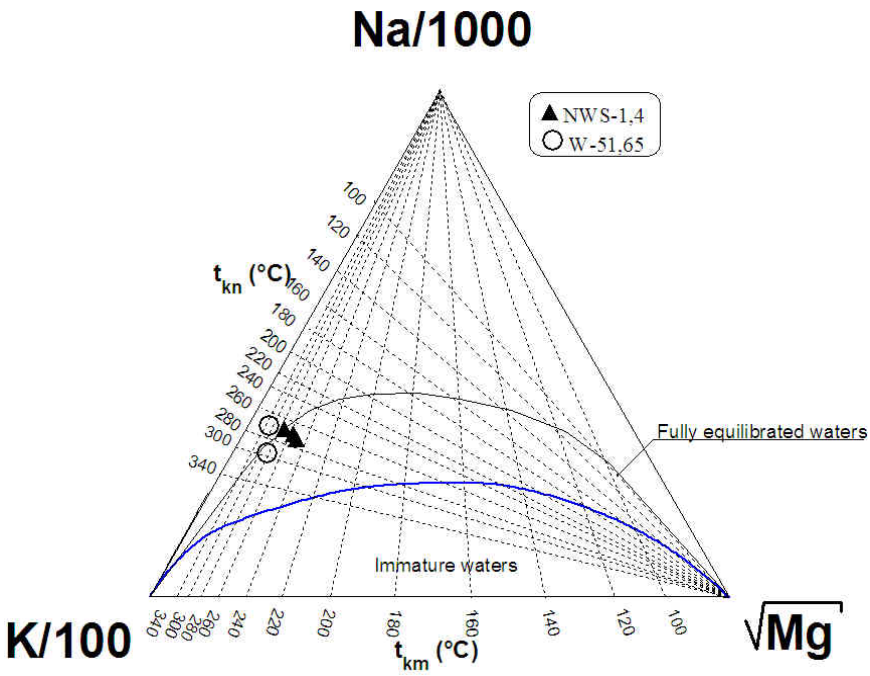

Figure 5: Na-K-Mg diagram of Giggenbach (1988) for the studied fluids.

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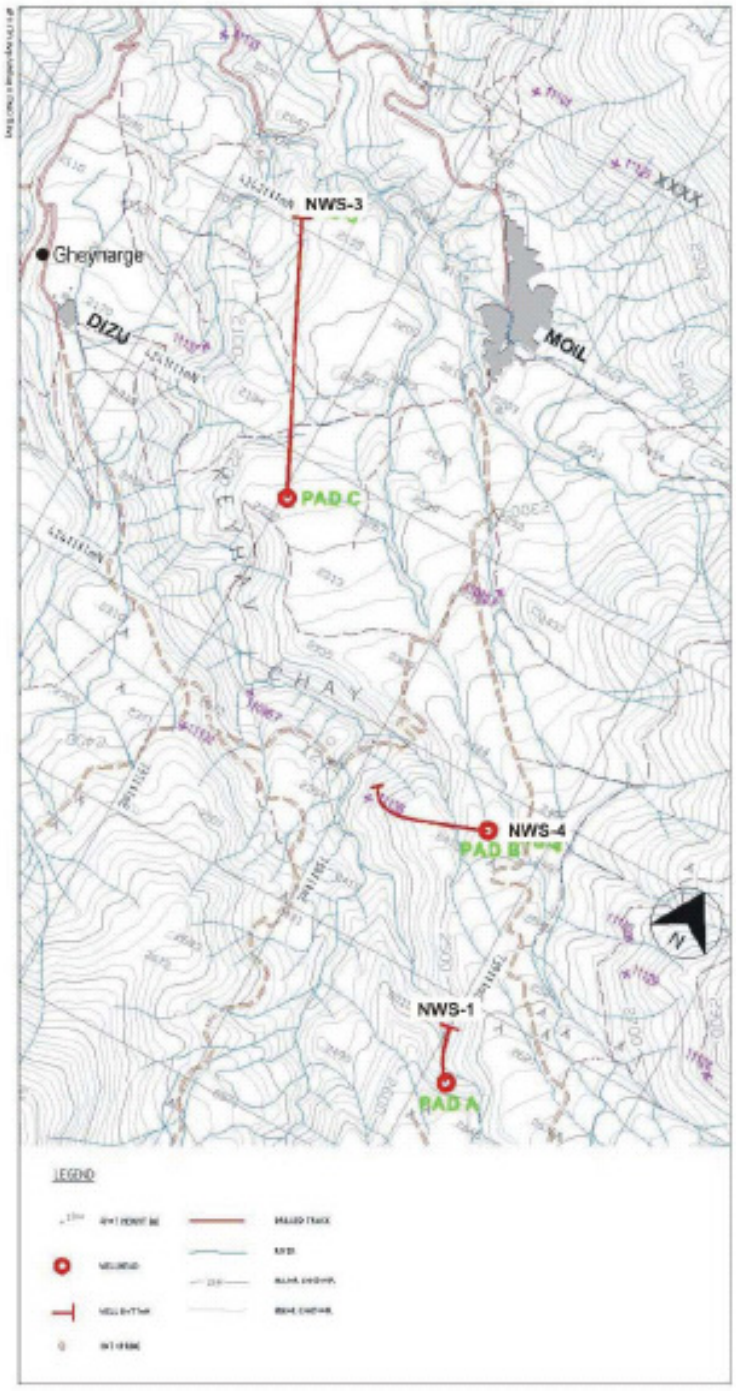

Figure1. Well location map (SKM, 2005).

Table 1: The average chemical composition of the studied thermal water in mg/l

		pH	TDS	Cl	SO_4	HCO_3	Na^+	K^+	Ca^{2+}	Mg^{2+}	Li	B	SiO2
NWS1	may-04	8,22	4995,7	2,75	122,71	90,57	1600	294,83	18,66	0,23	9,53	23,75	426,5
	jun-04	8,11	4712,8	2,46	116,27	107,3	1449	263,44	15,11	0,11	8,53	22,05	531,33
NWS4	sept-04	8,50	4680	2,5	109,64	73,21	1413	269	27	0,23	8,65	21,29	528,6
Baransky field (Russia)													
W51		7,46	2961	2961	40,00	28,1	1750	400	46	0,12	2,01	28	859
W65		7,34	3550	3550	34,5	29,3	1481	271	5,67	0,02	1,36	34,3	831