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Stable Isotope and Elemental Chemistry of Mt. Sabalan Geothermal Field, Ardebil Province of North West Iran

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ABSTRACT

Sabalan Geothermal Project is located in North West of Iran in the Province of Ardebil. Hot springs in the area have been used by local population from ancient times, and are considered as sacred, giving the region the name “Dashe Moghan (Magi’s Plane).

Three deep exploratory holes were drilled in 2003 and 2004 by the Renewable Energy Organization of Iran (SUNA) to a maximum depth 3200m, where temperatures higher than 240°C were encountered. Two of the wells did show sustained flow with a total power capacity of 6 MW. Connection of deep geothermal fluids and local hot springs are investigated in this paper through analysis of major ions and stable isotopes in hot springs and deep thermal waters. Constant elemental ratios show that local hot springs are chemically linked to the deep reservoir waters through concentration-dilution processes (such as steam loss and mixing with surface waters). $\delta^{18}O$ values of Sabalan thermal waters are between -8 to 12 and δD values range between -60 and -80. Isotopically thermal waters appear are connected to local meteoric waters by a relatively small oxygen-shift.

INTRODUCTION

The Sabalan geothermal prospect lies on the western slopes of Mt. Sabalan. The prospect site is located at about 20 km south of the City of Meshginshaar in the Province of Ardebil, north west of Iran. The area is located between 38° 12' 52" and 38° 20' 00" North and 47° 40' 30" and 47° 49' 10" East. The drilling locations are at an elevation of 2200 m in the north, to 3700 m in the south. The Sabalan geothermal prospect is planned for 200 MW developments starting with 50 MW as early as 2010.

Many hot springs found in the larger prospect area (Fig. 1) are believed to be connected to Mt. Sabalan volcanism which consist of young trachyandesitic lavas infilling a 14 km diameter caldera.

The geological setting of the Sabalan Porject area has been the subject of several recent studies such as Bogie et al. (2007) Khosrawi (1996) and Fotouhi (1995).

Tectonically, Mt Sabalan is a young volcano lying on the South Caspian plate which underlies the Eurasian plate to the North and overlies the Iranian plate (McKenzie, 1972).

The prospect area is located within the Moil Valley which exposes Quaternary Terrace deposits (known as Dizu formation), altered Pliocene volcanics and unaltered Pleistocene trachydacite rocks (Ar-Ar dated at 0.9 Ma) (Bogie et al., 2000).

Structurally, three main directions of faulting have been recorded: NE, NW and N-S. The latter are expected to be conjugate tensional faults between major NE trending

STRIKE-SLIP FAULTS

The northern slopes of Sabalan host many hot springs (seven in the Mouil Valley near Meshkinshahr, one further west at Yel Sou, and three aligned along a major NE trending structure near Ghotur-Suii as shown in Figure 1). The temperatures of these thermal springs range from 21°C to 82°C. Chemically they fall into different types including neutral, Cl-SO4 and acid SO4 (Bogie et al., 2000). Gigenhack (1992) analyzed the hot springs waters and found relatively low Na-K-Mg temperatures of about 150°C. A single sample from one the hot springs (Gheynarge) were analyzed for Trutum which indicated no recent interaction with atmosphere.

The present study comprises major ion and stable isotope analyses of all surface and deep thermal waters to better understand the hydro-geochemistry of the geothermal system, and especially cast light on 1) the overall chemistry of the deep geothermal system, and 2) connectivity of the surface hot springs and deep reservoir fluids. Isotope hydrology is especially aimed at understanding the provenance of the system’s recharge. Chemical geothermometers are used to calculate the temperature of the deep reservoir (as compares with observed temperatures from deep exploratory wells).

SAMPLES AND DATA

Thirty water samples were collected from hot springs and surface and meteoric waters in the fall of 2005. to complement the limited data collected and analyzed earlier (SUNA December 2004). Two samples were collected from each hot spring (a diluted for chemistry and a non-diluted for stable isotopes).

SUNA had previously) analyzed some samples for Oxygen-18 and Deuterium (SUNA 2004). Due to the limited number of the analyzed samples, the data did not present a valid statistical significance A more comprehensive sampling was therefore needed to improve the statistics.

The samples were analyzed for Oxygen-18 and Deuterium at the University of Ottawa. Duplicate samples and analyses were used for quality control. The oxygen data were repeatable within 0.6% and the Deuterium analyses were repeatable within 0.7%

The stable isotope data are presented in Table 1.

The new samples were also analyzed for major and trace elements by ACME Laboratory in Vancouver (British Columbia, Canada), The analytical work was administered and quality controlled by CERM3 (Center for Environmental Research in Minerals, Metals, and Materials, of the University of British Columbia). Major elemental concentrations and stable isotope analytical results are presented in Table 2.

DISCUSSION ON DATA

A summary of the earlier isotope data (SUNA-2004) is presented in Fig. 2. No reliable interpretation of this data is possible due to insufficiency of data points and also lack of information about the sample collection procedures. Fig. 3 combines the old and new stable isotope data. A local water line (connecting snow, rain, and cold surface waters) can be clearly defined on the Oxygen-18 / Deuterium correlation. This water line is slightly shifted from the global water line. It should be noted that some deviation from the global water line is seen in many geographic locations. The data points on the water line connect the high-elevation (cold) to low-elevation (warmer) precipitation.

From a purely hydro-geochemical point of view, it is clear that those Sabalan hot springs which are in close proximity of the drilling site (such as Geynarge and Ilando) have their source in the deep reservoir (represented by the NWS-1 and NWS-4 brines). An oxygen shift connects the local meteoric waters with the deep thermal waters. It can be seen that the recharge is not from the high elevation (i.e. snow). Local rain and river water infiltration is likely to be the main sources of recharge for the deep-reservoir (as represented by NWS-1 and NWS-4 samples).

Correlation of O-18 with chloride (Fig. 4) shows that the local hot springs and deep thermal waters are originated from single brine.

It can be seen that Gheynarje (a hot spring in close proximity of the drilling site) is relatively rich in chloride (for its isotopic value). It can be speculated that mixing of these waters with deep thermal waters may have been a reason for chloride and sodium enrichment in this hot spring. An alternative (and more plausible) interpretation is steam loss at high temperature, which would leave the isotopic vales relatively unchanged (Ghomshei and Clark, 1993), while enriching the fluid in minerals. It is therefore obvious that Gheynarjeh is not simply resulted from mixing of the original brine with surface waters. Steam loss should have also played a significant role in the final chemistry of this hot spring.

All the hot springs and deep thermal waters demonstrate a relatively constant δD which is an indication of being recharged by the same local waters. The oxygen shift is due to oxygen exchange with reservoir rocks. The observed moderate value of oxygen shift suggests a significant residence time in the reservoir. This is also evidenced by constant elemental ratio (e.g. Cl-Na), indicating chemical equilibrium between geothermal fluids and reservoir rocks.

Hot springs show a smaller oxygen shift (compared to that of the deep well samples), mostly due to mixing of deep waters with local surface waters. Gheynarjeh appears to have the highest shift (compared to other hot springs). This is possibly due to a more intimate connection between this spring and the deep reservoir. The unique geochemical behavior of Gheynarjeh is also demonstrated in the elemental correlations.

CHEMISTRY OF GEOTHERMAL WATERS

Geochemistry of constant ratio of conservative elements (as shown on the sodium-chloride correlation, (Fig. 4) shows that the geothermal system has reached geochemical equilibrium. Distinct linear correlation (with $r^2 > 0.95$) and passing of the regression line by the origin of the coordinate suggest that local hot springs are most likely evolved from the deep waters by simple concentration-dilution processes (i.e. mixing and/or steam loss).

This means that hot spring waters are likely created by a sequence of steam loss (during the ascent) followed by dilution of reservoir waters (by surface non-saline waters near the surface.

The sodium-potassium correlation (Fig. 5) shows a broken linear elemental correlation It is well known that the ratio of conservative elements (e.g. Na, K, and Cl) remains constant in geothermal waters originated from the same equilibrated reservoir (e.g. Ghomshei et. al., 1986). In the case of Sabalan, it seems that Na and Cl are the most conservative elements, as being evidenced by a linear correlation passing by the origin of the coordinate, in a Na-Cl plot (Fig. 6). Potassium is, however, less conservative (Fig 5). Potassium and sodium remain conservative for all hot springs (up to Gheynarjeh, which is the least mixed hot spring). What separates Gheynarjeh from the deep thermal waters is possibly a more complex process which involves potassium fractionation. This broken linear behavior of potassium has been seen in many other geothermal systems around the world and has been described by Ellis and Mahon, (1967) as being related to the following water-rock reaction:

Na^+ + K (Silicate) = K^+ + Na (Silicate).

This behavior may be caused either by interaction of hot ascending waters with surrounding rocks containing silicates (as inferred by the reaction above) or by simple precipitation of some sodium-bearing minerals during the ascent. The latter seems, however, less unlikely because of the strong linear correlation between sodium and chloride (Fig. 6). Whatever the reason, the sodium/potassium geothermometer can be trusted only in the linear part of the correlation (passing by the coordinate). These ratios give a temperature of about 230 to 245 ºC, which correspond to the observed deep temperatures (SUNA, 2004). Single element geothermometers (such as silica) is not reliable due to observed concentration dilution processes (as discussed earlier).

HYDROLOGICAL CONNECTION OF DEEP AND SHALLOW WATERS

Stable isotope and chemistry data; suggest that all the local hot springs and deep thermal waters are connected through the same geothermal system (which is isotopically and chemically equilibrated with reservoir rocks. This connection may indicate the presence of a large reservoir (which is most likely recharged from a large basin). The moderate oxygen shift may be indicative of a moderate residence time (i.e. some hydraulic conductivity within the reservoir rocks.

The isotopic shift at Sabalan shows that isotopic value of the original recharge waters correspond to relatively lower-elevation recharge (compared to high elevation local waters, engaged in the dilution of hot springs). This indicates that local high elevation waters can only contribute to near-surface mixing, and the recharge is from lower-elevation (i.e. a larger basin).

The local high-elevation meteoric waters clearly contribute to the dilution of local hot springs such as Illando and Gheynarge. It can be said that less than 50% of the hot spring waters are brought to surface (from the deep reservoirs) and the rest is from local meteoric waters (as evidenced from the chemistry and isotope data). For Ilando this number is closer to 15 to 20%. Salinity of Gheynarge, on the other hand is consistent with about 20% steam loss (boiling to 100 °C) and then about than 50% dilution with non-thermal waters.

While the chemical connection between the surface and deep thermal waters cannot be denied, the travel time from the deep reservoir to the surface (through natural conduits) needs to be investigated. In most geothermal systems, a significant time interval (in the order of months and years) separates the hot springs from the drainage area of deep wells (Shimada et al, 2000, Tokita et al, 2000) unless there is an open short-circuiting conduit linking the bottom of the wells to the hot spring (which is a highly unlikely scenario).

As for long-term effects, it can be said that any extensive pressure drop or cooling in the deep reservoir, may eventually affect the flow and temperature of the close-by hot springs (closer than 5 km). This is, however, very unlikely in the case of Sabalan (planned for 50 to 200 MW), as the deep reservoir is deemed be very large (as recharged from a large basin) and can keep its pressure and temperature if produced at a sustainable rate (write, 1995). The sustainable rate for geothermal systems depends on two factors: 1- the extent of the heat stored in the reservoir rocks, and 2- the volume of the recharge into the reservoir. Both these factors and also reservoir engineering conducted by SKM (2004) suggest that sustainable rate of production in Sabalan is very high (more than 200 MW).

CONCLUDING REMARKS

Stable isotope and chemistry data from the Sabalan Geothermal System indicate that the system has reached elemental and isotopic equilibrium.

A moderate oxygen shift may indicate presence of hydraulic conductivity in the geothermal system (as shown by flow testing of the deep wells).

The local hot springs are connected to the same equilibrated geothermal system. This indicates that the reservoir is extensive and large. Hydrological connection between the hot springs and deep waters is controlled by both steam loss and dilution.

The extent of the reservoir as implied by both isotopic and elemental data, suggest that planned extraction from the reservoir for power production, is not likely to affect the chemistry and flow of the hot springs.

Gheynarjeh is the closest hot spring to the deep geothermal reservoir. Evidence from isotope and elemental data suggest that Gheynarjeh is more directly connected to the reservoir fluids. This spring due to its close proximity to the production well fields may be affected by voluminous production in long term. Monitoring of the chemistry of this hot spring during the production is recommended.

REFERENCES

Bogie, I., Khosrawi, K, and Taleb, B. (2005). Geological Results from the Drilling of the Northwest Sabalan Geothermal Project, Iran. Proceedings of World Geothermal Congress 2005 Antalya, Turkey, 24-29 April 2005

Ellis, A.J., and Mahon, W.A. ((1967). Natural hydrothermal systems and experimental hot water/ rock reachtions (part ii). Geochim Cosmochim Acta, 31, 519

Fotouhi, M.; (1995): Geothermal development in Sabalan, Iran. *Proceedings of the World Geothermal Conference*, Florence, 1:191-196.

Ghomshei, M.M. and Clark, I.D. (1993). Oxygen 18 and Deuterium in deep thermal waters from the South Meager Creek Geothermal system. Geothermics, Vol. 22, No. 2, pp. 79-89

Ghomshei, M.M., Croft, S.A.S., and Stauder, J.J. (1986). Geochemical evidence of chemical equilibria in the South Meager Creek Geothermal System. Geothermics, Vol. 15, No. 1, pp. 49 - 61.

Khosrawi, K.; (1996): Geochemistry of geothermal springs in the Sabalan area, Azarbydjan, Iran. *The United Nations University Geothermal Training Programme Reports (Iceland), 1996 Number 7.*

Noorollahi, Y., Itoi, R., Fujii, H., and Tanaka, T. (2007). Geothermal Resources Exploration and Wellsite Selection with Environmental Consideration using GIS in Sabalan Geothermal area. Iran. . Proceedings of the Thirty-Second Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 22-24, 2007 SGP-TR-183

Shimada, K., Fumitaka Inuyama, F. and Tokita, H. (2000). HOT SPRING INTERFERENCE STUDY FOR PREDICTING HOT SPRING CHANGES IN GEOTHERMAL FIELDS. Proceedings World Geothermal Congress 2000 Kyushu - Tohoku, Japan, May 28 - June 10, 2000

Tokita, H. , Hiroshi Takagi, Yumi Kiyota1, Koji. Matsuda1, Hideki Hatanaka, Kanichi Shimada , Hirofumi Inuyama, Roger Young , Larry F. Bayrante, Oliver T. Jordan, Jesus Reymundo M. Salera and Francis Edward B Bayon. Proceedings World Geothermal Congress 2000. Kyushu - Tohoku, Japan, May 28 - June 10, 2000

Wright, P. M., 1995, The sustainability of production from geothermal resources: Proceedings of the World Geothermal Congress, 1995, Florence, Italy, International Geothermal Association, 2825-2836

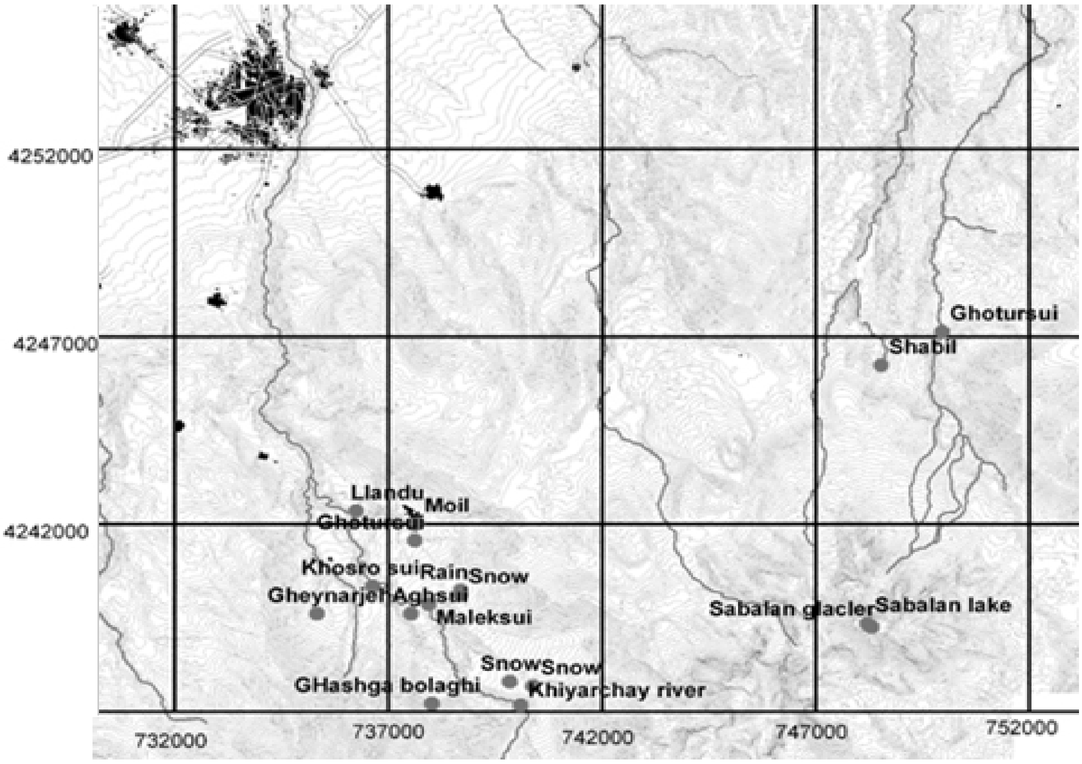

Fig. 1 – Location of the sampled hot springs and deep exploration wells.

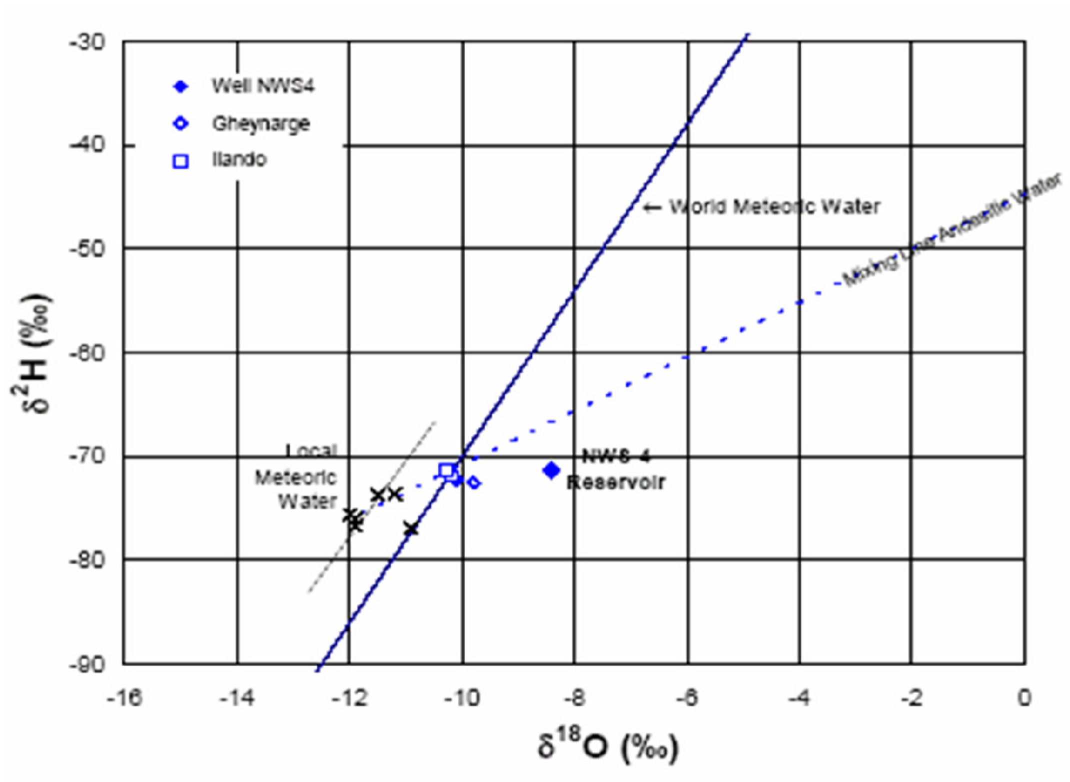

Fig. 2: Stable isotope data summary from SUNA-2004. Circles show Location of new isotope data from deep wells is shown

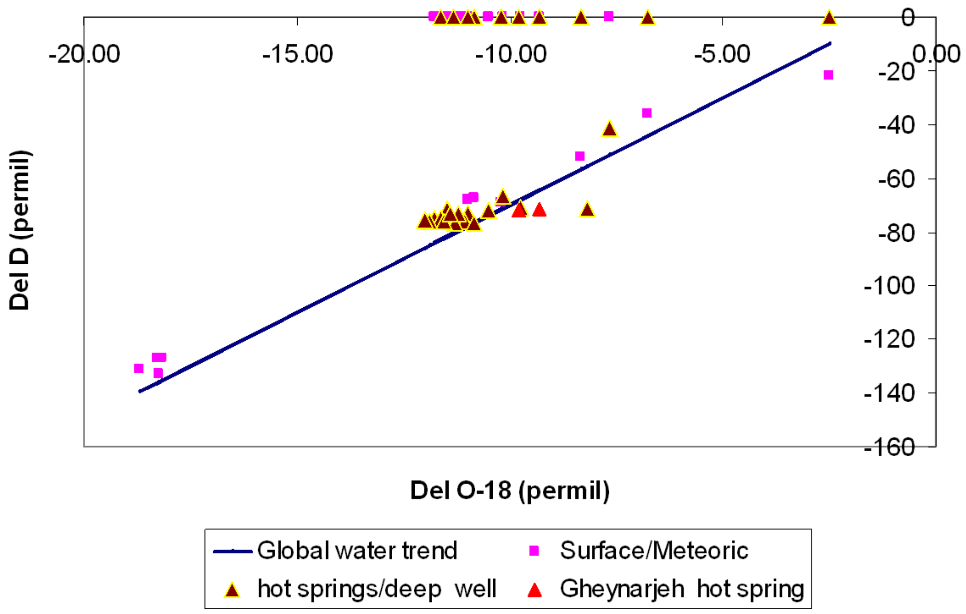

Fig. 3: New (2006) Stable Isotope data summary and interpretation. Oxygen shift connects deep waters tothe local water line (local rain). Local water line is shifted compared to global water line. The recent (2006) discharge From NWS1 and NWW-3 show isotopic values different from the NWS-4 (2004). It may indicate that NWS-4 is Recharged from local (high elevation) while NWS1 and NWS3 (being deeper) have been discharged from more regional (i.e. lower elevation) waters. More data is needed to confirm this concept.

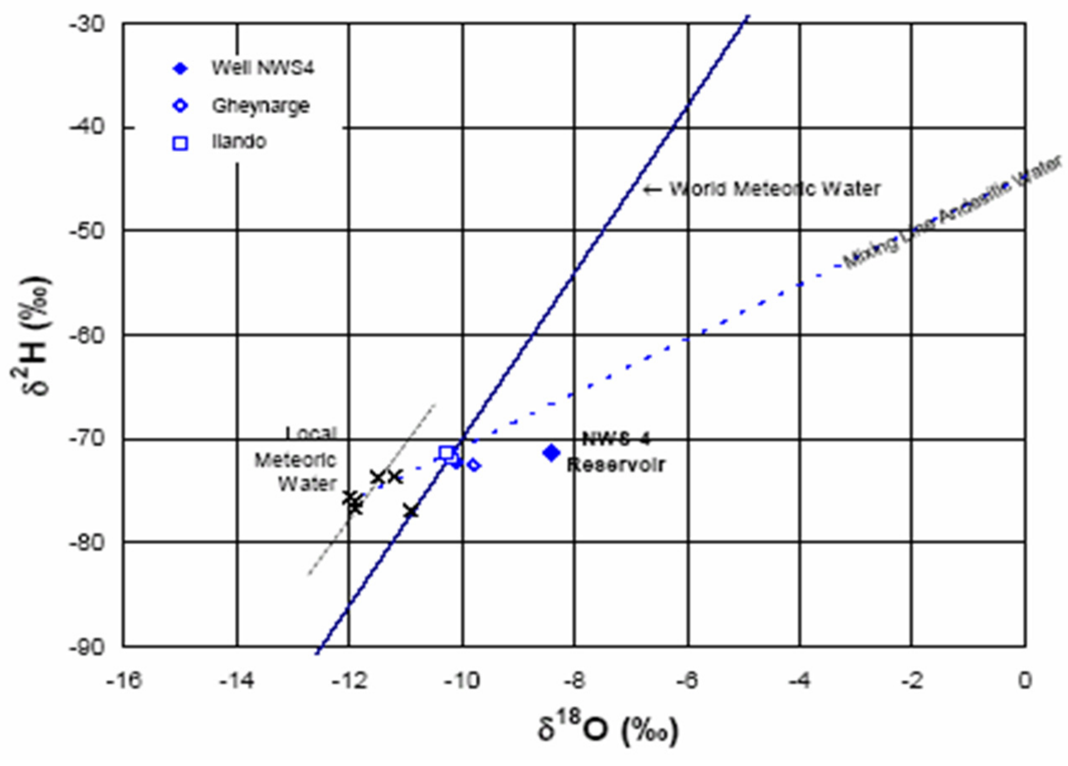

Fig. 4: Sabalan geothermal systems has reached geochemical andisotopec equilibrium (indicated by linear correlation). The hot springs are evolved from deep thermal waters by just mixing. Gheynarjeh shows a different behavior. Mixing with some high-chloride waters may be the reason for Ghyenarjeh's high salinity.

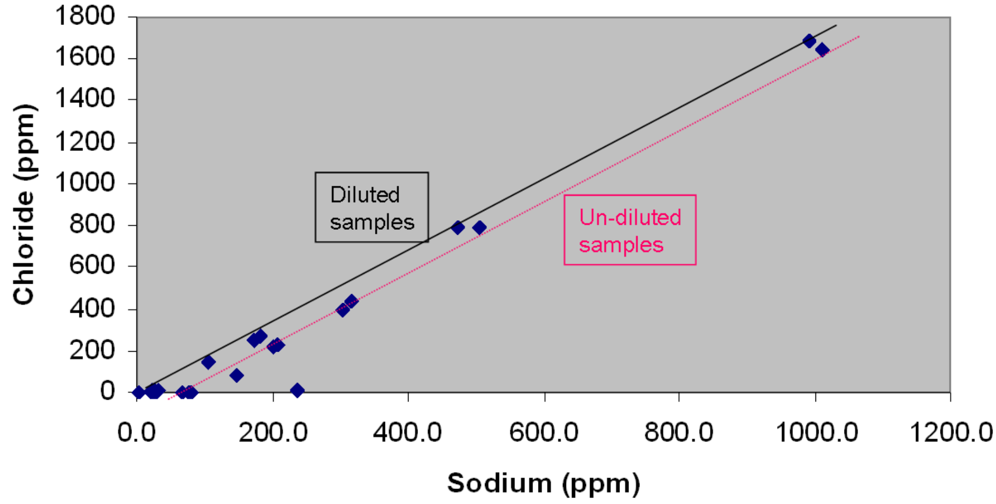

Fig. 5: Hot springs and deep thermal waters are connected through a concentration-dilution process. Concentration is due to steam loss and dilution is due to mixing with cold waters or mixing with steam. Un-diluted samples are slightly shifted from the mixing line due to small amounts of mineral precipitation.

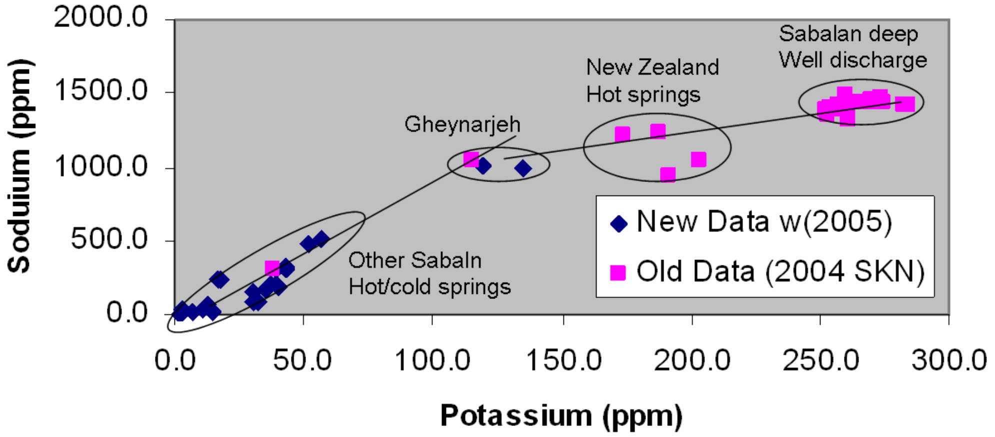

Fig. 6: Elemental correlation in Sabalan geothermal system. Potassium enrichment (or sodium dilution) Of deep thermal waters are possibly due to mineral precipitation (or re-equilibration with surrounding rocks.

Table1. The stable isotope data

Sample	Sample Name	Type	pH (T)	Conduct . µS (T oC)	H2 (VSMOW)	Delta O18 (VSMOW)
S-01	Khiyavchay river	Undiluted	8.04 (11.0)	56.3 (11.1)	-67.6	-10.83
S-03	Moil 1	Undiluted	5.03 (43.7)	1045(44.4)	-74.8	-11.76
S-05	Moil 1	Diluted	5.03 (43.7)	1045(44.4)	-41.5	-7.65
SA-07	Moil Cold spring	Undiluted	5.98 (16.3)	359 (17.0)	-75.6	-11.61
S-11	Ghotursui	Undiluted	3.48 (28.7)	696 (29.1)	-71.5	-11.48
SA-15	Maleksui	Undiluted	5.91 (43.9)	1225(43.5)	-73.2	-10.99
S-19	Aghsui	Undiluted	3.44 (34.4)	497 (34.7)	-66.5	-10.17
S-23	Gheynarjeh	Undiluted	6.40 (79.4)	5940(80.4)	-71.4	-9.30
S-27	Ilandu	Undiluted	5.78 (34.5)	2290(35.1)	-72.0	-10.49
S-31	Khosro sui	Undiluted	6.10 (58.6)	3310(58.8)	-71.1	-9.77
S-35	Ghashga bolaghi	Undiluted	8.71	53..8 (7.2)	-67.8	-10.99
S-37	Duzdu	Undiluted	5.66 (13.1)	478 (13.9)	-75.2	-11.32
S-39	Gavmishgoli	Undiluted	5.95 (43.8)	1452(44.5)	-76.1	-11.05
S-43	Sardabeh	Undiluted	8.8 (12.5)	311 (13.4)	-68.9	-10.21
S-45	Sardabeh hot spring	Undiluted	4.75 (35.8)	995 (35.8)	-75.0	-11.61
S-49	Ghotursui	Undiluted	2.84 (36.0)	1690(37.1)	-76.5	-11.30
S-53	Shabil	Undiluted	6.51 (48.3)	1658(48.7)	-76.3	-11.56
S-57	Sabalan lake	Undiluted	8.12 (2.2)	123.8 (3.2)	-22.0	-2.50
S-59	Sabalan Glacier	Undiluted	7.42	666	-35.9	-6.78
S-65	Rain	Undiluted	7.99 (13.1)	266 (11.2)	-51.9	-8.33
S-67	Snow site B	Undiluted	6.7	10.11	-127	-18.29
S-69	Snow office	Undiluted	6.87	11.3	-131	-18.70
S-71	Snow site A				-126	-18.16
S-73	Snow site E	Undiluted	6.84	20.2	-132	-18.24