Geological and Geothermal Investigation of Mount Taftan, SE, Iran

Fereydoun Ghazban

Faculty of Environment, Tehran University
P. O. Box 14155-6135, Tehran Iran
email: fghazban @ ut.ac.ir

Keywords

Geothermal energy, geothermometry, alteration, Taftan volcano, Iran

ABSTRACT

Preliminary geothermal investigation in Mt. Taftan volcanic region in southeastern Iran indicates that this area has a very high potential for generation of geothermal energy.

The Taftan volcano is intimately related to the subduction of Neotethys oceanic lithosphere under the Central Iranian continental plate. Magmatism in Mount Taftan is represented by subalkaline volcanics that vary from basaltic through andesitic to dacitic composition.

Springs with temperatures ranging from 10 to 35°C are located in the prospect area, fed by the sedimentary aquifers of Cenozoic age. Limited geochemical and hydrological data indicate that the thermal Cl-Ca-$SO_4^=$ waters rise toward the surface from reservoirs made up of a sedimentary sequence through faults and fractures. Fumerolic and thermal discharges from this volcanic region contain deeply derived H_2S with subsequent oxidation to $SO_4^=$ in the system. Based on Na-K-Mg ternary diagram, none of the discharge waters could be representative of deep fluids in "full equilibrium" with the reservoir rocks.

The dominance of acid alteration in the shallow portions of taftan indicates its oxidation of H_2S. Steam, accompanied by H_2S rises from depth and from fumaroles and produces acid sulfate fluids, which react with the surficial rocks to generate alteration mineral assemblages.

The required heat for geothermal energy seems to be from the cooling magma, which is heating ground water circulating in the area. The magma-generated steam is coming to the surface as fumerolic discharge and heats up the scarce descending cold meteoric water up to temperature of about 35°C, signaling the existence of the shallow heat source below. Geologic and geochemical investigation indicate a viable geothermal resource probably centered and upflowing beneath Mt. Taftan, which may contribute significantly to power generation in the future in this fossil fuel dependent country.

Introduction

Large areas of Iran are made up of volcanic rocks and thick pile of Tertiary volcanic rocks crosses the country in a 2255 km long belt from Turkey to Pakistan. A number of dormant or recently extinct volcanoes occurring within the Tertiary volcanic belt in Iran are particularly notable. According to Gansser (1966) and Jung, *et. al.*, (1975) at present there are two active volcanoes along this belt, i.e., Taftan and Bazman which are at their fumarolic stage.

Based on geological information, geothermal resources are available throughout Iran in variety of geologic form and settings but only the Hot Springs are utilized for bathing and therapeutic purposes. In recent years, the potential of some of these resources such as Mt. Sabalan and Mt. Damavand as likely power source and direct commercial utilization have been investigated (ENEL, 1983; Kingstone, Morrison Ltd., 1998 and Ghazban, 2000). All of the available data indicates that Iran has a very important geothermal energy potential.

This work aims primarily to highlight the potential of the Taftan geothermal system and its recognition in terms of geothermal energy. The geothermal fluids ascending from a reservoir and emerging at the surface provide information concerning the subsurface conditions. The alteration minerals provide the opportunity to examine geochemical processes from the perspective of fluid chemistry and relate how this impacts upon rock chemistry through alteration and deposition reactions.

Geological Setting of Geothermal Field

The area under study is morphologically characterized by the Taftan stratovolcano, forming a peak at 4050m above sea level. The most distinct geological characteristic in the area is the presence of widespread thick Quaternary volcanic rocks.

The Taftan volcano has a geological setting, which can be visualized from bottom to top as follow;

Pyroclastics and dacitic flows, form the main body of the volcano and overly the Upper Cretaceous and Eocene sedimentary units consisting of flysch and limestones and igneous rocks. This unit is the most extensive and the main part of the system. In general, Taftan has a flysch sub-stratum. The presence of hematite has made the pink appearance of the rocks.

Tuffs and ignimbrites form a sequence of about 50 meters thick. The ignembrites contains large phenocrysts of amphibole and biotite and the rocks containing these minerals could be as young as 2 Ma (Moinvaziri and Aminsobhani, 1978).

Andesitic flows, less than a million year old have kept their original morphology and porphyritic texture. The porphyroblast are mainly of plagioclase, amphibole and proxene. Lavas have covered an extensive area and they are mostly uneroded and there is no sign of alteration associated with them. However, in the southeastern summit there is extensive fumarolic activity with ejection of steam and sulfurous gases.

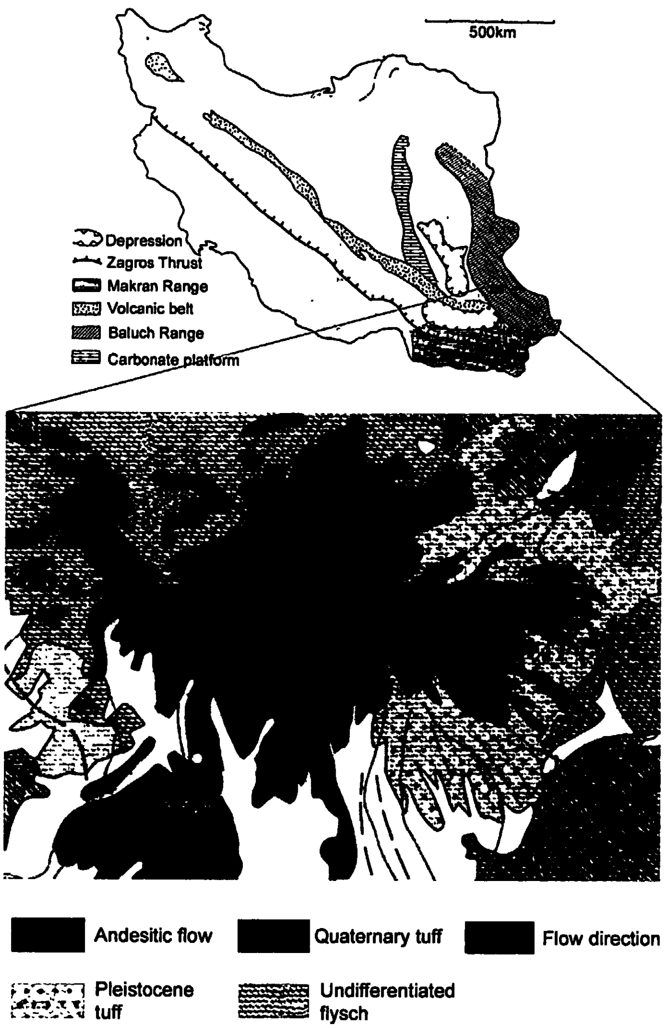

Figure 1. Simplified geological map of the Taftan prospect and surrounding area.

The entry of the molten material has led to fracturing in the area, thereby providing significant paths for convective fluid flow. The general geological map of the area is presented in Figure 1.

Volcanism

To understand the nature and occurrence of geothermal resources, the process that lead to the formation of geothermal anomalies must be considered. In southeastern Iran, the most intensive geothermal area is associated with Taftan and Bazman, which are at their fumarolic stage (Gansser 1955, Ghazban, 2000). The magmatic and related volcanic activities are associated with geothermal anomalies, which may have persisted from Upper Pliocene until recent time.

Taftan volcano is a calc-alkaline type (Berberian and King, 1976), and the magma, which generated it, is the result of a compressive regime. Thus, the main volcanic activity belongs to Neogene compressional phase but the volcanic intensity has continued from Upper Pliocene through recent time. The cal-alkaline rocks of Baluchestan in southeastern Iran are composed of tholeiitic to rhyodacite basalts, with isotopic ages of 4Ma. The rocks are similar to island arc calc- alkaline series and are possibly related to the subduction of the Arabian plate underneath Makran in the Oman region (Girod and Conrad, 1979, Dupuy and Dostal, 1978). The subduction and its associated tectonism have been triggering volcanism and magmatic events.

The general geologic features presented here are of fundamental importance to geothermal research as it implies the existence of magmatic activity and masses, compressed within relatively superficial zones of the crust, giving rise to relatively superficial thermal anomalies. Confirmation of thermal anomalies at relatively shallow depth is provided by the presence of numerous hydrothermal manifestations distributed over almost the entire area studied. Whenever permitted in recent times, the magmatic activity developed in Taftan started with explosive and volcanism ended with lava flows.

Magmatic/volcanic activity and melting processes associated with subduction constitute an enormous heat source. Thus, the Taftan volcano with the associated geology makes the area as a primary target for geothermal exploration.

Characteristics of Taftan Geothermal field

The most impressive thermal feature of the region is the Taftan volcano forming an active geothermal system. This is the zone of most intense geothermal activity in Iran with a variety of hydrothermal phenomena such as emission of sulfuric gas observable from a long distance. Hydrothermal explosions are evidenced by breccia with fragments made up of dacite and aglomerate in several localities. Active and recently active hydrothermal features are mostly within the Tafan caldera, close to the outer edge of the main ring.

Fumaroles and steam discharge have left a snow-white cover on the rocks, which could be calcium and aluminum sulfate (binachetto), and they have formed with opal and carbonates. At the southeastern flank of the volcano, there are zones of high gas emissions and fumaroles. Warm springs and altered grounds with steaming vents are the most impressive features present in this locality. In the valleys near the Taftan summit, gypsum crystals cover the surface of the rocks. The formation of this mineral is due to the interaction of dissolved sulfuric acid existing in the runoff and calcium ion in the rocks.

Altered rocks are exposed over an extensive area along the valleys and drainage system and are evidence of the existence and character of the Taftan geothermal system. Acidic alteration and exposure of hydrothermally altered minerals to clay minerals, iron-oxides (mainly hematite), alunite (K, Na) $Al_3(SO_4)_2(OH)_6$ and sulfides can be observed in the area. Significant sulfur and salt deposits are observed in the valleys. Native sulfur is precipitated along fractures and pores in altered rocks. There exist excellent channels for hydrothermal activity in the Taftan geothermal region. Silica sinter and silica residue are abundant in Taftan area and this is a reliable indication that the depositing fluids are derived from a reservoir hotter than about 180°C (Hochstein and Browne, 2000).

The geothermal system associated with Taftan appears to be vapor-dominated occurring in a recent volcanic area. There seems to be a gradual trend of increasing steam/water ratios. This is based on the fact that after a period of hot water discharge during the dry seasons, the system produces steam only. Thus, hot springs are scarce in the area and there are only one major hot spring and at the time of draught only steams emit from it.

The basis for generating geothermal energy in Taftan region is the heat from the cooling magma, which is heating the available ground water circulating in the area. As a result, the steam-warmed waters seemed to be escaping at the surface, signaling the existence of the shallow heat source below.

The local stratigraphy has been examined for possible occurrence of permeable aquifer beds or cap rocks and porosity and permeability. Geologically, the limestone aquifer of Cretaceous age plays an important role in effecting the thermal gradients.

Taftan Geothermal System

Soil covered siliceous sinter deposits are common throughout the eastern flank of Mount Taftan. Such sinter deposits could have formed where alkaline-chloride thermal waters flow over the ground. Chloride waters form through incorporation of magmatic gases (CO_2, SO_2, HCl) and fluid-mineral interaction (Giggenbach, 1988). The dominant aqueous component in surface discharges is chloride, but before boiling it may contain significant concentrations of dissolved CO_2. Due to sluggish reaction kinetics, amorphous silica precipitates from chloride springs forming sinter deposits. Chloride springs like East Taftan spring, discharge clear water which are typically close to boiling.

In recent years there has been a decrease in precipitation rate in the area and drought has hit the region. Under such conditions the fluid pressure within the system seems to have decreased. The decreased hydrostatic head was probably sufficient to allow the development of a vapor-dominated system and it is likely to generate vapor dominated conditions at depth. Also during the warming stage, melting glacier ice, filling canyons, have raised the regional water table, allowing alkaline-chloride Hot Springs to flow at relatively high elevations.

As snow and ice in the gorge diminished in volume, the water table slowly lowered through rock that had previously been heated to very high temperatures by upflwing thermal waters. This could cause the hydrothermal activity in topographically high places to change from outflow of alkaline-chloride water to discharge of high pressured steam, throttled by poor permeability within highly altered and silicified rocks. Alkaline-chloride waters still emerge at topographically low places in the western part of the volcano.

Hydrothermal Alteration

The formation of secondary minerals in geothermal system is controlled by chemical/physical conditions in the system. For instance the presence, abundance and stability of hydrothermal alteration minerals mainly depends on temperature, pressure, lithology, permeability and the fluid composition of the system. By studying the alteration minerals, estimate of subsurface temperature and permeability and any temporal changes can be deduced (Browne, 1984). Thus, studying the hydrothermal alteration here provided a good opportunity to determine characteristic features of shallow level and surface of this geothermal system.

The XRD analysis revealed that the bulk samples contained alunite, natroalunite, calcite, quartz, crystobalite, tridymite, kaolinite, smectite, illite/smectite, jarosite and pyrophyllite.

The occurrence of hydrothermal alteration minerals on the surface ranges from low to moderate temperatures. Most of the rocks in the altered zones are completely altered to an acid assemblage of alunite, sulfur, kaolinite and residual silica. This acid zone likely forms at relatively low temperature usually about 160°C whereas the presence of pyrophyllite with or without alunite and illite-smectite may have formed at higher temperatures exceeding 180°C. These acid alteration minerals occur in abundant to moderate amounts and associated with cristobalite, quartz, tridymite, anhydite and gypsum. The acid-sulfate waters, causing the alteration, are formed by dissolution of magmatic gases above the water table in the geothermal waters in Taftan area.

Quartz and tridymite are the only residual product, and therefore, it can be postulated that the dissolution of wall rock material is incongruent and leads to Al enrichment in the solution. The precipitation of alunite, an Al- and K- rich sulfate, indicate that H_2SO_4 molality of at least about 10^{-3} was locally reached (Hemley, *et. al.*, 1969, Henneberger and Browne, 1988). The increase in SiO_2 activity leads to an oversaturation of the system with respect to SiO_2 and subsequent formation of cristobalite.

The association of acid alteration zone with acid fluid inflow confirms the recentness of the acid alteration. Neutral pH alteration occurs in lesser amount at the surface. The assemblage consists of illite/smectite which may have appeared at temperatures of about 150-180°C, and illite (≥220°C) calcite and silica. Geothermal alteration assemblages including smectite or mixed-layer illite-smectite are typically found at temperatures below 200 (Jennings, *et. al.*, 1990; and Harvey and Browne 1991). The predominance of acid alteration over the neutral pH types suggests that the fluids presently flowing to the surface are mainly acidic.

The geothermal waters are close to saturation with respect to kaolinite or somewhat undersaturated, especially at the highest temperatures (Gislason and Arnorsson, 1990). The slight supersaturation in waters below about 100°C may not be sufficient to drive kaolinite deposition. This mineral is generally not found at depth in geothermal systems although it has been reported and is then accounted for by acid leaching.

Where conditions are sufficiently acidic (pH<3), and in the presence of K^+ and with SO_4^{2-} activity more than >3000 μg/ml, jarosite is a common mineral product that can form directly from its constituents (e.g. Alpers, *et. al.,* 1989). In addition, jarosite can form by reaction of kaolinite with acid-sulfate fluids having Fe^{3+} and K^+ activities.

Geochemistry

The chemical composition of the spring waters is given in Table 1. The thermal springs flow to the surface through a thick sequence of sedimentary rocks that includes carbonates and flysch. Consequently, they are rich in bicarbonates.

The thermal waters are generally characterized by high Ca-Mg content, and relatively low chloride (from 30 to 190 ppm) except East Taftan spring when it was discharging water showed chloride content at about 1250 ppm. Thus, chloride is found in all springs, although most of the springs are dilute when compared with east Taftan. It could be argued that the high Mg is being provided by extensive alteration of Mg-rich rocks. However, it is those waters with the highest chloride contents that have the highest Mg content, and no example of high Mg low Cl is present. The high chloride content of the water may represents a deep thermal component. Steam and gases separate from the rising water and heat the near surface waters. The low K (0.01 to 10mg/l) content is attributed to alteration of volcanic rocks and formation of alteration minerals such as alunite, which is abundant in the area.

As the water diminished in volume, the water table slowly lowered through rock that had previously been heated to very high temperatures by upflowing thermal waters. This could cause the hydrothermal activity in topographically high places to change from outflow of alkaline –chloride water to discharge of high–pressured steam.

An interesting question regarding the spring water from Taftan is how it has obtained its acidity (1.5 to 5.8). Is it because the fluid is a steam condensate or is it ground water mixed with mostly H_2S gas? High concentrations of volatile components often accumulate above or around a relatively shallow heat source. High H_2S in waters may indicate higher temperatures at depth. On the other hand, if the fluid is steam-heated ground water, then the implication is that there is steam somewhere at depth.

Abundance of the H_2S in the system might be the result of boiling of the subsurface hydrothermal fluids. Thus, upflowing H_2S may condense underground and react with the surrounding rock producing argillic alteration assemblages. Such a boiling system is characterized by very low Cl concentration, rich sulfate measured at thermal spring emergence (oxygen is available to oxidize H_2S) and pH is of acidic to neutral. The steam that separates from boiling, alkaline chloride water generally contains H_2S that oxidizes to H_2SO_4 when it comes into contact with air and produces the low pH waters found in the streams and springs.

Geothermometry

Knowledge of subsurface temperatures is essential in exploration for geothermal energy. In this study chemical geothermometers developed for geothermal systems have been used to estimate the subsurface temperatures of the geothermal field from the concentration of dissolved species in the waters (Fournier, 1981).

Reservoir temperature for water samples of the Taftan system according to quartz geothermometers range from 79°C to 150°C. There may have been change in composition during the rapid rise up to the surface by steam loss or dilution by cold meteoric waters.

Mixing of waters from different origins or aquifers with different temperatures could alter the concentrations of constituents used in geothermometers. The mixing process may sharply reduce the dissolved silica concentration, resulting in low calculated temperatures from silica geothermometers in the sampled springs. However, the effect of dilution appears to be insignificant in Taftan geothermal field because of small variation in spring temperatures.

Variation in concentration of chloride (ranging from 30 to 1250ppm) could be due boiling and steam loss and water-rock interaction, which result in cooling of fluid on their rise towards the surface. As indicated, the thermal spring waters could have been affected by exchange with rocks causing extensive alteration. Thus, a mixing model involving a hot component from depth and a meteoric component from the surface can not be adopted here.

Temperatures at depth can be estimated from the Na: K ratios as the alkali exchange between ground

Table 1. Taftan hydrochemical results (mg/l) and geothermometric evaluation results.

Source	t°C	Ca	Mg	Na	K	Cl	SiO_2	pH	t (Na/K) C	t (Na-K-Ca) C	t (Qtz) C
U.Torshab	10	180	48	45	4	51	30	4	207	110	79
L.Torshab	15	307	80	70	10	32	-	4.5	249	127	—
Ganamin	16	225	59	50	4	190	50	3.2	198	104	102
Morghab	14	40	9	8	0.01	30	49	5.8	—	—	102
E.Taftan	35	315	1460	270	2	1250	125	1.5	63	87	150

water and reservoir rocks is temperature dependent using the appropriate equation with corresponding to temperature of about 63 to 249°C. The Na-K geothermometer, however, is useful only at temperatures of more than about 150°C. At lower temperatures, calcium usually makes up a significant fraction of the cations, and the Na-K geothermometer seems to have produced anomalous temperature estimates.

The Na/K geothermometer appears to produce higher temperatures (e.g.,>198°C) and this may be due to the fact that the aqueous concentrations of Na and K are controlled by their stoichiometeric dissolution from the rock and slow exchange rate non-equilibrium conditions between Na and K bearing constituents, and therefore is reflective of temperature at deeper levels of geothermal system. Since all the cations for geothermometry are available an estimation of deep reservoir temperature is possible.

The calculated temperatures using Na-K-Ca ranging from 87°C to 127°C. Considering the analytical uncertainty, some of the calculated temperatures are in good agreement with each other. However, all these geothermometers point to the existence of a relatively wide range of temperatures over the hydrothermal parts of the Taftan system.

For most samples, two types of temperatures are calculated: (1) a low-temperature calculated with the chalcedony, quartz (79 to 110°C) and also Na-K-Ca, (87-127°C) and (2) higher temperature calculated with the Na/K geothermometers. By applying the geothermometric technique proposed by Giggenbach (1988) and reported in the Na-K-Mg ternary diagram in Figure 2, additions of cations from possible sources are observed.

Most of the waters in Taftan area fall on the line of partially equilibrated waters close to the Mg end of the diagram. As suggested by Giggenbach the Na-K-Mg geothermometers may be applied with confidence only for samples on or close to the equilibrium line. The alignment of springs on a single line suggests a source temperature of about 180°C.

The silica geothermometers in conjunction with K-Ca-Mg applied here may provide a better measure of shallow subsurface temperatures, whereas the high subsurface temperatures of some of the springs (e.g.,> 198°C) calculated from the Na/K geothermometers are valid for the deeper part of the system as previously mentioned.

Geothermal Model

A simplified conceptual model for Mt. Taftan thermal area hosting a geothermal system is envisaged here based on geological and geochemical information. The area is within a very tectonically active environment with major fault and fractures. It is quite obvious that the upflow of the geothermal system must be controlled by vertical faults/fractures.

The heat source is postulated to be centered beneath the coalescing cones of Mt. Taftan. This is based on abundance of a wide variety of hydrothermal features, ranging from warm, acid springs, fumaroles, and presence of acid alteration mineral assemblages. Away from the vent and alteration zones, a neutral chloride brine has already evolved by progressive neutralization of a previously acidic fluid by intensive water-rock interaction as the fluid migrates laterally.

The spring discharge is fed from the geothermal reservoir and from time to time by shallow groundwater. As the steam rises from their reservoir depths, it may heat the local meteoric water. Thus, the waters discharging at the surface have experienced extensive changes in their composition.

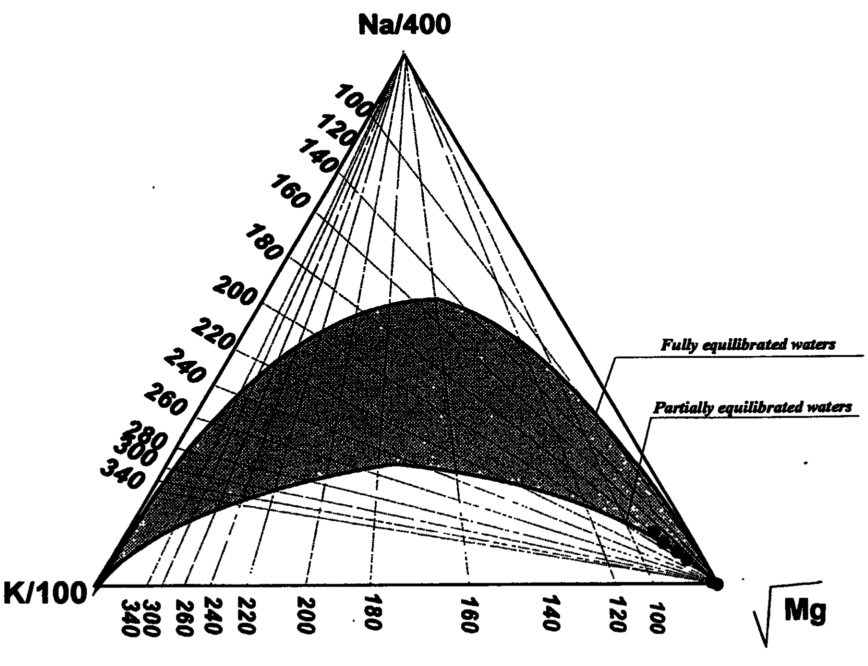

Figure 2. The Na-K-Mg ternary diagram.

Conclusions

It is concluded that the Taftan volcanic zone houses an extensive geothermal system. The Taftan volcano formed as a result of a tectonically compressive regime has been active from Upper Pliocene until recent time. It can be considered as an enormous heat source and is a favorable thermal anomaly. Thus, the hypothesis of a strong local thermal anomaly and the existence of relatively high temperature fluids at shallow depth are confirmed. Localization of geothermal field is linked to volcanic activity and the geothermal manifestations such as sulfur emanation; hot spring and hydrothermal circulation are present and active in the area. Taftan volcano with its associated geological setting makes the region a primary target for geothermal exploration.

Acid-fluid interaction with wall rock in a near surface conditions caused an incongruent dissolution and the formation of a mineral assemblage mainly consisting of kaolinite, alunite and silica. Sulfur gases mixing with snow-melt water produces strong sulfuric acid leading to an intense fluid rock interaction.

The present investigation shows that there is exploitable geothermal resource in selected areas proximal to the northern subduction of the Arabian plate underneath Makran in the Sistan and Baluchestan region in Iran. The geothermal prospect region is in reasonable proximity to populated areas. At this stage, geologically, the prospect is good for deep geothermal energy for direct use. The Mount Taftan might be suitable for installation of a binary power plant to satisfy the local need. In general, the geothermal resources here are unexploited and it is our vision to exploit these resources in a sustainable manner in the future.

Acknowledgement

The work presented in this article has been supported by a research grant provided by the Faculty of Environment, the University of Tehran. Mark Simpson and Pat Browne of the Geothermal Institute of the University of Auckland are sincerely acknowledged for their assistance in XRD data interpretation. The laboratory work was completed at the Geothermal Institute of the University of Auckland while Mitsubishi Corporation granted the author a scientific fellowship.

References

Alpers, C., N., Nordstrom, D, K, and Ball. W, 1989. Solubility of jarosite solid solution precipitated from acid mine waters, Iron Mountain California, USA. Sci. Geol. Bull, Vol. 42, pp.281-289.

Berberian, M., and King, G.C., 1981. Towards a paleogeogrphy and tectonic evolution of Iran. Canadian Journal of Earth Science. Vol.19. pp.210-265.

Dupuy, C., and Dostal, J., (1978). Geochemistry of calc alkaline volcanic rocks from southeastern Iran. Journal of volcanology and geothermal research Vol. 4. pp.363-373.

ENEL (Italian Electricity Agency), 1982. Geothermal power development studies in Iran. Final report. Ministry of energy Iran.

Fournier, 1981. Application of water geochemistry to geothermal exploration and reservoir engineering. Geothermal systems: Principal and case histories. Edited by L. Rybach and L.J., Muffler, Chap.4. pp.109-134.

Fournier, R.O., and Truesdell, A.H., 1974. Geochemical indicators of subsurface temperature, Part.2: Estimation of temperature and fraction of hot water mixed with cold water. J. Res.U.S. Geol. Surv. Vol.2. pp.263-276.

Gansser, A., 1955. New aspects of the geology in Central Iran. 4th World Petroleum Congress. Rome. Sec. 1/A5 paper 2., pp.279-300.

Ghazban, F., 2000. Geological and geochemical investigation of Damavand geothermal propspect, Central Alborz Mountain, Northern Iran. Geothermal Resources Council Transactions, Vol. 24., pp.229-234.

Giggenbach, W.F., 1988. Geothermal solute equilibria: Derivation of Na-K-Mg-Ca geoindicators. Geochim. Cosmochim. Acta. v.52. pp.2749-2765.

Girod, M., and Conrad, G., 1979. Les formation volcaniques recentes du sud de l'Iran; donnees petrolooogique preliminaires implications structurale. Bulletin volcanologieque, 39(4) pp.493-511.

Gislason, S.R., and Arnorsson, S, 1990. Saturation state of natural waters in Iceland relative to primary and secondary minerals in basalts. In; fluid-minerals interaction edited by R. J. Spencer and I-Ming Chou. The geochemical society special publication No.2 pp.373-393.

Harvey, C, C, and Browne, P, R, L 1991. Mixed layer clay geothermometer in the Wairakie geothermal field, New Zealand. Clays and clay minerals, Vol. 39 pp.614-621.

Hennenberger, R.,C., and Browne, P.R.L., 1988. Hydrothermal alteration and evolution of the Ohakuri hydrothermal system, Taupo Volcanic Zone. J., Volcanol. Geothermal Research. V. 34. pp.211-231.

Hochstein, M., P., and Browne, P, R, L, (2000). Surface manifestations of geothermal systems with volcanic heat source. Encyclopedia of volcanoes. PP.835-855.

Jennings, K., Browne, P.R.L., Clarke, D.,S., and Brathwaite, 1990. Aspects of hydrothermal alteration at the Waihi epithermal Au-Ag deposits, New Zealand; 12th New Zealand Geothermal Workshop Proceedings. P.237-242.

Jung, *et. al.*, 1976. Post Mesozoic volcanism in Iran and its relation to the subduction of Afro-Arabian under the Eurasian plate. *In*: A far between continental and oceanic rifting (VII). Edited by A. Pilger and A. Roster. E. Schweizerbastsche Verlagsbuch-handlung. Pp.175-181.

Moin Vaziri, H., and Amin Sobhani, E., (1978). Etudi volcanologique du Taftan. Ecole normale superieure de Tehran.