Geothermal Resource Assessment in Derik Region (NW-Iran)

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Abstract

Derik geothermal region has area of 242 km^2 and is located 10 km to the west of Salmas city in west Azarbaijan province of Iran. The most outstanding surface manifestations of geothermal energy in this region are three warm springs and outcrops of travertine deposits and quaternary basalt outcrops around warm springs. Temperature range of warm springs varies from 31 to 32.6 °C. We visited and sampled warm springs of the Derik region, then chemical analysis and geochemical studies were conducted. Based on silica geothermometers, estimated temperature range of Derik geothermal reservoir is 53 to 90 °C. Due to the presence of extensive outcrops of travertine deposits in the region, it is believed that probably geothermal reservoir host rock is a carbonate lithological unit. Based on data from a shallow borehole in the region it is found that thermal gradient of the region is about 50 °C/Km, so, probably geothermal reservoir is located in 1000 to 1800 meters depth regarding geothermometry results. According to volumetric method stored thermal energy in the geothermal reservoir is approximately 7.67×10^7kj.

Keywords: Geothermal, Exploration, Warm Spring, Resource assessment, Derik, Iran.

1- Introduction

Despite of many oil and natural gas reserves in Iran, there are a lot of geothermal resources in this country too. Based on available data most of the Iranian geothermal resources are low-temperature and not suitable for power generation. Therefore, they can be used for some direct use purposes such as spas, greenhouses, fish farms and space heating and etc.

In order to exploring of geothermal regions, some projects were conducted specially in the northwestern provinces of the country. The Niroo Research Institute (NRI) has implemented a reconnaissance geothermal exploration project in the west Azarbaijan province. As a result it is found that 12 geothermal prospects exist in west Azarbaijan province including Derik region which would be introduced in this paper.

In general terms, the execution of a geothermal field involves two phases: one of high risk (incertitude) associated to the exploration aimed to identify the probable reservoir; and the other of less risk is related to the development and exploitation. At the first stage, during the reconnaissance, the low detail studies take place in a large area and as investigations advance the area is reduced and studies are of greater detail (prefeasibility and feasibility) but in smaller area. First part involves high economical risk levels, to be faced with progressively crescent inversions but that are of relatively low cost. Second part, involves minor risks but requires major investments (Olade, 1994, Fig. 1).

As it can be seen in the Figure 1, usually, preliminary geothermal exploration projects start from a very large region with more than several thousand square kilometers. Then, gradually study area decreases and some much smaller geothermal prospects would be identified. Several geothermal surface manifestations were applied for this purpose such as hot/warm springs; young volcanic rocks, travertine deposits, altered areas and so on.

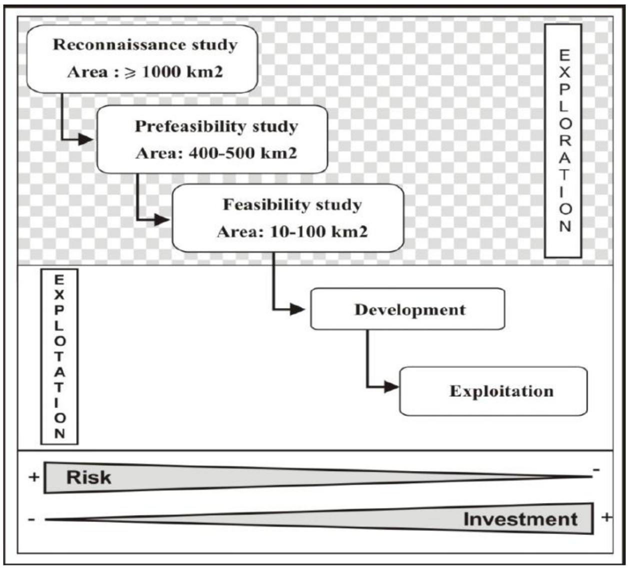

Figure 1) Flow chart showing the stages in the execution of a geothermal project and the risk and investment associated, (OLADE, 1994).

2- The study area

Derik geothermal region (DGR) is located in west Azarbaijan province in the northwestern part of Iran. It is positioned 10 km to the west of Salmās city (Fig. 2). DGR area is 242 km2 and its western border is very close to Turkey border. This region is mountainous and elevations of its highest and lowest points are 2600 and 1300 meters above sea level respectively. Due to the presence of three warm springs, travertine deposits and altered areas, DGR regarded as a geothermal prospect.

3- Applied data

Several data sources have been used for determining of DGR. First of all, we used Salmas geological map (with 1:100,000 scale) which has been generated by Geological Survey of Iran (GSI). It is used for identifying of rock formations such as probable young volcanic rocks, travertine deposits, altered areas and different types of faults in DGR. At the next step we applied ASTER satellite images in order to finding of altered areas in DGR. Another source of scientific data was aeromagnetic data which have been generated by GSI. They have 7.5 km flight line spacing and widely used for identifying of magnetic intensity anomalies, hidden intrusive bodies and faults as well. Finally, we used warm spring's data which provided by NRI experts precisely. For this task we conducted a library research and searched all available data such as reports. Then we visited and sampled all warm springs and transferred samples to the laboratory.

4- Sampling and treatment

Sampling and analysis provide the data for all geochemical interpretation. Sometimes low-temperature activity in one area is represented by a single isolated thermal spring although clusters of springs forming a field or an area are also a common feature, (Arnorsson, 1995b).

All of the Derik warm springs were visited and sampled in May 2014. Also, during the sampling activities some general data about springs were collected such as geographical position, elevation, temperature, pH, E_C and flow rate. From each spring 8 separate water samples were taken. Table 1 illustrates more information about water samples and their treatment procedures. Moreover, CO_2 and H_2S concentrations of the springs were measured in the field too.

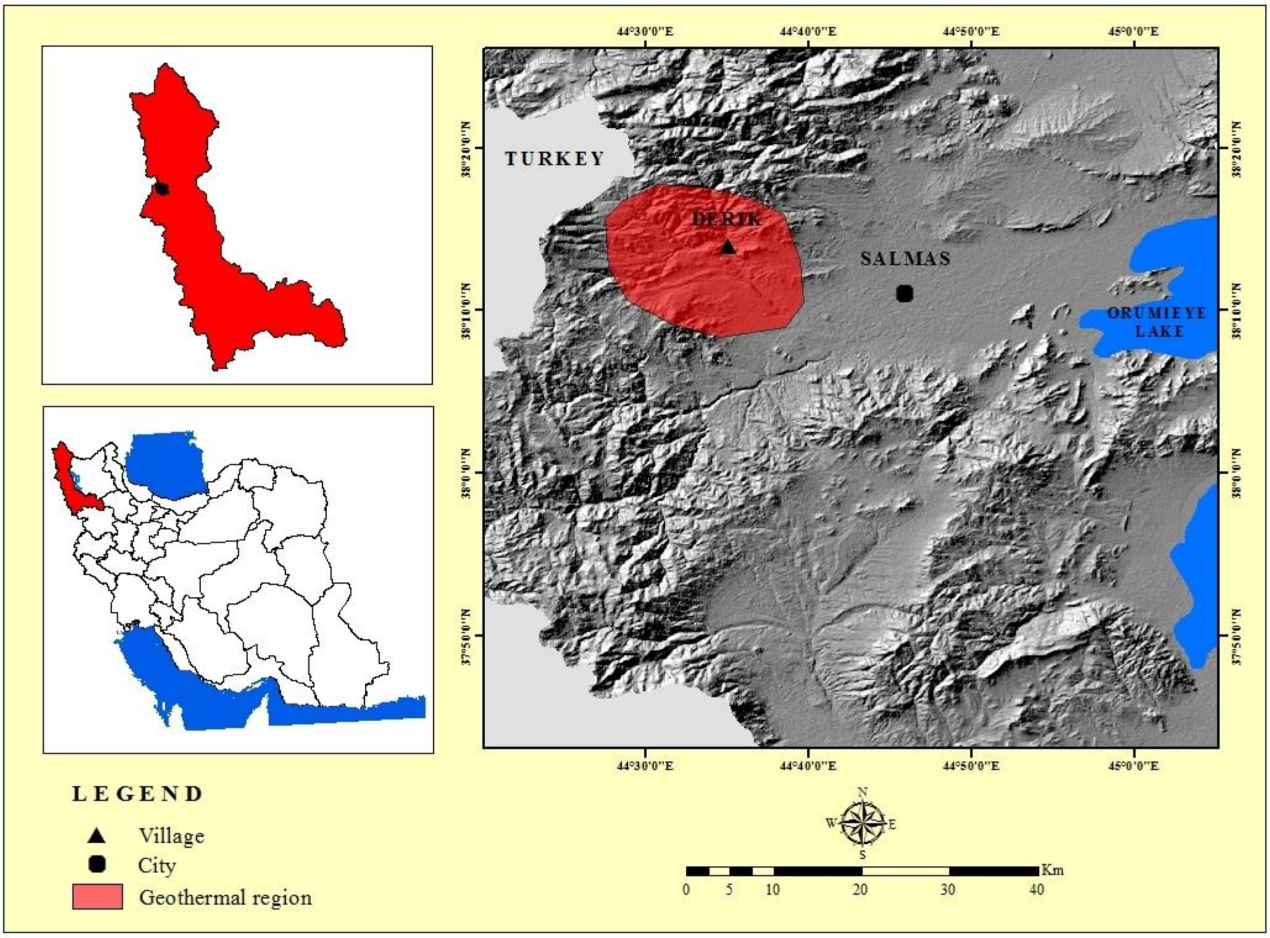

Figure 2) Location of Derik geothermal region in Iran.

Table 1) Sampling Procedures of the warm springs.

Chemical agent	Container material	Sample Volume (ml)	Treatment procedure
Cations	Plastic/Glass	1000	Immediately filtered and add nitric acid till pH<2. Sampling time should not be more than 15 minutes
SiO_2	plastic/glass	200	Add nitric acid till pH<2
B	plastic/glass	1000	Stored in refrigerator
HCO_3	plastic/glass	100	Stored in refrigerator
Cl	plastic/glass	50	Stored in refrigerator
F	plastic	100	Stored in refrigerator
SO_4	plastic/glass	100	Stored in refrigerator
As	plastic/glass	1500	Stored in refrigerator

5- Method of analysis

All of the samples were moved immediately to the Niroo Research Institute (NRI) chemical laboratory in Tehran. Despite of large distance between warm springs and the laboratory (about 900 km) the samples were analyzed less than 48 hours after sampling time in order to decreasing of errors in the final results.

In laboratory in order to analysis the cations, anions and etc. different methods were applied. Analytical methods which were used in this study are illustrated in Table 2.

Due to the presence of warm springs and other geothermal surface manifestations there should be a geothermal reservoir in DGR. In order to specifying of Derik geothermal reservoir characteristics we used many types of data including geological maps, satellite images, warm spring's data and aeromagnetic data which are follows:

5.1- Geology

Mapping of geothermal manifestations, structures, and hydrothermal alterations is an essential part of any geothermal survey. Geological mapping help to define many important parameters which control the flow of hydrothermal fluids such as rock types, alteration, strike and dip of rock formations and the location of faults, fractures and dykes (Saemundsson & Einarsson, 1980).

Table 2) Applied Methods for Chemical Analysis of Warm Springs.

Chemical agent	Analytical method
SiO_2	Spectrophotometry
Mg	EDTA Titration
Na	Flame Photometry
K	Flame Photometry
Li	Flame Photometry
Ca	EDTA Titration
HCO_3	Titration
SO_4	Gravimetry
Cl	Titration
F	Chlorimetry
B	Spectrophotometry
As	Photo method
Fe	Spectrophotometry
CO_2	Titrimetric
H_2S	Methylene Blue

All geological data about DGR were obtained from Salmas and Qotour geological maps. Their scale is 1:100,000. DGR is covered mainly by Salmas geological map and a small part of it is located in Qotour geological map. This area (DGR) is located in Khoy-Mahabad structural zone (Aghanabati, 2005). Actually, 22 stratigraphic units are outcropped in Derik region, (Khodabandeh et al, 2003). Geological map of DGR is shown in Figure 3.

As it can be seen in this Figure, DGR lithological units from oldest to youngest are as follows:

- P^d_r: Dolomite, calcareous dolomite and limestone (Ruteh Fm.)- Permian
- Pd: White sand, red quartzitic sandstone with shale (Doroud Fm.)- Permian
- K: Alternation of shale, slate, sandstone and dolomite- Cretaceous
- K^d: Dolomite- Cretaceous
- K^{sh}: Shale, slate with intercalations of sandstone and limestone- Cretaceous
- K^l: Crystallized limestone and dolomite- Cretaceous
- M^c: Basic conglomerate- Miocene
- M^{cs}: Conglomerate with intercalations of sandstone and shale- Miocene
- Q^p: Tuff and agglomerate- Quaternary
- Q^b: basalt, olivine basalt- Quaternary
- Q^{tr}: Travertine- Quaternary
- Q^{t1}: Old terraces
- Q^{t2}: Young terraces
- Q^{al}: Recent alluvium

Also, there are some intrusive and metamorphic rocks in DGR which their age is unknown. Those rocks are as follows:

- Mt^m: White and some gray crystallized limestone
- Mt^{sh}: Biotite, Muscovite, amphibole, quartz, chlorite and sericite schist
- Mt^{rsh}: Alternation of schist and metarhyolite
- Mt^r: Metarhyolite, metahyodacite with acidic tuff
- Mt^v: Metadacite, metahyodacite

and intrusive rocks are as follows:

- Gr^{gh}: Goshchi granite
- Mt^{gr}: Metagrainte
- Mt^d: Mteadiorite, diorite gabbro

Based on Salmas and Qotour geological maps there are numerous faults in DGR whose their length varies from 2 to 3 km. longest fault of the region has 5.8 km length. All faults are aligned in NW-SE, NE-SW and E-W directions, Figure 3, (Khodabandeh et al., 2003).

6- Geochemistry

The major goals of geothermal geochemical exploration are to obtain some data about the subsurface composition of the hot fluids in a geothermal system and use them to acquire information about temperature, origin and flow direction of the hot fluid in the geothermal reservoir, (Mwangi, 2013).

A number of important exploration and reservoir production questions can be answered from studies of the chemistry of geothermal fluids and reservoir rocks. Therefore, geochemical studies play a relatively important role in geothermal exploration and development.

The composition of thermal fluids depends on many factors. The most important of them are temperature, reaction between host rock and hot fluid. Mixing, boiling and cooling may have considerable influences on the final composition of thermal fluids, (Henley & Ellis, 1983). One of the common surface manifestations of geothermal resources is warm spring. So, most of the geochemical studies in geothermal exploration relates to the warm springs.

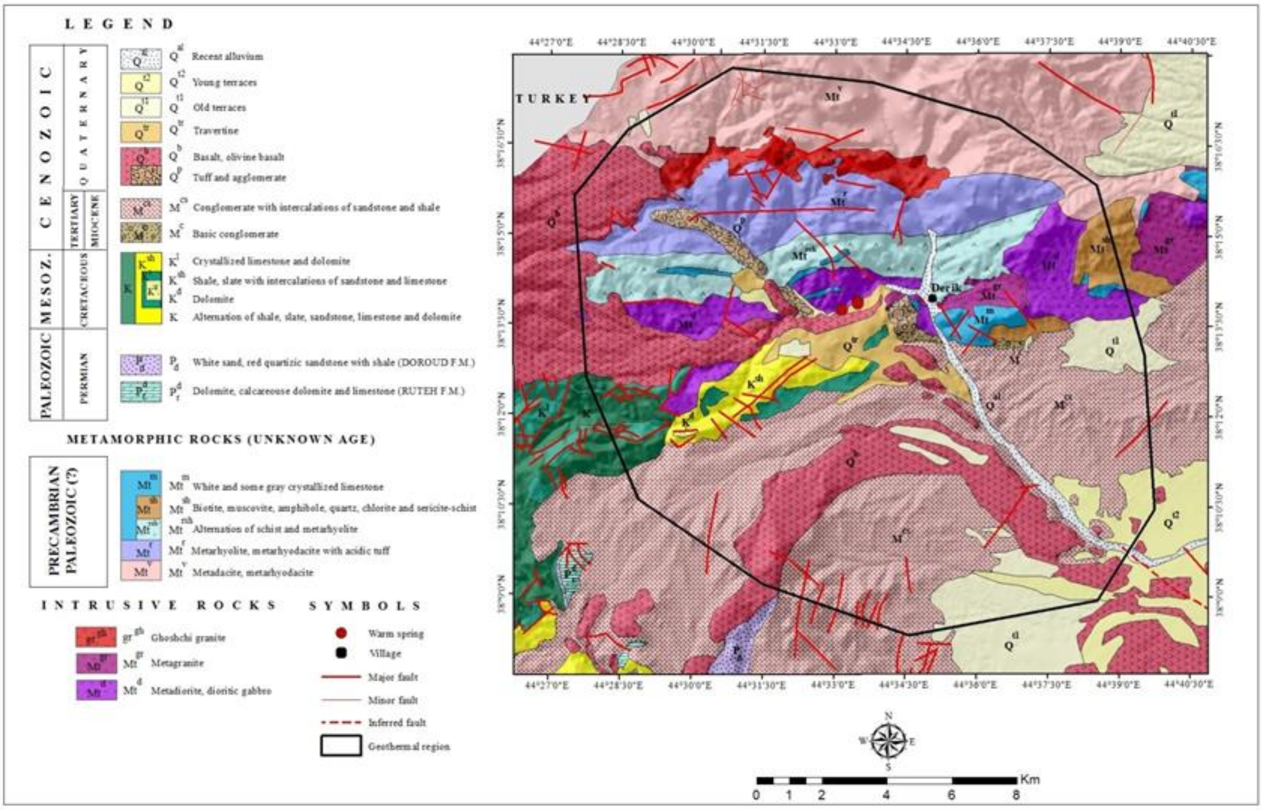

Figure 3) Geological Map of Derik geothermal region based on Qatur 1: 100,000 geological map (Khodabandeh et al., 2003). Qotour region is located in the eastern part of Derik region.

Based on the importance of warm springs in geothermal exploration, we studied three warm springs precisely in order to identifying of some chemical information about geothermal reservoir in DGR.

7- Warm springs

There are three warm springs in DGR which are located in central parts of the region (Fig. 2). Their temperature range is from 31 to 32.6° C. Their pH is slightly acidic and varies from 6.53 to 6.74. Total flow rate of the springs is about 13.5 l/s. In Figures 3 and 4 Derik warm springs are shown. General characteristics of them are illustrated in Table 3 too. As it can be seen in Figure 4, the third Derik warm spring is consisted of many small springs that emerge along a river which in this study they are regarded as one spring. Around the 3th Derik warm spring there are a few dry warm spring that they can be recognized by travertine deposits around them. Also, there are some travertine cones and alteration minerals near Derik 3 warm springs (Fig. 4).

Table 3) General characteristics of Derik warm springs

Warm Spring	Longitude	Latitude	T (˚C)	Flowrate (l/S)	pH	Ec (μS/cm)
Derik 1	460848	4231330	31	5	6.74	1366
Derik 2	461313	4231532	32.6	5	6.83	1326
Derik 3	460995	4231525	31.8	3.5	6.53	1345

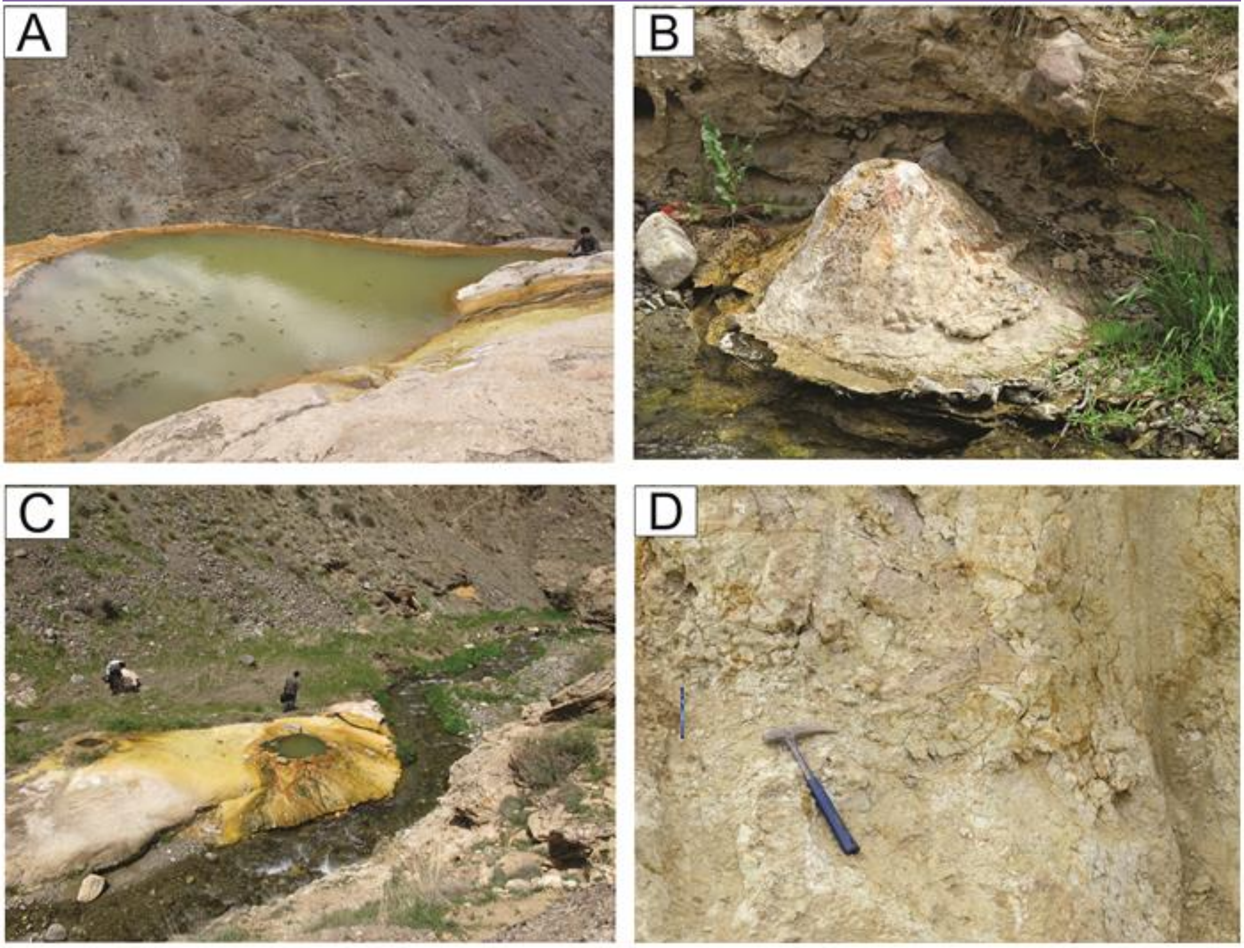

Figure 4A) Derik 2 warm spring, B) travertine cone near Derik 3 warm spring, C) Derik 3 warm spring, D) alteration around warm springs.

7.1- Chemistry of warm springs

Geochemical studies included sampling of warm springs, analyzing and interpretation of the chemical results. Chemical composition of Derik warm springs are shown in Table 4. We used laboratory data to analyze chemical characteristics of geothermal resource in DGR.

According to Cl-SO_4-HCO_3 diagram it is found that Derik springs are bicarbonate type, Figure 5.This type of waters reveals mixing of geothermal fluid with cold underground waters. Due to high CO_2 content of underground waters bicarbonate warm springs have high CO_2 content too. In bicarbonate springs Cl concentration is low and their relevant geothermal reservoir temperature cannot be very high (Mohan et al., 1980).

Based on Cl-Li-B diagram it is found that boron content of Derik warm spring is very low. It is a sign is relatively low temperature in geothermal reservoir (Arnorsson and Fridriksson, 2009, Fig. 6). This task indicates that geothermal reservoir temperature is lower than 150 °C because in higher temperatures boron would be used in composition of secondary minerals.

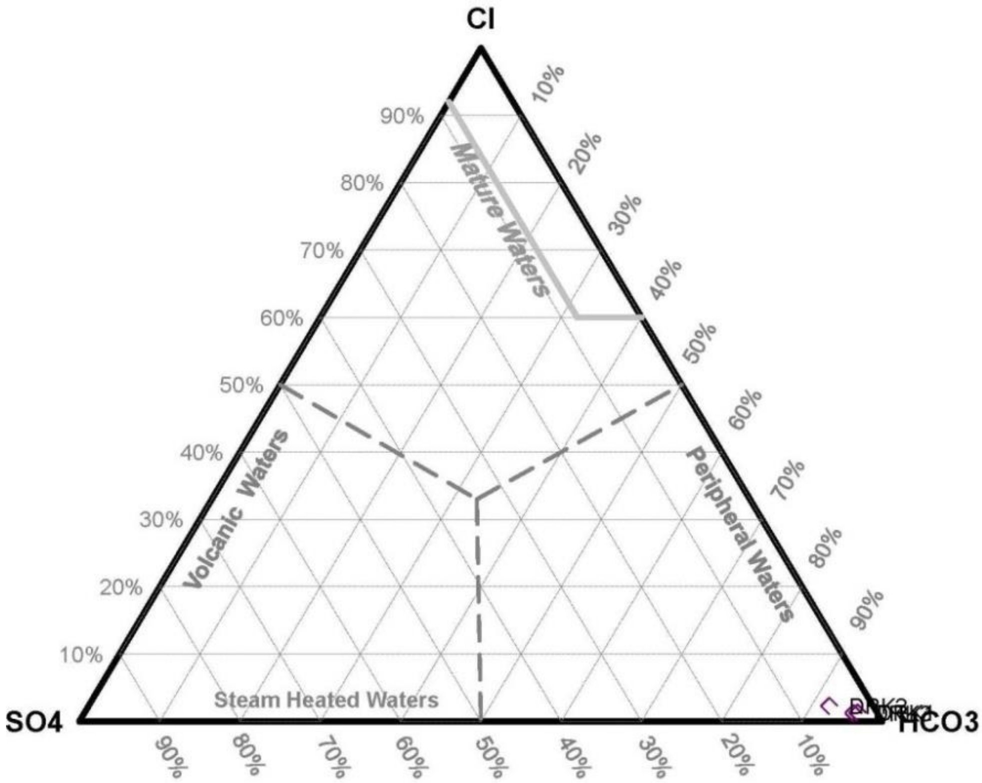

Figure 5) Cl-SO_4-HCO_3 Ternary diagram of Derik springs (Giggenbach, 1988).

Table 4) Results of Derik warm springs chemical analysis (mg/l).

Chemical agent	Derik (1)	Derik (2)	Derik (3)
Na	80	90	95
K	13	12	13
Mg	92	89.7	101.7
Ca	545.1	192.4	549.1
Al	0.09	0.06	0.05
Fe	0.005	0.008	0.005
As	0.1	0.1	0.1
Li	0.4	0.4	0.4
F	1.2	1	1.2
Cl	30.2	29.7	29.7
SO_4	56.8	69.5	70.6
B	0.1	0.08	0.09
CO_2	803	924	1249.6
H_2S	0.1	0.1	0.1
SiO_2	36.5	33.5	34
TDS	768	751	836.5

In the Na-K-Mg diagram Derik springs are very close to Mg corner which indicates that they are immature and not equilibrated with host rocks (Fig. 7). In fact, geothermal fluid had not sufficient time to equilibrated with host rocks and have been mixed with cold underground waters. This phenomenon disturbs geothermometry calculations. For example, in these circumstances probably cation geothermometers indicate some unreal temperatures for geothermal reservoirs.

8- Geothermometry

Geothermometry is used to estimate the temperature of the reservoir fluid and it is the most important geochemical tool for the exploration and development of geothermal resources. They are also very important during production in monitoring of the response of geothermal reservoir to the production load.

Difference in the results of individual geothermometers need not be a negative outcome for their interpretation (Arnorsson, 2000a). Different geothermometers are valid for different temperature range. The processes that may interfere with and affect rates of equilibration between minerals and water, mixing with cold ground water, Boiling and condensation during up flow, (Arnorsson, 2000b).

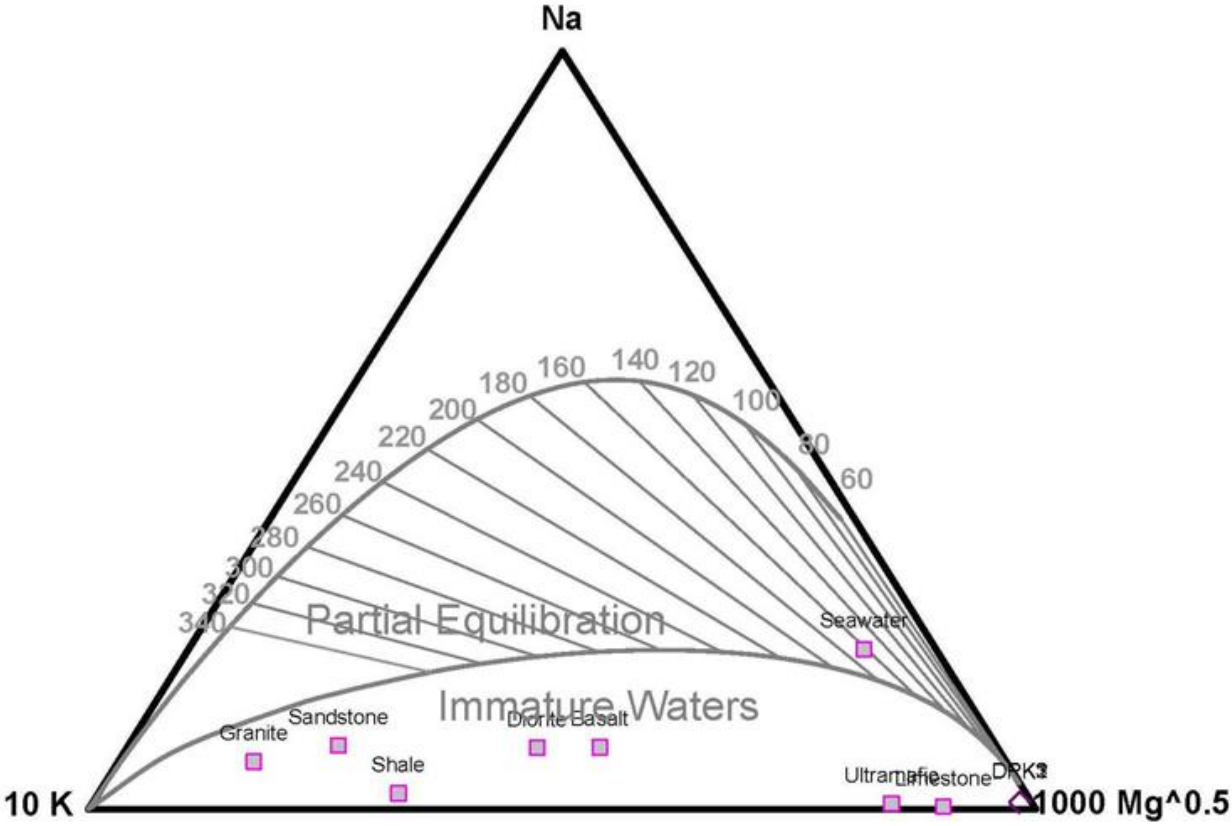

Figure 7.Na-K-Mg Ternary diagram of Derik warm springs (Giggenbach, 1991).

Table 5) Estimated Temperature of Derik Geothermal Resource Based on Different Geothermometers.

Name	Chalcedony cond	Quartz adiabatic	Quartz cond	Na-k-Ca	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)	K/Mg (Giggenbach)
DRK1	57	90	88	38	262	247	274	49
DRK2	53	87	85	56	243	221	256	48
DRK3	54	88	85	39	245	224	259	48

The most important water geothermometers are silica (quartz and chalcedony), Na/K ratio and Na-K-Ca geothermometers. Others are based on cation ratio and any uncharged aqueous species as long as equilibrium prevails (Arnorsson & Gunnlaugsson, 1985).

The results of geothermometry studies about Derik warm springs are illustrated in Table 5. As it mentioned earlier possibly geothermometry results are not very reliable because geothermal fluid isn't fully equilibrated with host rock. This task is more tangible for cation geothermometers. Beside that due to the presence of silica in warm springs it can be possible to use silica geothermometers instead of cation ones. According to the available experiences silica geothermometers give more reliable temperatures. Based on quartz geothermometers maximum and minimum temperatures of Derik geothermal reservoir are 53 °C and 90 °C respectively.

9- Gradient well

One of the most important geophysical methods in geothermal exploration is thermal methods. Thermal methods divided to surface measurements of temperature in soils and evaluating of temperature in 20-200 m drill holes. In the second one, the main purpose of drilling such medium deep holes is either to measure the temperature gradient or to delineate aquifers, (Hersir & Bjronsson, 1991).Gradient boreholes or more often deep exploratory boreholes are drilled to follow up surface exploration if the results of the various methods correlate tolerably well, (Saemundsson, 2007).

Almost 36 years ago, Enel Company had conducted a thermal surveying in West Azarbaijan province. One of the gradients well located in DGR whose information is illustrated in Table 6.

Table 6) General information about Thermal Surveying Borehole in DGR, (Enel company, 1979)

X	Y	Elevation (m)	Depth (m)	Thermal gradient (°C/10 m)	Heat Flow (10^{-6}cal/Cm.s)
44° 36′ 49″	38° 09′ 58″	1665	105	0.50	2.67

The borehole is 8.6 km far from Derik warm springs. However, despite of relatively large distance from borehole to warms springs, thermal gradient value can be considered for DGR which is about 1.6 times more than earth's average thermal gradient. In the other word, due to the lack of reliable data, it assumes that geothermal gradient in all parts of DGR is the same as borehole value.

9- Gradient well

Remote sensing techniques are emerging as useful reconnaissance tools for mapping the geology, detecting anomalous surface temperature anomalies and identifying geothermal indicators including hydrothermal alteration minerals (clays, sulfates), sinter and tuff in prospective geothermal areas (Calvin et al, 2005). The use of remote sensing in geothermal exploration prospects is expected to give a clearer picture of the areas of geothermal and can identify areas that may have geothermal resources to assist the purposes of further exploration.

In the present study, we used ASTER satellite images in order to delineate hydrothermally altered areas in DGR. 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 (Henley & Ellis, 1983).

By mapping alteration mineral assemblages at the surface (but more commonly within drillholes), it is possible to locate the zones with highest temperatures, pressures, or permeabilities—all of which are important in geothermal exploration. The same techniques are used to map fossil hydrothermal systems associated with epithermal ore bodies. Although springs and fumaroles are the most obvious surface manifestations of the hydrothermal system, alteration zones supply additional information that points out the areas of greatest temperature and permeability. Alteration zones can also guide exploration geologists to hidden systems or to ancient spring activity. The mapping process involves systematic sampling across the study area and analysis of mineral phases by x-ray diffraction and petrography. Study areas can range from a general map of altered areas over hundreds of square kilometers, (Wohletz & Heiken, 1992).

Finally, four types of altered areas were found in DGR including argillic alteration (Jarosite, Kaolinite and Illitealtererd areas), alunitization, Fe-oxide alteration and silicification. Among them, argillic alteration is the most important altered areas in DGR, Figure 8. Altered areas are concentrated mostly in northern parts of DGR.

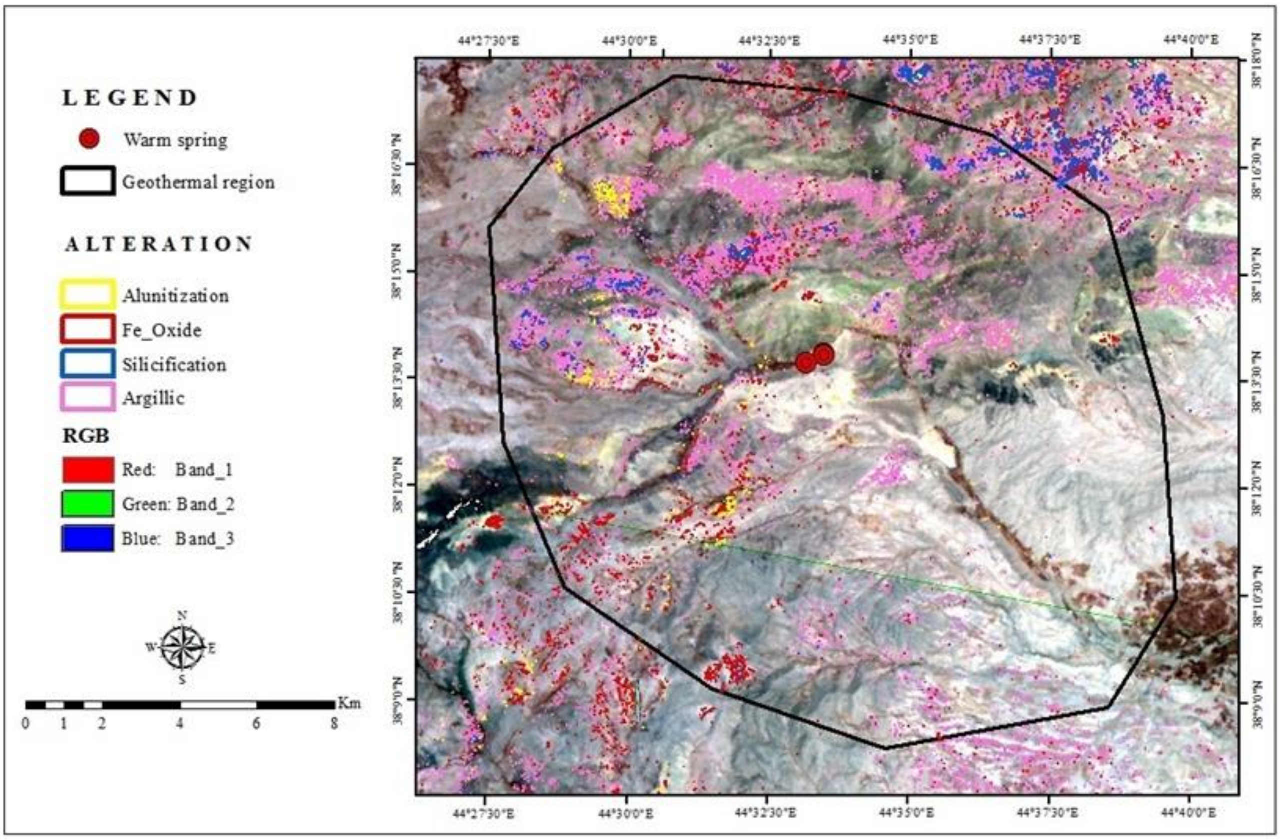

Figure 8) Altered areas in Derik geothermal region.

Kaolinitic altered areas are widely distributed in the north, northwest and northeast of DGR and strongly related to the faults. Jarositic altered areas are very scattered in the north and south of Derik warm springs. Illitic altered areas are broadly spread in the north and southwest of Derik warm springs.

9- Integrated interpretation

When the geological surveys have been completed, it is necessary to synthesize all the acquired data and to draw conclusions based on the totality of the evidence. Each survey can give a misleading indication. The best way to visualize the comprehensive picture of the geothermal prospect is to construct, on a workable scale, a composite map or synthesis map of the prospect region, (Dipippo, 2007).

In fact, regarding all obtained data it would be possible to locate the geothermal prospect. It is also possible to recognize some basic characteristics of the given geothermal resource. At the moment there isn't any drilled deep well in DGR. So, all information about it has been acquired mostly from surface explorations including geological, geochemical and geophysical studies.

According to the results of the above-mentioned studies it is revealed that there is a low-enthalpy geothermal reservoir in Derik region. In DGR there are quaternary basalts which can probably be heat source of Derik geothermal resource. In fact, cooling of these basalts can maintain heat for geothermal resource in the region. Moreover, based on Aeromagnetic data it is revealed that there is a large intrusive body in deeper parts of DGR. Large and small diameters of intrusive body are 15 and 6 km, respectively (Fig. 9).

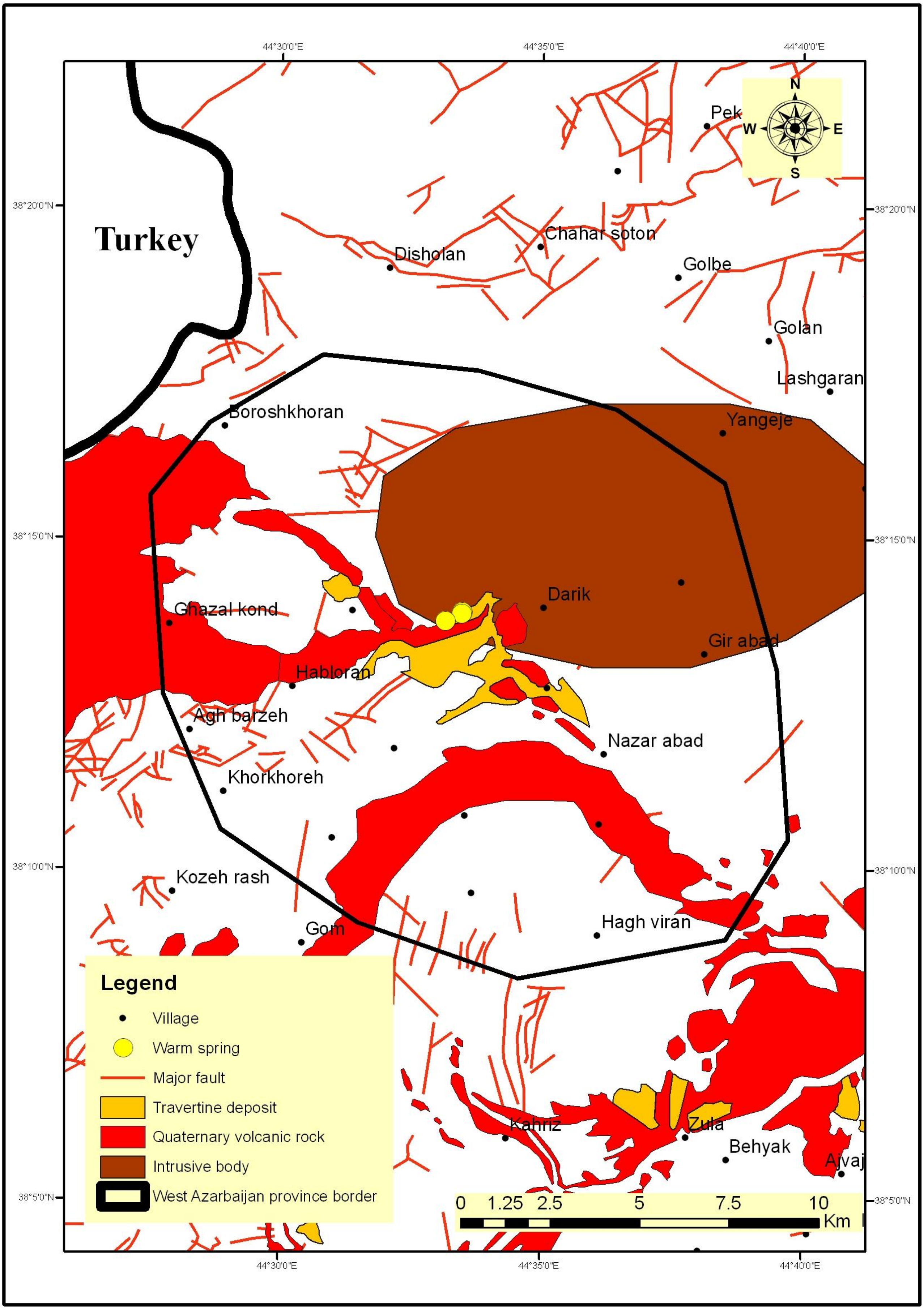

Figure 9) Surface Geothermal Manifestations and location of Buried Intrusive Body in Derik Geothermal Region.

Based on the information of shallow borehole in DGR, it is found that thermal gradient in the region is 50 °C/1 km. So, regarding the minimum and maximum temperatures for DGR, geothermal reservoir could be located from 1000 m to 1800 m below earth's surface.
Derik geothermal resource probably has been created in the following lithological conditions:
- **Prd** rock unit containing limestone and dolomites (Ruteh Formation) as reservoir rock.
- **Pd**rock unit including shale and sandstone (Doroud Formation) as reservoir and caprock.
- **K**rockunit containing shale, slate, sandstone and dolomite as reservoir and cap rock.
- **Kd**rock unit including dolomite as reservoir rock and $\mathbf{K^{sh}}$ unit containing shale, sandstone and limestone as reservoir and cap rock.

Due to the presence of very extensive outcrops of travertine deposits in DGR, it is more probable that reservoir rock is a carbonate rock. More scientific data would be necessary to prove this idea.

10- Derik geothermal resource thermal energy assessment

Thermal energy of Derik geothermal resources is calculated by volumetric method. The volumetric method is considered the most comprehensive, useful and reliable depiction of the accessible to virtually any geological environment and the required parameters can be measured or estimated, (Muffler & Cataldi, 1978). In the present study, the volumetric method was chosen to assess the energy content of Derik geothermal resource.

Derik geothermal resources thermal energy, E is obtained from:

$E= E_r + E_f=[V\rho_r(1- Ø_t)\ C_r\ (T- T_{ref})] + [V\rho_{ft}Ø_t\ (h_t- h_{ref})]$

Where

- V = reservoir volume
- Cr = rock specific heat (kJ/kg ˚C)
- ht = fluid specific enthalpy at temperature under consideration (kJ/kg)
- href = fluid specific enthalpy at reference temperature (kJ/kg)
- ρr = specific rock density (kg/m3)
- ρft = specific fluid density at temperature under consideration (kg/m3)
- Tref = reference temperature (˚C)
- T = temperature of the volume of rock and water under consideration (˚C)
- Øt = porosity (%)

In accordance with the terminology of (Muffler & Cataldi, 1978) the total heat is calculated to 10 km depth for the geothermal resource thermal energy but only the heat in uppermost 3 km is considered accessible.

Therefore, based on the available data, Derik geothermal resource thermal energy was calculated. It should be mentioned that at the present time we do not have any subsurface data about the DGR, so the following data are estimated:

- Reservoir area : 242 km^2
- Reservoir thickness: 3 km
- Reservoir volume : 724 km^3
- Rock density: 2600 kg/m^3
- Porosity: 0.1 (% 10)
- Rock specific heat: 0.916 kJ/kg ˚C
- Reference temperature: 11 ˚C (mean annual temperature in Salmas)
- Reservoir temperature: 53 ˚C
- Fluid specific enthalpy at temperature under consideration: 205.15 kJ/kg
- Specific fluid density at temperature under consideration: 988.92 kg/m^3
- Fluid specific enthalpy at reference temperature: 46.28 kJ/kg

Therefore, finally it is revealed that total stored thermal energy in uppermost 3 kilometers of Derik geothermal resource is 7.67×10^7 kJ.

11- Conclusions

Derik Geothermal Region (DGR) is located 10 km to the west of Salmas city in west Azarbaijan province of Iran. The main surface manifestations of geothermal energy in DGR are warm springs, young basaltic rocks and travertine deposits.

Warm Springs's temperature varies from 31 to 32 °C. Warm springs are bicarbonate type and probably have been mixed with cold underground waters. Based on quartz geothermometers, maximum and minimum temperature of Derik geothermal reservoir is 53 °C and 90 °C respectively. So, Derik geothermal reservoir is a low-enthalpy reservoir. According to information of a shallow borehole in the region thermal gradient of DGR is 50 °C/1 km. Therefore, geothermal reservoir in Derik region could be located in 1000 to 1800 meters below the earth's surface.

Probably, young volcanic rocks could be geothermal reservoir heat source. Also, carbonate rocks such as limestone and dolomite with different ages can play role as reservoir rock in DGR. According to volumetric method, stored thermal energy in DGR was calculated as 7.67×10^7kj. Due to the reservoir temperature, geothermal fluid of Derik reservoir can be used for direct use plants such as fish farming, Balneologic purposes and also for snow and ice melting of roads and sideways.

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