Resource Assessment of Vartun Geothermal Region, Central Iran

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Received: 23 April 2013 / Accepted: 23 May 2013 / Published online: 25 March 2013

Abstract

Vartun geothermal region (VGR) is located in west central part of Iran, 300 km in the southeast of Tehran. VGR area is 277 $km^2$and there are some geothermal surface manifestations such as warm springs and travertine deposits. There are three warm springs which their temperature varies from 35.3 to 43.1 °C. Their pH is a little bit acidic and is about 6.1-6.2. Based on geothermometery studies Vartun geothermal reservoir approximate temperature was estimated 46-182 °C. According to the geological, aeromagnetic and remote sensing studies VGR probable reservoir and cap rock was recognized. Therefore Permian dolomite, limestone and sandstone were regarded as reservoir rock while cap rock includes shale and quartzite. Thermal energy of Vartun geothermal resource was estimated 1.14×10^{17}kj.

Keywords: Geothermal, Vartun, Warm spring, Iran, Resource assessment.

1- Introduction

Mahallat Geothermal Region was identified by Renewable Energy Organization of Iran (SUNA) about 12 years ago. This Region is located in central part of Iran and has an area of about 51,000 km^2 and covers three provinces: Qom, Markazi and Isfahan (Fig. 1).

Due to presence of some surface geothermal manifestations in this region such as warm springs, extensive travertine outcrops and etc., Renewable Energy Department of Niroo Research Institute (NRI) conducted a geothermal resource assessment project in the region. As a result several geothermal prospects were determined. One of those prospects is Vartun geothermal resource (VGR) which is shown in Figure 1. The VGR area is located at 37 kilometers in NE of Isfahan city and covers an area about 277 Km^2.

In order to identification of VGR many datasets were used such as warm springs, available geological maps, aeromagnetic surveying and remote sensing. According to these datasets a primary conceptual model of VGR were determined.

2- Geology

According to the geological map of VGR some parts of the region especially in southern parts consist of Quaternary terraces deposits. Also travertine deposits outcrops around warm springs. Mesozoic formations disclosed in the northern parts of the VGR.

They include dolomite, sandstone and shale. There is no sign of any volcanic rocks on the surface. For more information about the geological features of VGR geological map of the region is shown in Figure 2.

Figure 1) Location of Vartun geothermal region in Iran

Despite of extensive Quaternary deposits which cover the main parts of the VGR, some faults have been identified in the region. Generally, they have two main directions, NW-SE and NE-SW. All of the warm springs are genetically related to the tectonic activities and concentrated along fault zones.

These warm springs are located along NW-SE direction faults which represent the main tectonic trend in the region (Fig. 3). There is an inferred fault which is elongated in North-South direction.

3- Surface manifestations

3.1- Warm spring

The amount and composition of chemicals dissolved in the warm spring water provides a geochemist with ideas as to the composition of the rocks hosting the geothermal system, the thermal history of the water, and the time since it was last in contact with the atmosphere. There are three warm springs in VGR which their locations are shown in Figure 3.

Table 1) General characteristics of VGR warm springs.

Name	Longitude	Latitude	T (C˚)	rate Flow (l/s)	pH	Ec (mS/cm)
Hoze Morad	52˚ 09′ 45″	32˚ 55′ 14″	43.1	2	6.1	5.43
Hoze Emamreza	52˚ 09′ 45″	32˚ 55′ 11″	41.8	2	6.1	5.28
Vartun	52˚ 08′ 36″	32˚ 56′ 09″	35.5	3	6.2	4.82

Also, the main chemical and physical characteristic of the springs are summarized in the Table 1. Based on geothermometery studies approximate temperature of Vartun geothermal reservoir was obtained which they are shown in the Table 2.

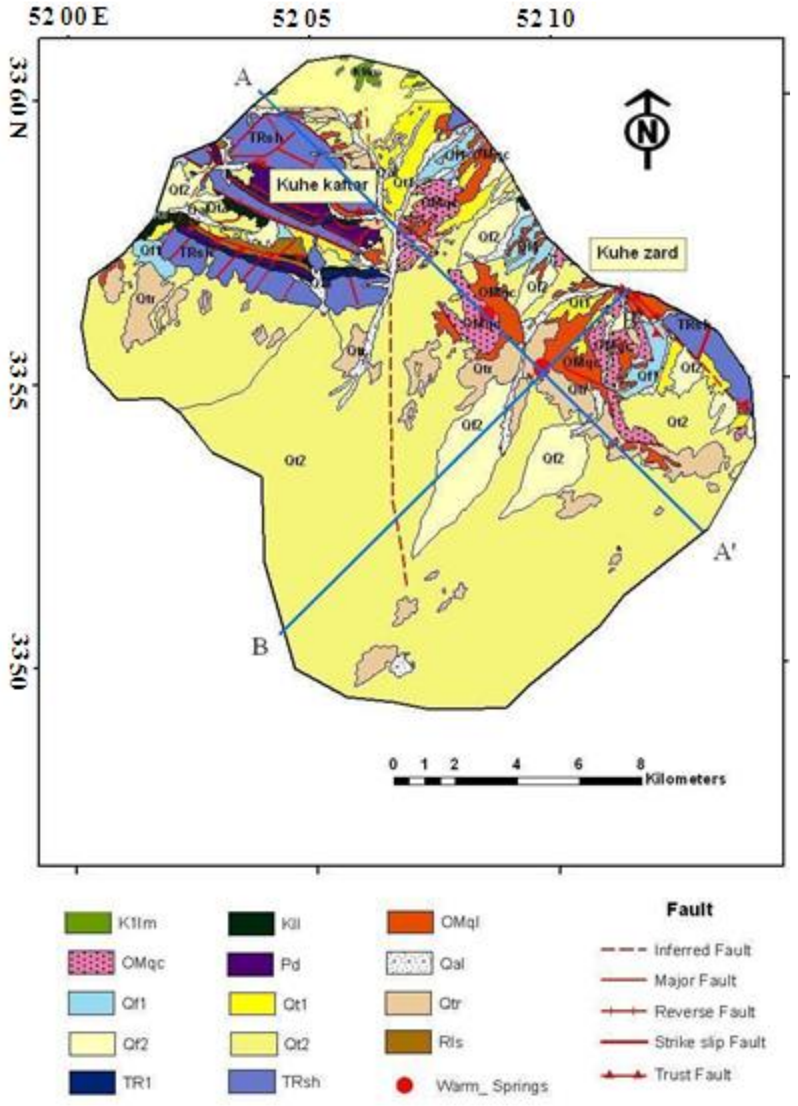

Figure 2) Geological map of Vartun geothermal region.

3.2- Alteration zones

Due to the large size of Mahallat region satellite images were used to determine geothermal areas. Remote sensing techniques are emerging as useful reconnaissance tool for mapping the geology, detecting hydrothermal altered areas and identifying geothermal indicators including geothermal area (Urai *et al*., 2000).

Alunitic alteration is closely associated with certain warm spring environments. Alunite is a potassium aluminum sulfate mineral, which tend to form massive ledges in some areas. The presence of alunite suggests high SO_4 gas contents were present, which is thought to result from the oxidation of sufide minerals, (Lagat, 2007).

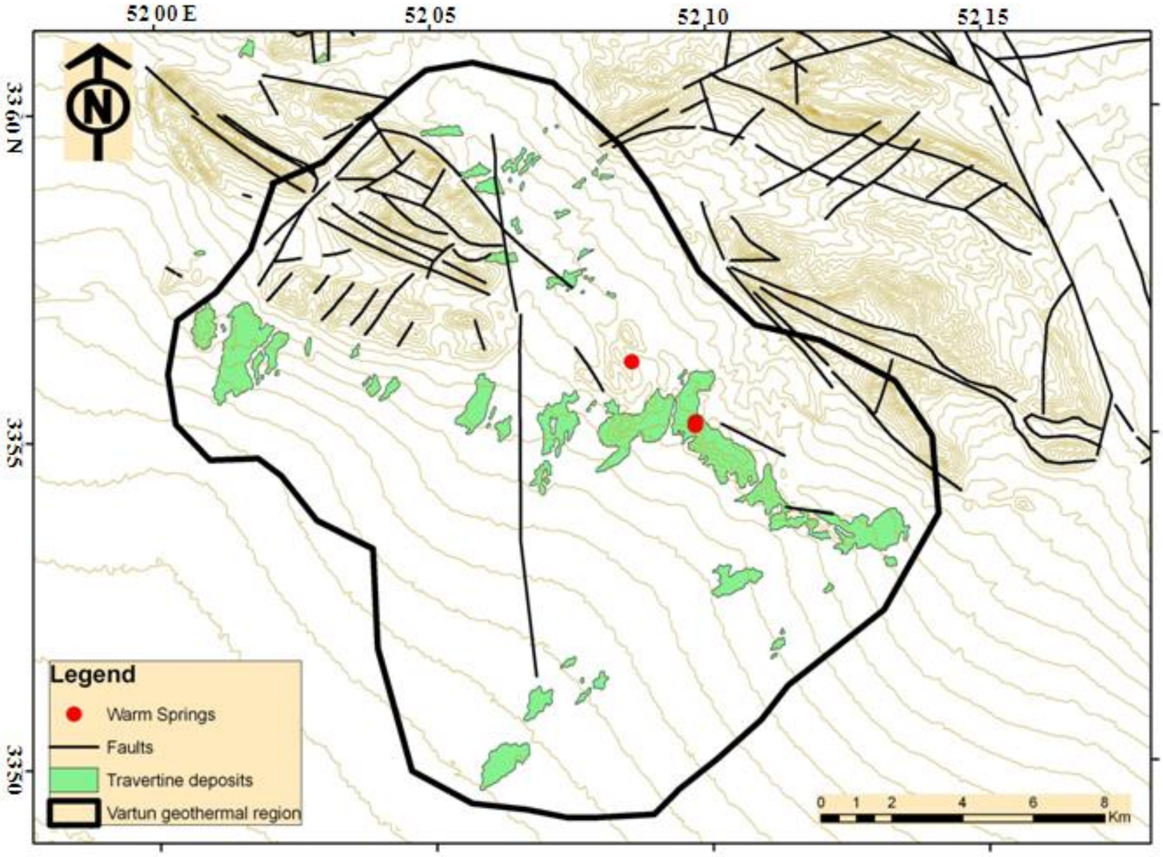

Figure 3) Location of warm springs in Vartun geothermal region.

Argillic alteration is that which introduces any one of a wide variety of clay minerals, including kaolinite, smectite and illite. Argillic alteration is generally a low temperature event, and some many occur in atmospheric conditions (lagat, 2007).

Based on Aster satellite images studiestwo altered zones were found in VGR, argillic-sericitic and kaolinite-alunite. Argillic-sericiticalteration is determined in two different zones, around warm springs and in the north-eastern part of Vartun village.

Kaolinite-alunite alteration is found in the 7 kilometers from North-western of Hoze Morad warm spring. This altered zone includes 6 Kaolinite-alunite areas. Several faults are recognized around these altered zones.Another altered zone is located at 3.5 kilometers from the Southeast of Hoze Morad warm spring and is surrounded by faults.

3.3- Travertine deposits

Travertine is a chemically-precipitated continental limestone formed around seepages, warm springs and along streams and rivers, occasionally in lakes and consisting of calcite or aragonite, of low to moderate intercrystalline porosity and often high mouldic or framework porosity within a vadose or occasionally shallow phreatic environment. Precipitation results primarily through the transfer (evasion or invasion) of carbon dioxide from or to a groundwater source leading to calcium carbonate super saturation, with nucleation/crystal growth occurring upon a submerged surface, (Pentecost, 2005).

Table 2) Chemical characteristics of VGR warm springs (mg/l).

Samples	**Vartun**	**Hoze Morad**			**Hoze Emamreza**		
Sampling year	**2008**	**2008**	**2007**	**Average**	**2008**	**2007**	**Average**
Ca	574.4	588.8	572.8	580.8	579.2	585.6	582.4
Mg	97.9	85.4	75.8	80.6	94.1	71	82.55
Na	450	453	415	434	450	415	432.5
K	36	37	38	37.5	35	39	37
Cl	631	613.3	664.8	639.05	613.3	659.8	636.5
SO_4	1319	1322	1248.1	1285.05	1323	1248.1	1285.5
T.D.S	3645	3586	3536	3561	3588	3539	3563.5
HCO_3	722	746.6	697.8	722.2	746.6	717.4	732
SiO_2	29.7	31.4	26.75	29.07	31.7	25.48	28.59
B	0.3	0.4	0.8	0.6	0.4	0.67	0.53
Li	0.7	0.7	0.6	0.65	0.7	0.6	0.65
F	0.5	0.5	-	-	0.5	-	-
Al	<0.02	<0.02	-	-	<0.02	-	-
Fe	0.1	0.01	-	-	0.3	-	-
H_2S	<0.1	<0.1	-	-	<0.1	-	-
CO_2	122	116.5	-	-	122	-	-

Travertine deposits usually form around warm springs so it can be a useful sign of geothermal activity in a region either active or fossil one. Irregular fault movements can be responsible for spring migration leading to the deposition of a range of travertines at different levels (Soligo *et al.*, 2002).

Due to the warm spring activity a lot of travertine deposits have been accumulated in the VGR. The main outcrops of travertine are distinguished in three parts of the VGR, Figure 2. They are as follows:

- Northwestern part of warm springs. As travertine deposits are strongly related to the faults so there should be some faults in the vicinity of travertine outcrops but some faults are covered by young terraces in this area.
- Near to the warm springs there is a thin band of travertine deposits which its direction is NW-SE.
- In the Southwestern part of the springs, close to Vartun village there are a few travertine outcrops.

4- Aeromagnetic Surveying

For regional exploration, magnetic measurements can be important for understanding the tectonic setting, such a study has been applied in Iceland or at Dixie valley, Nevada, USA (Smith *et al*., 2002; prieto, 2003).

In order to recognition of Vartun region geothermal potential available aeromagnetic data were obtained from Airborne Geophysics bureau of Geological Survey of Iran (GSI). Flight line spacing of the data is 7.5 kilometers. In Figure 4, aeromagnetic map of VGR is shown. As it can be seen in the figure, due to the very large flight line distances, magnetic anomalies could not be used to delineate geothermal prospects.

But based on the VGR aeromagnetic data analysis it is found that the nearest deep intrusive body is located at 8.5 Km from VGR Eastern boundary and 16 km from East of Hoze Morad and Hoze Emamreza warm springs. Among of all confident and inferred faults which were revealed by aeromagnetic data, two confident faults were recognized in VGR. One of them has NE trend and another has east to west trend. Both faults have no evidence at the surface. One of the best results of aeromagnetic surveying is the very close relation of Vartun warm spring and a confident magnetic fault which is shown in Figure 4.

5- Reservoir characteristics

5.1- Heat source

According to the geological maps there isn't any evidence of young volcanic rocks in VGR. So it seems that recognizing of heat source in this region isn't clear. The youngest volcanic rocks in the prospect area have assigned as Eocene geological age. Beside that on the basis of aeromagnetic surveying results there is an intrusive body which is located at 9 km from the East of VGR boundary. Due to the far distance between this body and warm springs it can´t be considered as a heat source for Vartun geothermal reserve.

Another possible heat source for VGR is abnormally high regional heat flow which provides sufficient heat to warm the infiltrating water. The main reason to form a geothermal reservoir in the VGR is the presence of suitable conditions such as a proper cap rock. In fact there is not any other geothermal reservoir in the region due to the lack of necessary factors to make a reservoir. It needs some more scientific information to prove this theory.

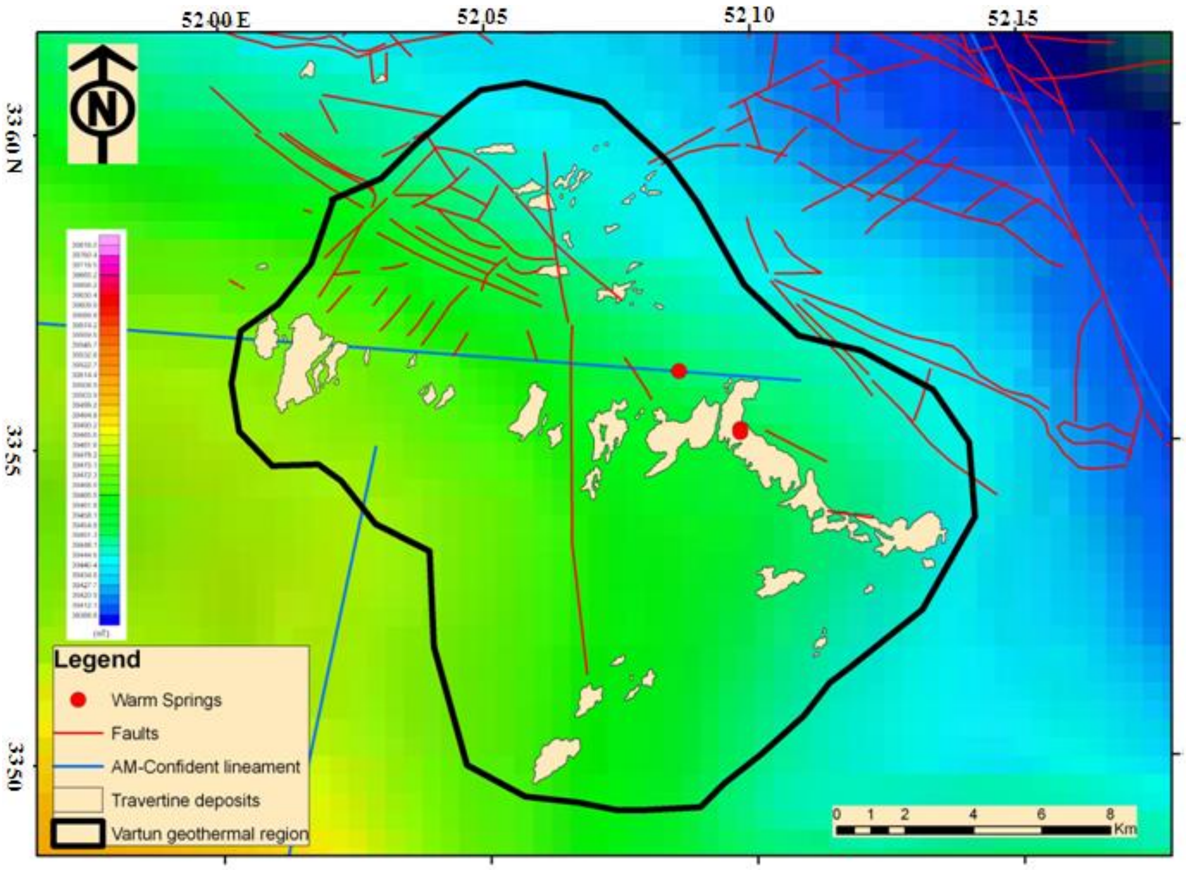

Figure 4) Aeromagnetic map of VGR.

5.2- Reservoir rock

According to analysis of geological maps and filed works it is found that Permian rock units can be proper reservoir rocks for VGR, Table 1. The main reason for this theory is lithological characteristics of these rock units and also presence of faults and fractures among them.

These rock units are as follows:

- **Pd** rock unit which includes dolomite, Thickness: 150-200 m (Permian),
- **Pls** rock unit containing limestone and dolomitic limestone, Thickness: 200-250 m (Permian),
- **Ps** rock unit that includes sandstone, Thickness: ≈100 m (Permian).

5.3- Cap rock

As the Sorkh Shale Formation which consists of impermeable shale and quartzite rocks covers Permian rock units in VGR, so it can be a suitable cap rock for geothermal reservoir in the region. In VGR it includes ferroginous quartzite and fine-laminated shale. This unit covers older rocks (Permian rock units such as Pd) in the region.

5.4- Inflow zone

Fluid pathways are critical for the productivity of a reservoir and are commonly controlled by structures such as fractures and faults, (Sheridan and Hickman, 2004; Curewitz and Karson, 1997; Faulds *et al.*, 2006). Fault intersections appear to be particularly favourable sites for springs (Pécsi *et al.*, 1982). In VGR there are two areas which can be considered as infiltration zones of cold meteoric waters into the reservoir (Figure 5). They are as follows:

5.4.1-Koohe Kaftar area

It is positioned 5.5 kilometers in NW of the springs and its elevation is 2365 m. This area is tectonically very active due to the existence of faults and trust faults. Definitely these tectonic features develop secondary permeability in VGR.

5.4.2- Kohe Zard area

It is located 4.5 kilometers in NE of the springs and its elevation is 2556 m. Similar to Koohe Kaftar area there are some faults and fractures in Kohe Zard area which can lead meteoric water into the geothermal reservoir.

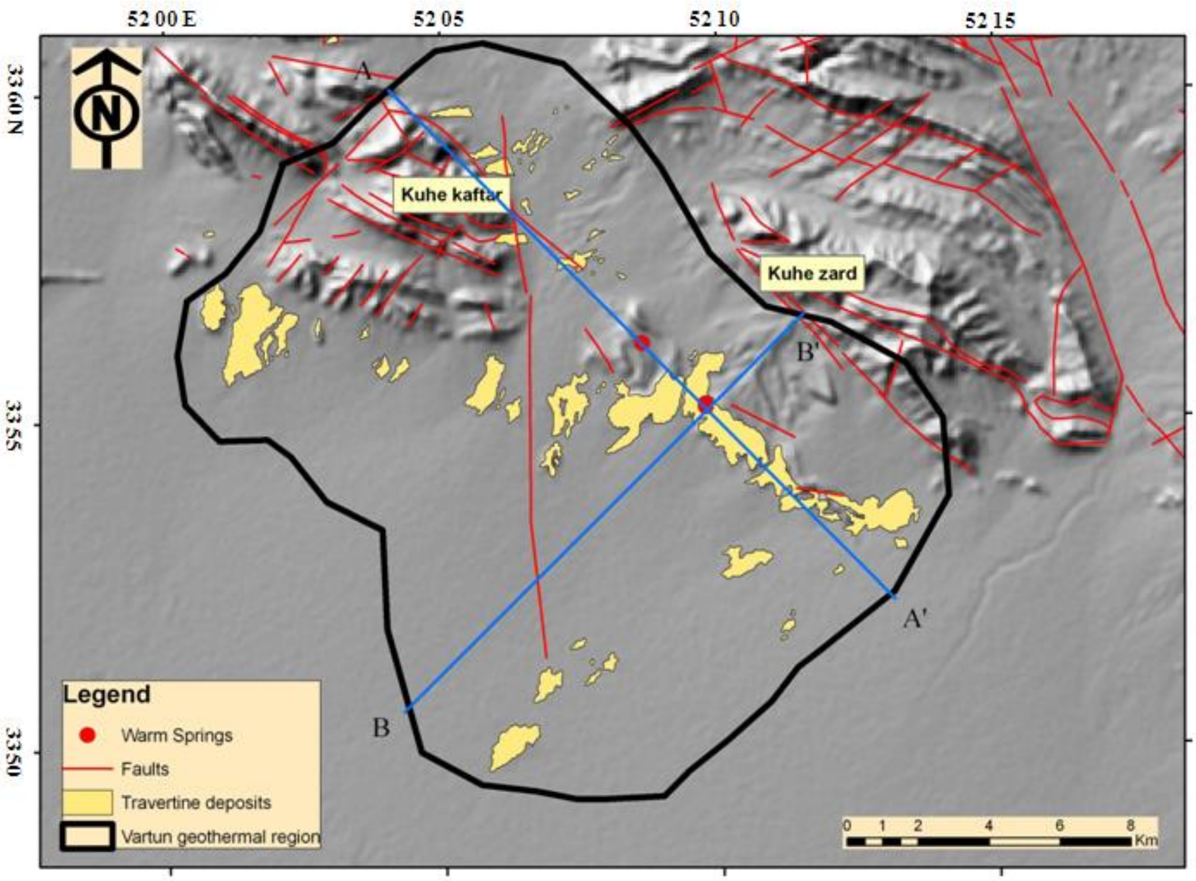

Figure 5) Location of cross sections and inflow zones in VGR.

6- Conceptual model

According to the all obtained information such as geology, warm springs, aeromagnetic and remote sensing data a primary conceptual model of VGR were constructed. Definitely this model would be updated by means of new geological, geochemical and geophysical investigations.

Vartun geothermal reservoir was assessed in two perpendicular profiles (Fig. 6). As it mentioned earlier travertine deposits have an axis which is elongated in NE-SW direction. So the profiles were cut the reservoir in two different directions. One is parallel to the above-mentioned axis (AA´) and the other is perpendicular to the travertine axis (BB´). Also, both profiles intersect all the warm springs in VGR (Fig. 6).

Along the AA´ cross section which intersects Vartun warm spring, there are some travertine outcrops and two warm springs including Hoze Morad and Hoze Emamreza (Fig. 6a). At the surface there isn't any fault in geological maps near the Vartun warm spring but based on aeromagnetic data one magnetic fault can be seen very close to the spring. So Vartun warm spring is strongly related to this fault.

As it can be seen in Figure 6b, Profile BB´ is also intersects Hoz-e-Morad and Hoz-e-Reza warm springs and travertine deposits.

According to the remote sensing data some argillitic and alunite altered areas were determined along the BB´ cross section.

Based on the available geological data Vartun geothermal resource heat source is not very obvious.

7- Volumetric resource assessment

The volume method is considered the most comprehensive, useful, and reliable depiction of the geothermal resource base. It is applicable to virtually any geological environment and the required parameters can be measured or estimated. The inevitable errors can be partly compensated for, while the major uncertainties on recovery factor and resupply of heat are foreseen to be resolved in the future (Muffler and Cataldi, 1978).

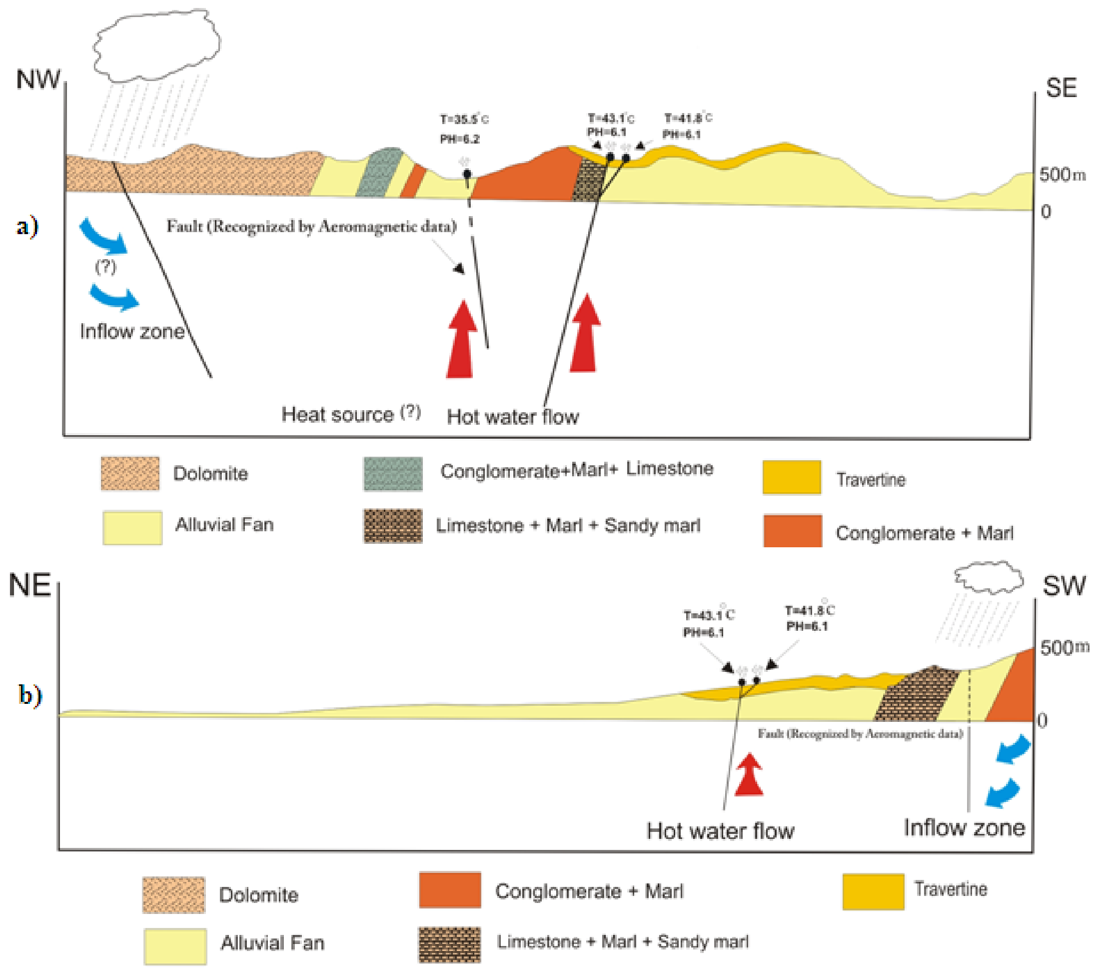

Figure 6) Geological profiles of VGR: a) AA´ cross section, b) BB´ cross section.

In the present study, the volume method was used to assess the energy content of the Vartun geothermal resource. The maximum depth for Vartun geothermal resource was assumed 3000 meters (Table 3). The geothermal resources base, E_{RB} is obtained from the following equation:

$$E_{RB}= E_r+E_F= V\rho_r\, Cr(1-\varphi)(T-T_r)+V\rho_{ft}\varphi(h_t-h_{ref})$$

Where:

E_{RB} = stored heat in the system (Kj)

E_r = thermal energy contained in the rock (Kj)

E_F = thermal energy contained in the reservoir fluid (Kj)

V = reservoir volume (Km^3)

ρ_r = specific rock density (Kg/m^3)

C_r = rock specific heat ($Kj/Kg^{\circ}C$)

Φ = total porosity (%)

T = temperature of the volume of rock and water under consideration ($^{\circ}C$)

T_{ref} = reference temperature ($^{\circ}C$)

ρ_{ft} = specific fluid density at temperature under consideration (Kg/m^3)

h_t = fluid specific enthalpy at temperature under consideration (Kj/Kg)

h_{ref} = fluid specific enthalpy at reference temperature (Kj/Kg).

Table 3) Results of solute geothermometry by using WATCH computer program (°C).

Warm spring	Surface T.	T_Q	T chalced	$T_{Na/K}$
Hozmorad	43.1	78.6	46.7	182.3
Hozemamreza	41.8	77.9	46	182
Vartun	35.5	79.5	46.7	175.1

The Vartun geothermal resource parameters are summarized below:

Reservoir area = 277 Km^2

Reservoir thickness =2 Km

Reservoir volume = 554 Km^3

ρ_r = 2605 Kg/m^3; C_r = 0.879 $Kj/Kg^{\circ}C$

Φ = 0.1; T = 102 $^{\circ}C$; T_{ref} = 17.68 $^{\circ}C$

ρ_{ft} = 958.05 Kg/m^3; h_t = 419.06 Kj/Kg

h_{ref} = 71.41 Kj/Kg

So, Vartun geothermal resource base was estimated as follows:

$E_{RB} = 1.14 \times 10^{17}$ Kj

8- Conclusions

Based on all investigations in Vartun region the following results were obtained:

- There is a low temperature geothermal resource at the east of Isfahan city and very close to Vartun village.
- Main geothermal surface manifestations in the region are three warm springs (with 35.5-43.1 $^{\circ}C$ temperature range) and a huge volume of travertine deposits.
- According to the geothermometery studies temperature range of Vartun geothermal resource is 46-182 $^{\circ}C$.
- Based on geological maps of the Vartun region dolomite, limestone and sandstone are possible reservoir rock and shale and quartzite are cap rock of the geothermal reservoir.

- Approximate stored thermal energy in Vartun geothermal resource is 1.14 × 10^{17} Kj. It is estimated by volumetric method.

Acknowledgments
The authors would like to thank Dr. Sergio Espinosa and an anonymous reviewer for their comments that help improve the manuscript.

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