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Study on the Role of Shemshak Formation in Creation of some Geothermal Resources in Iran

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ABSTRACT

It is very clear that one of the important parts of a geothermal system is cap rock which covers reservoir properly. In fact, cap rock doesn't allow geothermal fluid to escape from the reservoir. During implementation of some geothermal resource assessment projects in Iran it is found that there is a close relationship between some geothermal resources and Shemshak Formation outcrops. More studies revealed that Shemshak Formation is the cap rock of determined geothermal resources around Damāvand volcano, Rāmsar, Mahallāt and Ābegarm cities and Nāyband village. These geothermal systems have different geological characteristics but common cap rock. This Formation's thickness is 1027 m and consisted of shale, sandstone, siltstone and claystone. Geographically it is outcropped in the Northern, Central and Eastern sections of the country and had been formed during lower Jurassic. Due to the suitable lithology and sufficient thickness of Shemshak Formation it is a unique cap rock for those geothermal reserves which have been formed in the above-mentioned parts of Iran. So, it might be a clue for determining of new geothermal reserves in other regions of Iran.

1. INTRODUCTION

Geothermal exploration in Iran dated back to 44 years ago. Actually, interest in the geothermal energy originated in Iran since Mr. James R. McNit, a United Nations geothermal expert visited Iran in December 1974. He reported that Iran has very promising prospects for geothermal energy development. Consequently, a contract between Ministry of Energy (MOE), ENEL (an Italian company) and Tehran Berkeley consulting Engineers of Iran was signed in 1975 for geothermal exploration in northern part of Iran (McNitt, 1974).

According to the results of the above-mentioned project and also investigations of Electric Power Research Center (EPRC), priorities were given to the Northwestern parts of the country and Damāvand volcano in the south of Caspian Sea. The Renewable Energy Organization of Iran (SUNA) as part of Ministry of Energy had been done a global investigation in all of Iran during 2000-2002. The investigations approved 10 big areas which have more potentially suitable regions for this purpose. Figure 1 shows these big geothermal prospects in Iran. This first step was useful for showing high potential of hydrothermal potential. Iran has 31 provinces and SUNA, since 2010 up to now, focused on the exploration of geothermal areas in each province according to the standard methods, (Porkhial and Yousefi, 2015).

So far, 5 of 31 provinces in Iran have been studied systematically in order to find hydrothermal prospects. Due to these investigations it is found that there is 22 geothermal prospects in studied provinces. Those provinces include West Azarbāijān, East Azarbāijān, Ardabil (all in the NW of the country), Qazvin (in the north of central part of the country) and south Khorāsān (in the eastern part of country). All of the surveyed provinces consists of 16.2 % of the total Iran area.

One of the most important geothermal prospects in Iran is Meshkinshahr region. From 2002–2004, three deep exploration wells were drilled for evaluation of subsurface geological conditions, geothermal reservoir assessment, and response simulation. Two of the wells were successful, for which a maximum temperature of 230 °C at 3200m depth was recorded. To supply steam required for a geothermal power plant, totally 11 production and injection wells were drilled and the wells were tested. As a result of the reservoir simulation, a 55 MW power plant is projected to establish in the Sabalān field as a first geothermal power plant in Iran. So far, for the first unit a 5 MW turbine, has been installed and it is planned to be online as soon as possible. (Noorollāhi et al., 2019). The full load power plant is predicted to generate an annual energy of 410 GWh (Tofigh and Abedian, 2016). SUNA is planning to continue to full load by adding next modules in coming years depending on the suitable financing conditions of course.

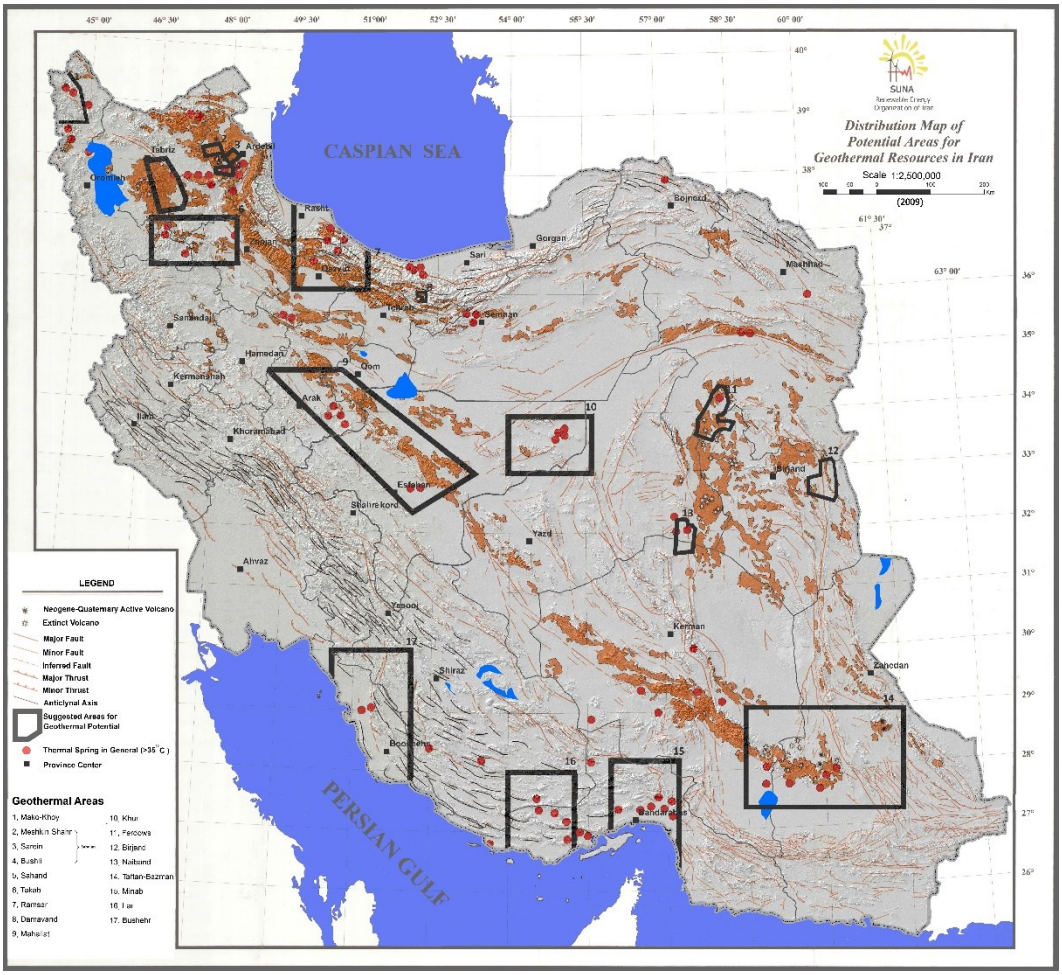


Figure 1. Geothermal map of Iran (SATBA, 2019)

During implementation of geothermal exploration projects in different parts of the country it is found that there is a significant and meaningful relation between Shemshak Formation and some geothermal prospects in Iran. For example, such conditions can be seen in Nāyband, Mahallāt and Rāmsar regions and Damavand volcano as well. It should be noted that these prospects have different geological conditions and also there are some considerable distances between them. For instance, Rāmsar prospect is located 850 km far from Nāyband region. Initially, this relation was regarded as an accidental phenomena but detailed geological studies in Mahallāt region revealed that due to the Shemshak Formation characteristics this relation is logic. In this paper at first we will describe the main components of a geothermal reservoir and then we'll illustrate Shemshak Formation in more detail. In the following we'll explain briefly those geothermal prospects which there are outcrops of this Formation around them.

2. GEOTHERMAL RESERVOIRS

There are different types of geothermal resources in the nature. Meanwhile, there is a suite of geological conditions that could result in a variety of geothermal systems. Consequently, all geothermal fields differ from one another. However, depending upon certain common characteristics, these can broadly be classified into the following categories: (1) vapor-dominated, (2) hot water, (3) geopressured, (4) hot dry rock (HDR), and (5) magma, (Gupta and Roy, 2007). Some of these geothermal resources can be classified into some subdivisions which are not discussed here. In this paper we are dealing with hydrothermal systems in Iran which are the most common type of geothermal resources in the world.

In every hydrothermal resource there are five features that are essential to making a geothermal reservoir commercially viable. They are a large heat source, a permeable reservoir, a supply of water, an overlying layer of impervious rock, a reliable recharge mechanism, (Dippipo, 2006; Gupta and Roy, 2007; Boden, 2017).

As it is mentioned earlier, cap rock is one the main components of a geothermal reservoir. It is an impermeable rock, with low permeability which is overlying the reservoir. In other word, it is necessary to prevent the escape of hot reservoir fluids through convection. But it should be noted that the heat loss through conduction is not prevented by the cap rock. Since volcanism is associated with tectonic movements causing fissures, ideal unfissured impermeable cap rock is nowhere to be found. The geochemical processes associated with geothermal fields, i.e., hydrothermal alteration of rocks and mineral deposition, are helpful in sealing off the fissures. Typical examples of cap rocks rendered impermeable through chemical action and deposition are seen at The Geysers and Otake geothermal fields. At The Geysers, calcite- and silica-filled fractures, up to 1 in. wide, are commonly seen. The geochemical and hydrothermal

processes are complicated and vary from place to place. At many other steam-producing fields, original impervious rocks constitute the cap rock. Examples are the lacustrine Huka Formation at Wairakei (New Zealand), the deltaic clay at Cerro Prieto (Mexico) and Salton Sea (California) and the Flysch Formation at Larderello (Italy) (Gupta and Roy, 2007).

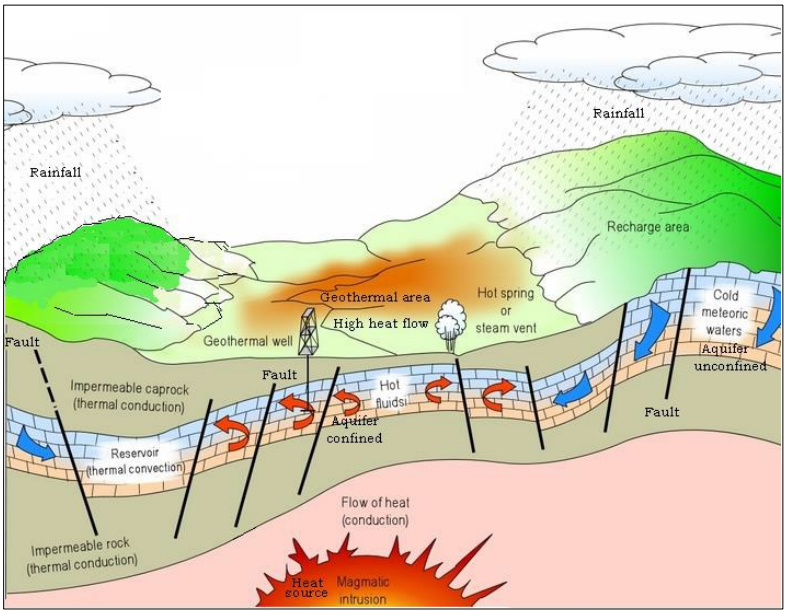


Figure 2. Schematic sketch of an ideal geothermal (hydrothermal) reservoir (Gupta et al., 2016)

2. SHEMSHAK FORMATION

This Formation is one of the widespread sediments which has been formed in the northern side of Zagros trust. Geographically Shemshak Formation is vastly outcropped in the north, center and eastern regions of Iran. Distribution map of the Shemshak Formation in the north of Iran is shown in figure 3. Mostly it is composed of clay and sand, so it has low relief. Due to this character it is easily recognizable at the surface. Shemshak Formation is a precious and valuable lithological unit in Iran because approximately all of the Iranian coal reserves have been accumulated in this Formation, (Darvishzadeh, 2003).

The name of this Formation is obtained from Shemshak village and mine in the northeast of Tehran (Darvishzadeh, 2015). According to the relevant studies it is revealed that this Formation has been formed during late Terriassic- lower Jurassic (Assereto, 1966). Its Thickness is 1027 m and lithologically from bottom to top it is divided into four sections. They are as follows (Darvishzadeh, 2003):

- Lower sandstone with 76 m thickness containing alternation of fine to medium grained sandstone and sub greywacke and thin bedded shale and coal shale.
- Coal bearing section with 333 m thickness including silt-clay bearing sediments and a lot of coal lenses and layers.
- Upper sandstone with 531 m thickness composed of medium grained sandstone, sub greywacke, micaceous siltstone and shale.
- Upper coal bearing part with 87 m thickness including clay shale with many coal layers in the lower sections. In upper sections it is composed of marl, siltstone and shale.

In figures 4 and 5 several stratigraphic columns of Shemshak Formation in the north and center of Iran have been shown. Alternation of sandstone and shale layers of Shemshak Formation in Mahallāt region is shown in figure 6.

In type section Shemshak Formation covers Jiroud Formation (Carboniferous) but in other places its lower borders composed of different formations which are belonged to Precambrian to Triassic (Elika Formation). In all places Shemshak lower border accompanied with unconformity which confirms orogenic activities before its Formation. At the top, Delichai Formation (upper Jurassic) covers it without any distinct border, (Darvishzadeh, 2003).

4. GEOTHERMAL RESOURCES WITH SHEMSHAK FORMATION OUTCROPS

According to the previous studies it is found that Shemshak Formation is a suitable and proper cap rock for some geothermal resources in Iran. The main reasons for this idea are as follows:

Lithology

As it is mentioned earlier, nearly all sections of Shemshak Formation include fine - grained sediments such as fine – grained sandstone, siltstone, clay and shale. Due to their character, these rocks can protect reservoir fluid very well.

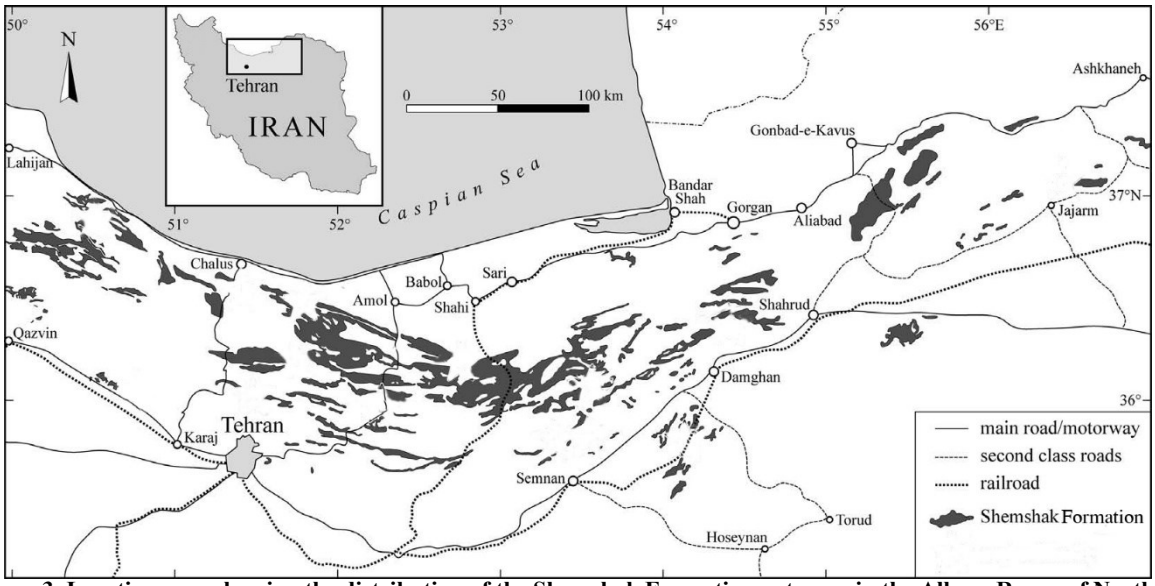


Figure 3. Location map showing the distribution of the Shemshak Formation outcrops in the Alborz Range of Northern Iran (modified from Shekarifard et al., 2012)

Thickness

In type section, Shemshak Formation thickness is 1027 m but in other localities, it is not the same as type section. For example, in the following places different thicknesses have been reported:
In Shāhrood region (in the northeast of Iran): 1200 m (HādjiPour, 2009)
In the north of Semnan city (in the east of the country), 962 m (Hāshemi et al., 2014)
In the Ābeali region (In the northeast of Tehran): 2357 m (Farāhāni et al., 2005)

Low thermal conductivity

Normally, shales have low thermal conductivity. Therefore, not only thick shale beds of Shemshak Formation can seal the geothermal reservoir but also can keep it warm. Based on the laboratory experiments, among all of the rocks thermal conductivity of shale, is 1.4 w/m.k which is very low (Beardsmore and Cull, 2001).
In the following part of the paper, four geothermal regions will introduce. Due to the exploration studies it is revealed that probably cap rock of all of them is Shemshak Formation. In all of these regions, this Formation is outcropped around warm springs.

4.1 Nāyband Geothermal Region

This region is located in 170 km to the south west of Birjand, center of Khorasane Jonoobi Province. This province is positioned in the east of Iran, Figure 7. In this region, significant geothermal surface manifestation is 5 warm springs whose temperature varies from 36 to 75 ° C. General Information about the warm springs are illustrated in Table 1. Their flowrate is from 0.5 to 4 l/s, and their pH is slightly acidic and turns to neutral. Based on evaluation of the present data it is determined that Ashkerostam hot spring (with 75.3° C temperature) is the second hottest spring in Iran. Total thermal energy of the warm springs are 2.55 Mwt (Nouraliee, 2001).As it can be seen in Figure 5, warm springs are formed along Nāyband fault. So this fault is likely the reason for forming of geothermal resource and warm springs in this region too.

Nāyband 100 K geological map shows that presumabley Shotori Formation would be reservoir rock and Nāyband Formation composed of massive dolomites (Triassic), (Chance et al., 1981). Nāyband Formation is the one of Formations of Shemshak group in central Iran tectono-stratigraphic zone. This group is divided to three subgroups which are Hozesheikh (in lower part), Nāyband (in middle part) and Hozekhān (in top), (Aghānabti, 2005). According to the available data in this region the thickness of that part of Shemshak Formation which covers Nāyband geothermal region is around 1400 m (Chance et al., 1981).

It is believed that normal thermal gradient would be the origin of heat in Nāyband region. Nāyband fault has 800 km length and is the outstanding and distinguished fault in eastern Iran. Hence, circulation of rain water along Nāyband fault would be the cause of Nāyband geothermal resource formation.

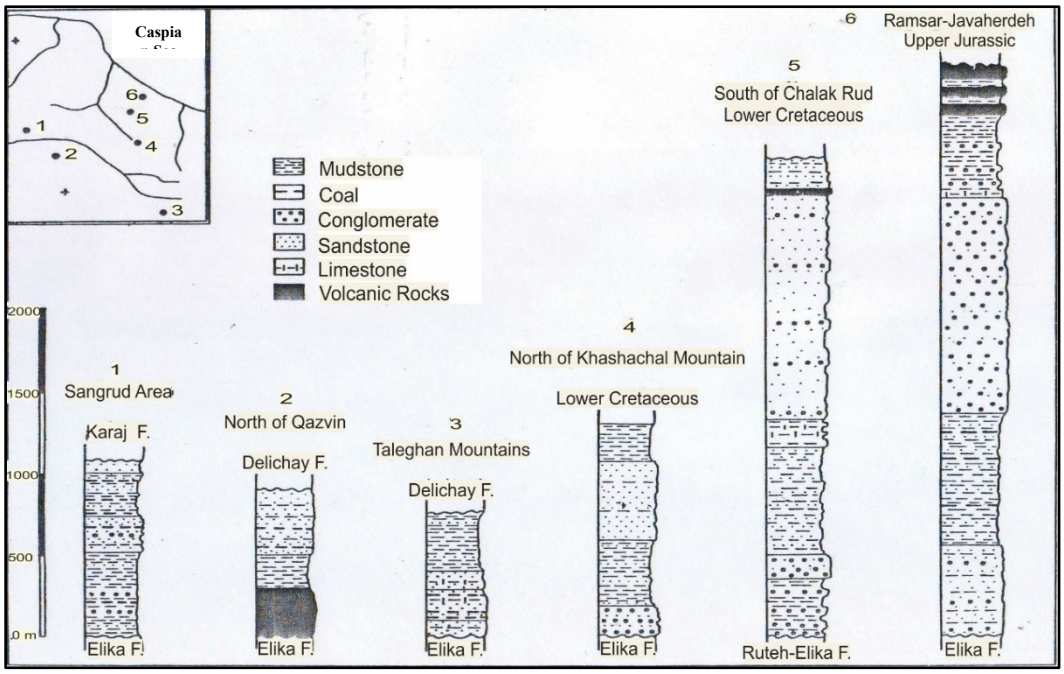


Figure 4. Six stratigraphic columns of Shemshak Formation in the southwest of the Caspian Sea (Darvishzādeh, 2003)

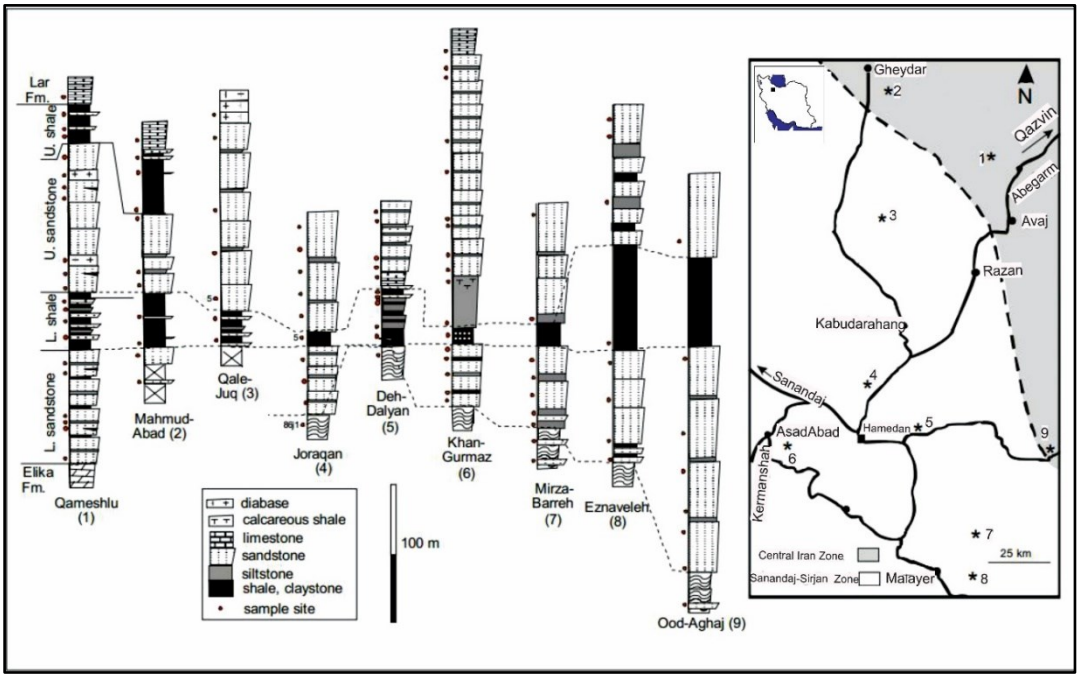


Figure 5. Some stratigraphic columns of Shemshak Formation in the north of Iran (Khodābakhsh et al., 2007)

4.2. Rāmsar geothermal region

This geothermal region is located around Rāmsar city which is 150 km to the northwest of Tehran. There are 8 warm springs in this region. In figure 6, geological map of Rāmsar geothermal resource is shown. Some information about Rāmsar warm springs are presented in Table 2.

Based on the latest researches and studies it is found that there are more warm springs in this region which have not been reported yet. These springs are located between Tonekābon and Chāboksar cities, (Rasā et al., 2011). As it could be predicted, warm springs have close relation to Rāmsar fault with NW-SE strike. This fault is aligned paralleled to Caspian Sea shoreline. No young volcanic rocks are outcropped in this region. So, it seems that heat source of this geothermal resource is not volcanic activity.



Figure 6. Alternation of sandstone and shale layers of Shemshak Formation in Mahallāt region (Due to the lower resistance against weathering shale layers are extremely eroded but sandstone layers are relatively fresh)

Table 1. General Information about the warm springs of Nāyband region

No.	Spring name	Geographical coordinates (UTM)		Elevation (m)	Temperature (°C)	Flowrate (l/s)	pH
		X	Y				
1	Zardgāh	533894	3583022	146	36.5	4	7.59
2	Dige rostam (1)	547090	3570103	805	68.5	2	6.4
3	Dige rostam (2)	547090	3570103	807	65	0.5	6.4
4	Ashke rostam (1)	547090	3570103	799	75.3	2	6.35
5	Ashke rostam (2)	577090	3570103	791	75.1	2	6.26

Table 2. Location and physicochemical information about Rāmsar region warm springs (Mokhtārpour et al., 2013)

No.	Name	X	Y	Temp. °C	pH	EC (µS/cm)
1	Māthare shāh	36-54-08	50-39-21	48	6	38800
2	Hotel Ghadim	36-54-09	50-39-27	65	6	40000
3	Hotel Jadid	36-54-07	50-39-26	49	6	40500
4	Zirepol	36-54-05	50-39-41	42	6	39900
5	Abesyāh	36-53-55	50-39-57	30	6	148300
6	Sādāt Mahaleh	36-52-52	50-41-22	40	6	233000
7	Kesh	36-52-24	50-41-25	47	5.5	19600
8	Sang boneh	36-52-24	50-41-25	45	5.5	18190

Geochemical studies of warm springs revealed that their oxygen content is low. So it is believed that they originate from very deep parts of the region (Nabavi, 1976). In other word, Rāmsar geothermal reservoir has been formed by deep circulation of rain waters in the underground channels and fractures of the region.

In the west side of warm springs, a lithological unit (TRJJ2) is widely outcropped. It is composed of siltstone, shale, sandstone and some intercalations of coal (Bahārfirouzi et al., 2002) Lithological characteristics of this unit is very similar to Shemshak Formation, and it can be regarded as a same formation in Rāmsar region. Based on the preliminary studies it seems that TR2-31, Sl and TRedl (Elika Formation) units are the reservoir rocks of this region. TR2-31, Sl composed of limestone and fossiliferous limy sand and TRedl includes dolomites and is equal of Elika Formation in this region, (Baharfirouzi et al., 2002), (Figure 8).

4.3. Damāvand geothermal region

This region is located in 75 km to the north east of Tehran. Possibly it is formed in the eastern flank of Damāvand volcano, figure 9. So far, several scientists have studied this region. Its area is around 200 km^2 and includes 6 warm springs. Some general information about those warm springs are illustrated in table 3. Their temperature varies from 29 to 63°C and their pH is slightly acidic to neutral. Among them, Lārijan spring is the most important warm spring in the region. As, it is formed very close to a young volcano, it is believed that Damāvand region's heat maintained by cooling of magma body under the Damāvand volcano. Also, in this region Shemshak Formation is widely outcropped especially in the north, northeast, central and southern parts of it, (Nouraliee and Talebi, 2007).

In Damāvand region, Shemshak Formation composed of alternation of silty shale, sandstone, coal bearing clays and greywacke (Alenbāch, et al., 1976). Therefore, it can be the caprock of Damāvand geothermal reservoir.

Evaluation of lithological units in this region reveals that probably Elika Formation can be the geothermal reservoir rock. This formation belongs to Triassic and consisted of dolomite and limy dolomite, (Allenbāch et al, 1997). According to the geothermometry studies, approximate temperature of Damāvand geothermal reservoir is between 130 to 170 °C, (Nouraliee and Talebi, 2007).

Table 3. Some information about warm springs in Damāvand geothermal region

No.	Name	Latitude	Longitude	Elevation (mabsl)	Temp. °C	pH	Flowrate (l/s)
1	Askāb	35-52-06	52-09-35	1787	29	6.5	5
2	Zagh Cheshmeh	35-52-11	52-09-23	1715	29	6.5	0.5
3	Ābe Gholghol	35-52-11	52-09-13	1702	24	6	1
4	Bālā Harāz	35-52-05	52-09-11	1690	25	6.5	1
5	Lārijān	35-54-20	52-11-34	1760	63	7.5	37
6	Strābāku (Qalābon)	35-58-49	52-16-34	1768	32	6.5	28.3

4.4. Mahallāt geothermal region

This geothermal region is located in 7.5 km to the northeast of Mahallāt city, Figure 10. The main surface manifestations of geothermal energy in this region are 6 warm springs and widespread outcrops of travertine deposits. The temperature of warm springs are 34 to 47 °C. Their pH is slightly acidic and varies from 6.54 to 6.87, (Nouraliee, 2012). In table 4, some information about Mahallāt region warm springs are illustrated. Based on the available geological map it is revealed that probably heat source of this geothermal reservoir is radioactive decay of granites which are outcropped in some distances from warm springs. As it can be seen in figure 10 Shemshak Formation is outcropped in a considerable part of the Mahallāt region.

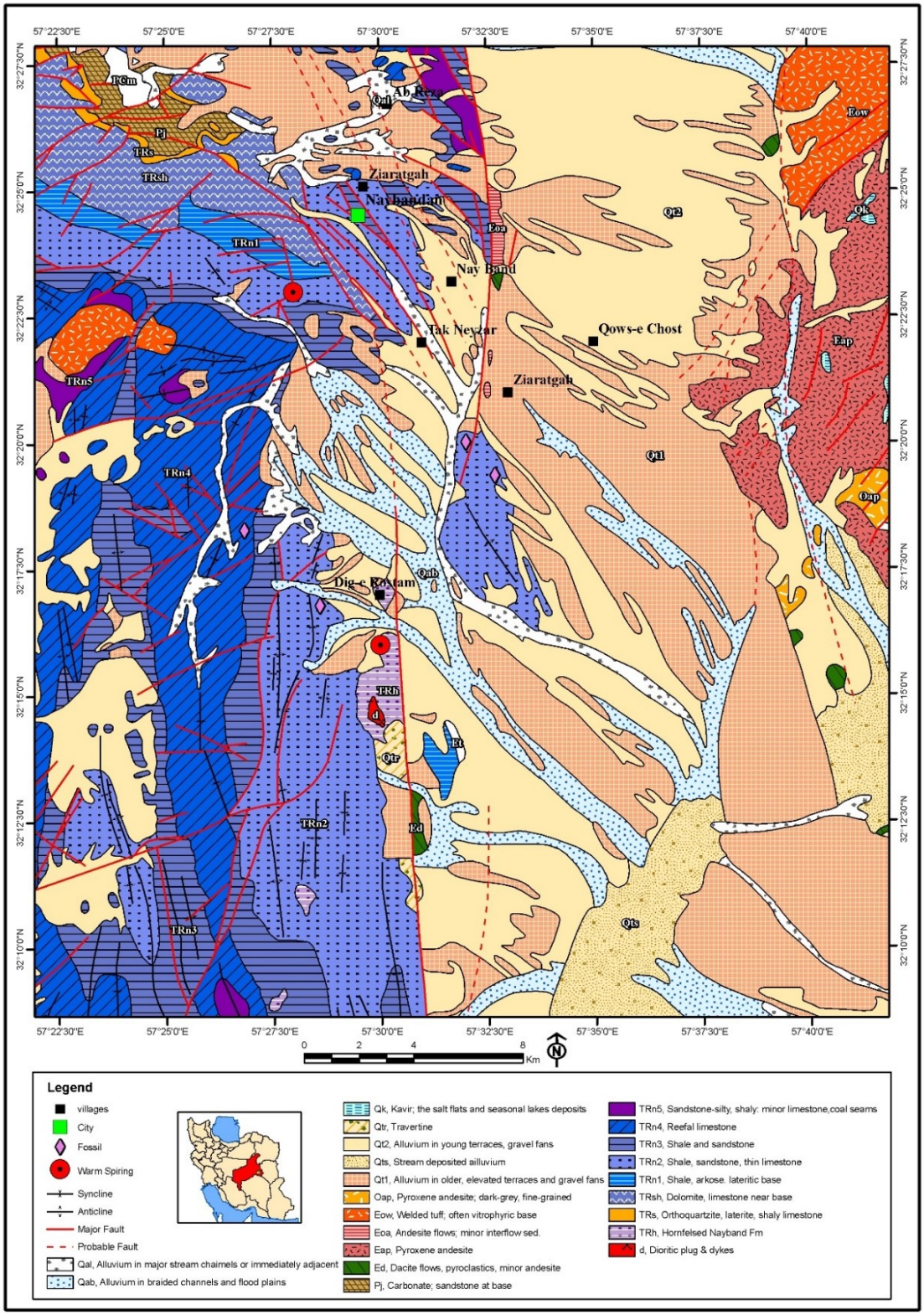


Figure 7. Geological map of Nāyband geothermal region (Based on 100k Nāybandān Geological map, Chance et al., 1980)

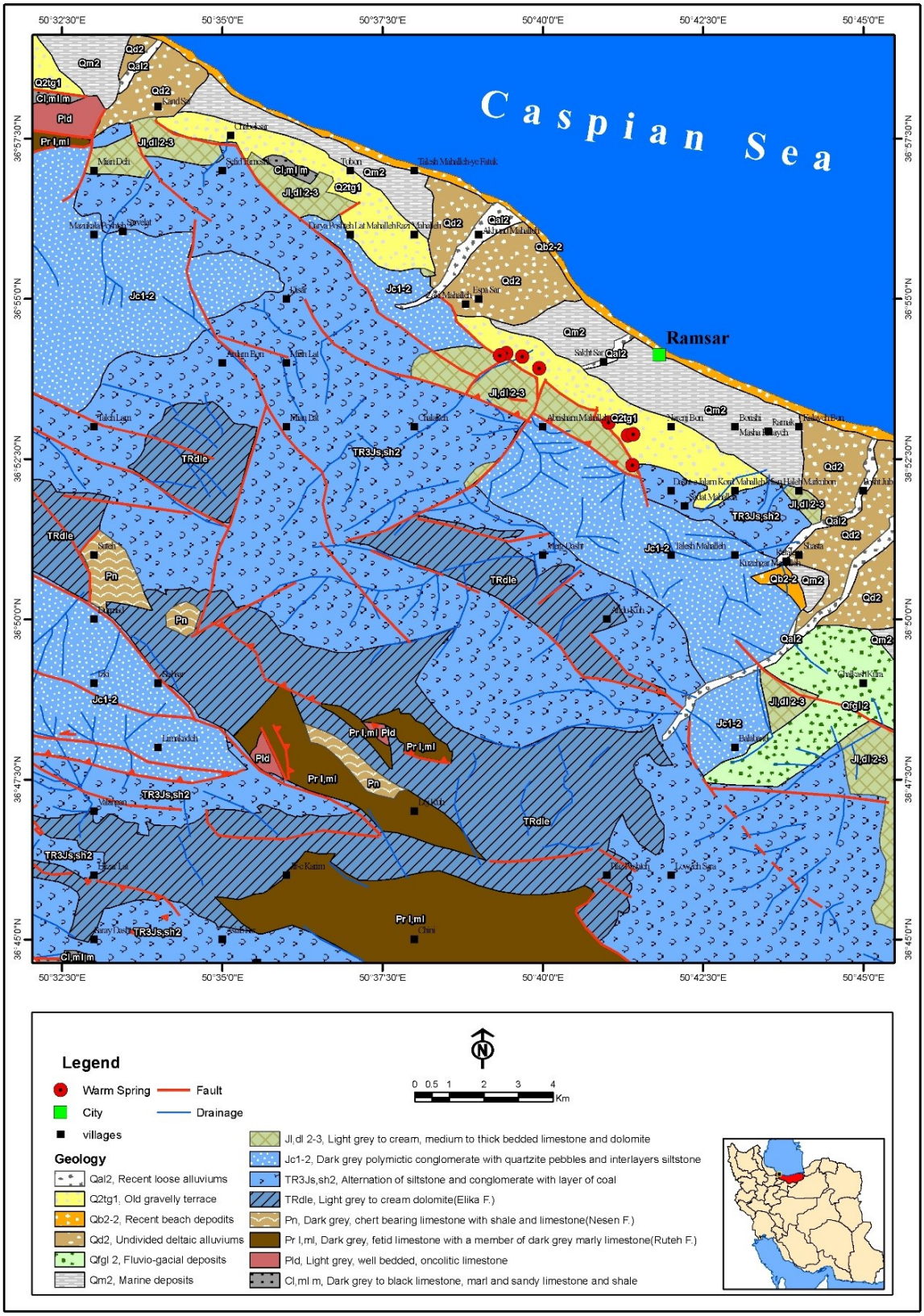


Figure 8. Geological map of Rāmsar geothermal region (Based on Rāmsar 100K Geological Map, Baharfirouzi et al, 2002)

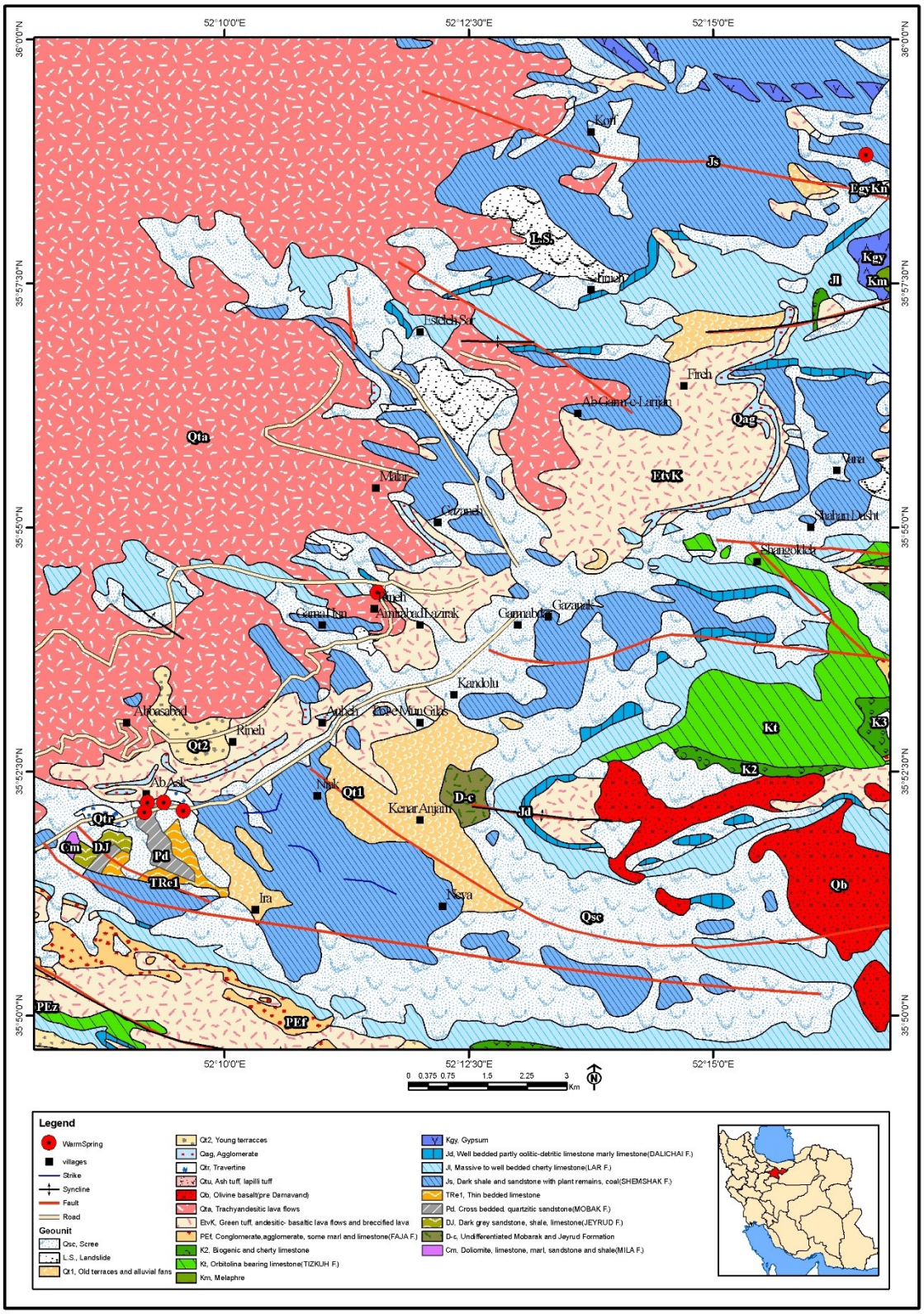


Figure 9. Geological map of Damāvand geothermal region (Based on Damāvand 100K Geological Map, Allenbach et al., 1997)

Table 3. Some information about warm springs in Damāvand geothermal region

No.	Name	Latitude	Longitude	Elevation (mabsl)	Temp. °C	pH	Flowrate (l/s)
1	Askāb	35-52-06	52-09-35	1787	29	6.5	5
2	Zagh Cheshmeh	35-52-11	52-09-23	1715	29	6.5	0.5
3	Ābe Gholghol	35-52-11	52-09-13	1702	24	6	1
4	Bālā Harāz	35-52-05	52-09-11	1690	25	6.5	1
5	Lārijān	35-54-20	52-11-34	1760	63	7.5	37
6	Strābāku (Qalābon)	35-58-49	52-16-34	1768	32	6.5	28.3

Table 4. Location and some general data about warm springs in Mahallāt geothermal region

No.	Name	UTMx	UTMy	Elevation (mabsl)	Temp. °C	pH	Flowrate (l/s)
1	Ābedonbeh	459031	3763453	1848	47	6.54	1.45
2	Ābe solymanieh	459201	3763341	1826	46	6.55	2
3	Ābesoda	459560	3762953	1737	45	6.54	23
4	Ābehakim	458919	3762289	1753	34	6.87	6
5	Sarbāz	458261	3762957	1875	42	6.8	4
6	Shafā	458344	3762921	1870	47	6.61	8

5. Conclusions

Implementation of some geothermal exploration projects in different parts of Iran revealed that Shemshak Formation is determined in some of geothermal prospects. Due to its characteristics and extensive outcrops it is believed that this Formation can be the cap rock of geothermal reservoirs in the northern, central and eastern regions of Iran. The main reasons for this idea is its lithology, thickness and also low thermal conductivity. This Formation in its type section is composed of four main sections which all of them contain a lot of shale layers. It is also contain many siltstone and fine-grained sandstone and clay layers as well. Shemshak Formation's thickness is 1027 m in its type section but in some other places it is thicker than that. Besides, naturally, shale layers have also low thermal conductivity that do not allow to heat conduct to the upper parts of the geothermal reservoir. Therefore if there exist suitable situations for forming of a geothermal reservoir this Formation could be a good sign for exploring unknown geothermal prospects in Iran. For example, if in a given region there is a granite intrusive body, an active fault and sufficient volume of rain water and Shemshak Formation, it is possible to form a geothermal resource even if there are not any surface manifestations. Hence, regarding these conditions Shemshak Formation can be a possible indicator of blind geothermal systems in Iran too.

At least there are four geothermal regions in Iran including Nāyband, Rāmsar, Damāvand and Mahallāt regions which is believed that probably their cap rock is Shemshak Formation. These regions have different geological conditions but the same cap rock. Possibly, there might be more geothermal reservoirs which have been protected by Shemshak Formation in Iran that have not been identified and studied yet.

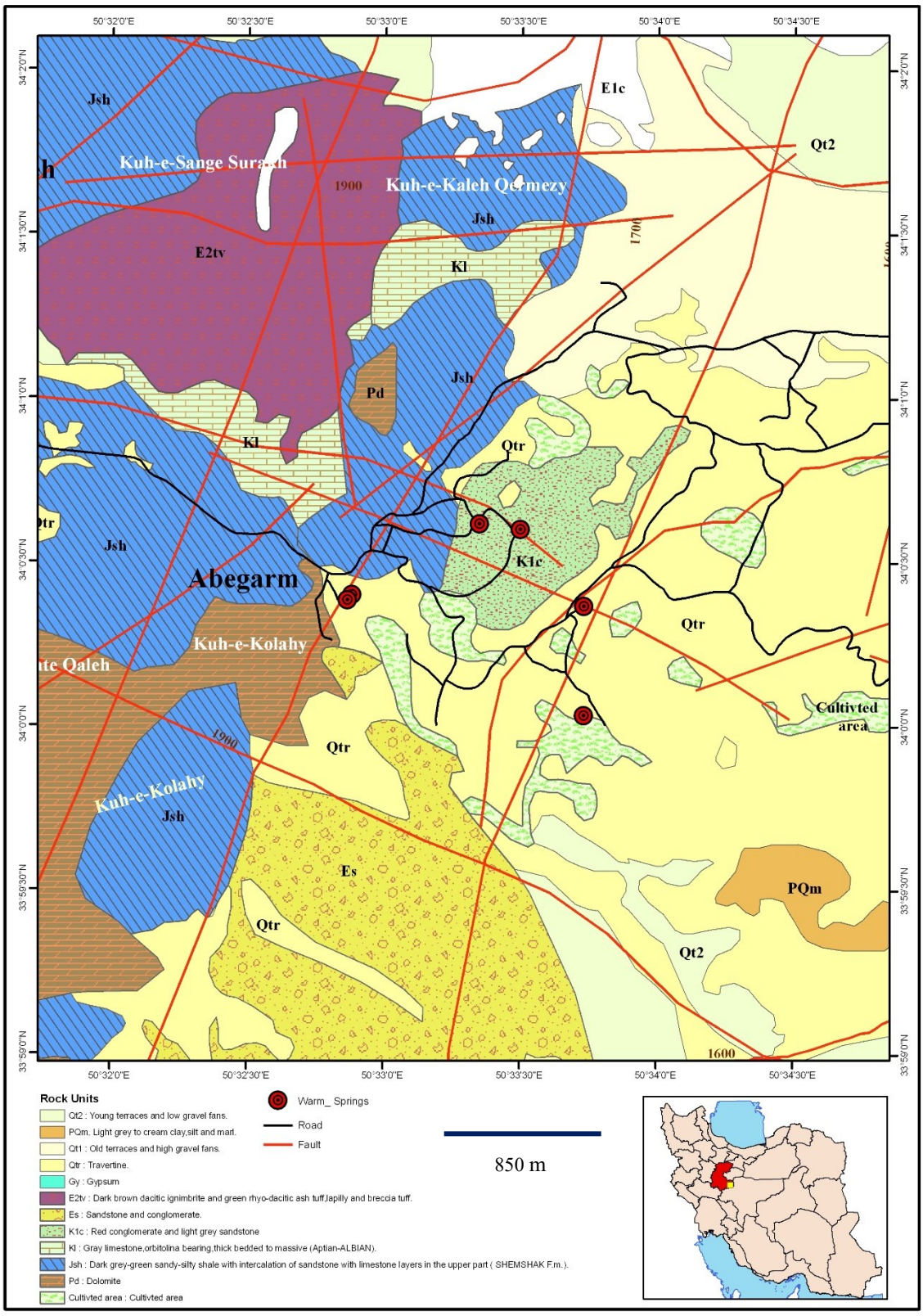


Figure 10. Geological map of Mahāllāt geothermal region

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