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Investigation on Hydrothermally Altered Rocks in Salmās Geothermal Region, NW- Iran

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ABSTRACT

Salmās region has 145 km^2 area and is located in the Southeast of Salmās city in the Northwestern part of Iran. Based on the classification of Iran Techtono- sedimentary zones, this region is positioned in metamorphic- Ophiolithic belt of Sanandaj-Sirjan zone. Due to the presence of 8 warm springs (with temperature range from 27-40 °C) in this region, it is believed that there is a geothermal reservoir in deeper part of it. Geologically, this region is composed of metamorphic rocks (with unknown age), Ruteh formation (dolomite), conglomerate, and ophiolitic complex and Qushchi granite. Zindasht (with nearly E-W strike) and Tamar-shurgol (with nearly N-S strike) strike-slip faults are the most important faults of Salmās region. In order to study on geothermal potential of prospect region, its altered rocks were investigated. In this region by using ASTER satellite images, sampling of altered rocks and analyzing the samples with microscope and XRD method it is found that there are four types of hydrothermal alteration. They are including argillic, propylitic, silicic and Fe-oxide alterations. Using altered rocks (especially argillic ones) and other available data such as gravity survey results, travertine outcrops, warm spring location and faults map, it is revealed that an area between Kanisefid and Shurgol villages has a proper potential of geothermal energy in Salmās region. This area is located in the west side of central part of Salmās region. There is not any outcrop of young volcanic rocks in the study region so it is believed that Salmas geothermal region is a low –temperature geothermal resource.

1. INTRODUCTION

In order to generating of updated geothermal map of Iran, Niroo Research Institute (NRI) has implemented a reconnaissance survey in the west Azarbaijan province to identify geothermal prospects. Salmās region is one of the determined prospects in that province. This region is located 11 km to the southeast of Salmās city and has 145 km^2 area, figure 1. The most significant geothermal surface manifestations are warm springs, many travertine outcrops and several altered areas. During the past 5 years some detailed exploration studies have been conducted in Salmās region. They include geological, geochemical and gravity studies. In geological investigations a very detailed study on altered areas was done whose results will be presented later. Finally based on the results of all scientific studies a suitable area was identified for further exploration activities.

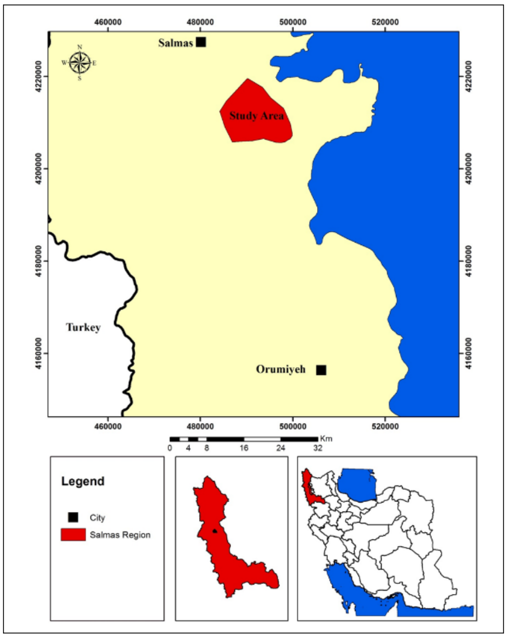

Figure 1. Location of Salmās region in west Azarbaijan Province

2. GEOLOGY

According to the tectonostratigraphic zones of Iran, Salmās region is located in the metamorphic and Ophiolitic belt of Sanandaj-Sirjān zone, (Stoklin, 1968). In fact, this zone is a part of central Iran zone which has certain characteristics. This very long zone is composed of metamorphic rocks which is parallel to Zagros trust. It is located between Sanandaj city in the northwest and Sirjān city in the southeast. This zone is called by some other names such as Orumiyeh-Esfandagheh (Takin, 1971) and inner Zagros (Stoklin, 1968). Geological map of Salmās region is shown in the figure 2. Lithologically, Salmās region is composed of the following lithostratigraphic units (from older to younger) (Khodabandeh et al., 2002):

- **Metamorphosed rocks group** with unknown age including Mtar, Mtam, Mtr and Mtmt units. It is a group of volcanosedimentary rocks and intrusive rocks including metamorphosed granite and diorite with unknown age which are outcropped in the southern half of the region. In some parts of the region its upper border is a trust fault that is covered by Permian carbonate sediments. This group has been formed in Precambrian-Paleozoic. The main rocks of this group are metavolcanics, metabasalt, schist, amphibolite, gneiss and marble, metadiorite and crystallized limestone.
- **Routeh Formation** (Prd) which is composed of dolomite, dolomitic limestone and limestone. It is belonged to Permian.
- **Basal conglomerate** (Mc) that is consisted of thick bedded conglomerate with some intercalations of shale and sandstone. Its thickness is several meters and belongs to the lower Miocene. This unit covers older units with angular unconformity.
- **Thick bedded conglomerate** (Plc). It has several hundred meters thickness and covers Miocene units with angular unconformity.
- **Ophiolitic complex**. This complex is composed of green schist facies metamorphosed igneous and sedimentary rocks. It is mainly includes ultrabasic rocks such as serpentinite, basic igneous rocks such as gabbro, diabase and basalt, intermediate igneous rocks like diorite, andesite and metamorphed rocks such as greenschist, amphibolite with sedimentary rocks such as radiolaritic chert and plagic limestone.
- **Intrusive rocks** (Mtd, Mtgr and grgh): Mtd unit is consisted of slightly metamorphed diorite. Mtgr unit includes metamorphed granite and grgh unit which is the famous Qushchi granite. This granite is vastly outcropped in the southeast of the Salmās region. It is like a large batholite which has metamorphed adjacent rocks. According to the radioactive age dating this granite has been formed in 252 million years ago or late Permian, (Shahābi, 2012).

Geometrically and geographically, major faults of Salmās region divided into two groups, N-S and NW-SE trending faults. In the intersection point of both fault groups, an area of fractured rocks has been formed, figure 2. The main faults of the region are as follows (Khodabandeh et al., 2002):

- **NF1 fault**
  This fault has an important role in the formation of Istisu warm springs. Its length is around 5 km and filed studies show that it is nearly vertical. NF1 is a sinistral fault.
- **WS1 fault**
  It has east-west strike and is located in the south of Istisu warm springs. This fault is cut by NF1 fault. It is a trust fault which has 50- 60° dip to the north. In fact, WF1 fault isn't like a single fault and includes several parallel fractures. Its crushed zone has about 10 meters width.
- **Thamar-Shurgol fault**
  This fault has an important role in the structural situation of Salmās geothermal region. It separates colored mélange and metamorphed units in the region. Meanwhile, in both side of the faults there are fundamental differences in the lithological characteristics. It has an area of fractured rocks and east-west strike.
- **Zindasht fault**
  It is an important major fault in Salmās region too. It is a dextral fault and its plain has 80° dip to the southwest. This fault and its minor fractures passes from Istisu warm springs. Also, there are several cold springs along this fault. The same as WS1 fault, Zindasht fault isn't a single fault and includes an area of many fractures and minor faults.

3. SURFACE GEOTHERMAL MANIFESTATIONS

The most obvious expression of a geothermal reservoir occurs when fluids leak to the surface along faults and fissures or through permeable rock units. Depending on the reservoir temperatures and discharge rates, these surface manifestations take the form of seeps, fumaroles, hot springs, boiling springs, geysers, phreatic explosion craters, and zones of acid alteration. In addition, there are deposits of silica sinter, travertine, and/or the bedded breccias that surround phreatic craters (Wohletz and Heiken, 1992). Surface geothermal activity is of direct interest to earth scientists, since it provides clues to understanding the nature of the resource and the physical and chemical processes taking place (Lienau and lunis, 1998; Watson, 2017).
In Salmās region, there are some surface manifestations of geothermal resources which are briefly described in this part of the paper. They are as follows:

3.1. Warm springs

There are 8 warm springs in two different and separate points of Salmās region, figure 2. Their temperature varies from 28 to 41 degrees Celsius. More data about them are illustrated in table1. Istisu and Shurgol warm springs are located in the eastern and western parts of the Salmās region respectively.

3.2. Travertine deposits

Travertine deposits are outcropped in southeast, center, east parts of the Salmās region. Major faults and other structural features control the formation of travertine deposits in this region, figure 2.

3.3. Altered areas

There are some altered areas in Salmās region which can be seen in different parts of the region. These areas will be described completely in the next part of the paper.

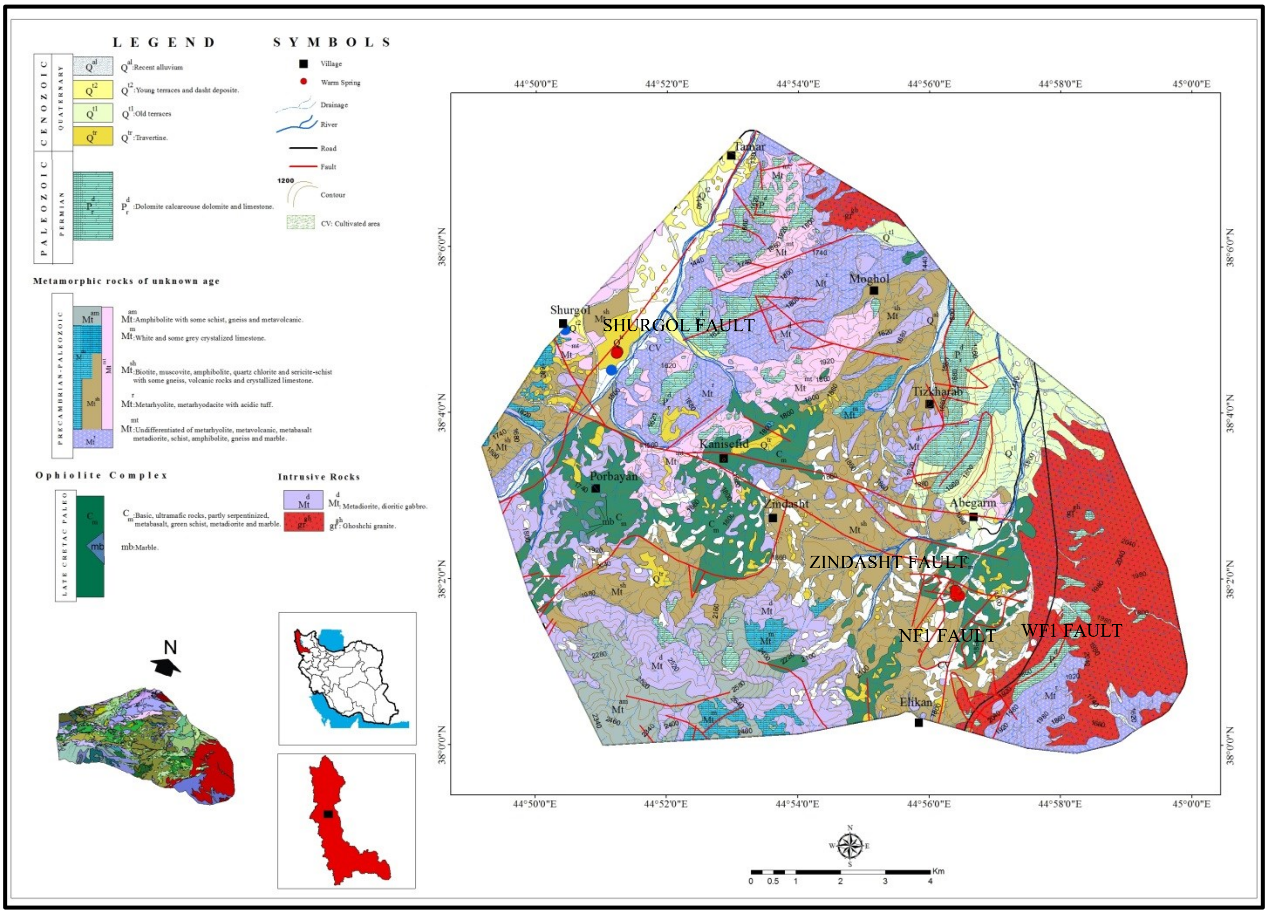

Table 1. General information about Salmās region warm springs

Name	Longitude	Latitude	EC (µS/cm)	Temperature (°C)	Flowrate (l/s)
Istisu-1	44-56-25	38-01-51	1693	40	0.25
Istisu-2	44-56-25	38-01-51	1693	41.6	0.25
Istisu-3	44-56-25	38-01-51	1694	36	0.25
Istisu-4	44-56-26	38-01-50	1696	34	0.25
Istisu-5	44-56-25	38-01-50	1710	37	0.25
Istisu-6	44-56-25	38-01-51	1660	39	0.25
Shurgol-1	44-51-14	38-04-42	2100	27	1
Shurgol-2	44-51-14	38-04-42	1927	28	4

4. HYDROTHEML ALTERED AREAS

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 and 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. In the other hand, hydrothermal alteration changes the compositions of both fluid and rock, including the physical properties of rocks, such as their porosity, magnetism, density and resistivity. Hydrothermal alteration minerals including clay minerals are observed widely in geothermal systems, both in active and fossil geothermal systems (Cathelineau and Nivea, 1985; Harvey and Browne, 1991; Teklemariam et al., 1996; Pandarinath et al., 2008; Marfil and Maiza, 2012; Alacali and Savascin, 2015). By studying of the geology and alteration minerals of a given geothermal system it will be possible to deduce its thermal history. For example, study on the surface geology and alteration provide evidence that thermal activity at a geothermal region in New Zealand has been long lived, possibly as long at 120 000 years. (Bignal and

Browne, 1994). The main factors controlling hydrothermal alteration are temperature, pressure, rock type, permeability, fluid composition and event duration (Browne, 1978; Robb, 2005; Mayer, 2016). 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. (Wohletz and Heiken, 1992). Characterization of hydrothermal alteration can be invaluable in the search for and definition of a geothermal field. Broad scale alteration zoning can help focus exploration or development efforts in the overall hottest and potentially most permeable portions of a field. Local alteration zoning patterns within these favorable areas can help locate thermal fluid entries and in some cases may allow detection of these entries prior to their penetration by drilling. For example in the Broadlands-Ohaki geothermal fields, New Zealand, fluid entry zones are characterized by abundant adularia (Brown, 1971). The distribution of hydrothermal alteration phases relative to present temperatures also can provide insight into the history of a geothermal system. (Hulen and Nielson, 1986).

In order to study on the altered areas in the Salmās region we used ETM[1] and ASTER[2] satellite images. So, by using remote sensing techniques, altered rocks were identified. For field check, some rock samples were taken from the region and samples have been studied by polarizing microscope and XRD analysis method. According to the conducted studies and altered mineral assemblages, four types of hydrothermal alteration were found in Salmās region including argillic, propylithic, silicic and Fe-oxide altered areas. In the following altered areas in Salmās region will be introduced.

4.1. Argillic alteration

Argillic alteration is one of the hydrothermal alteration types. In argillic alteration, hydrothermal fluids change primary minerals to clay minerals in lower temperatures. This alteration occurs when the underground water's pH decreases and tends acidic (Guilbert and Park, 1986). Kaolinite and Smectite group minerals are the common minerals in argillic alteration (Heald et al., 1987). Argillic areas in Salmās region have been recognized around Tamar, Moghol and Zindasht villages, in the east of Ābegarm and Alikān villages, in the south of Porbayān village and in the northwest of Kānisefid village, figure (3-a). Study on the argillic areas revealed that those areas which are formed around Tamar, Moghol, Kānisefid and Porbayān villages are affected by a certain structural alignment.

4.2. **Propylithic alteration**

Propylitic alteration turns rocks green, because the new minerals formed are green. These minerals include chlorite, actinolite and epidote. They usually form from the decomposition of Fe-Mg-bearing minerals, such as biotite, amphibole or pyroxene, although they can also replace feldspar. Propylitic alteration occurs at high temperatures. This type of alteration will generally form in a distal setting relative to other alteration types. Presence of chlorite and epidote indicate temperatures of 220-340ºC and appearance of actinolite-tremolite occurs at 280-350ºC (Lagat, 2009).

In Salmās region, Propylithic altered rocks are determined in the following localities: In the north of Zindasht village with NE-SW alignment, in the south of Zindasht village with NW-SE alignment and in the southwest of Shurgol village with NE-SW alignment, Figure, (3-b).

4.3. **Silicic alteration**

Silication or Silicic alteration is a general term for the addition of silica by forming any type of silicate mineral. These are commonly formed in association with quartz. Examples include the formation of biotite or garnet or tourmaline. Silication can occur over a wide range of temperatures. The classic example is the replacement of limestone (calcium carbonate) by silicate minerals forming a "skarn", which usually form at the contact of igneous intrusions (Lagat, 2009). Silicic altered rocks have been recognized in two areas in the region, Figure, (3-c). They are located in the east of Ābegarm village and also as a belt from northeast to the west of the region. They have been formed in Mtr, grgh, Mtmt, Prd and Mtd lithological units.

4.4. **Fe-oxide (Oxidation) alteration**

Oxidation is simply the formation of any type of oxide mineral. The most common ones to form are haematite and limonite (iron oxides), but many different types can form, depending on the metals, which are present. Sulfide minerals often weather easily because they are susceptible to oxidation and replacement by iron oxides. Oxides form most easily in the surface or near surface environment, where oxygen from the atmosphere is more readily available. The temperature range for oxidation is variable. It can occur at surface or atmospheric conditions, or it can occur as a result of having low to moderate fluid temperatures (Lagat, 2009). In Salmās region, Fe-oxide altered rocks are identified by determination of hematite, limonite and goethite minerals in the region, figure (3-d). As it is shown, the most significant Fe-oxide altered rocks are located in Mtam unit in the southwest of the region. In the south and around Alikan in Mtsh unit, there is some signs of Fe-oxide alteration. Also in the northeast of Zindasht village some Fe-oxide altered rocks can be seen in Mtsh rock unit. In the north of the Salmās region, there are two belts of Fe-oxide altered rocks. One of them is elongated from northeast to the center of the region and is formed in Mtr unit. Another area is located in the west of the region in Mtr unit and is elongated from center to the southwest of Salmās region.

5. Comparison of altered areas and other available data

As it is mentioned earlier, some altered areas may represent fossil geothermal systems. So in order to avoiding inactive geothermal resources we studied all altered areas regarding other geothermal surface manifestations, geological structures and available

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[1] Enhanced Thematic Mapper (TEM)

[2] Advanced Spaceborn Thermal mission and reflection radiometer (ASTER)

geophysical data as well. Actually, we did this job to find those altered areas which are directly related to an active geothermal system in the study area. Therefore, in this part of the paper, altered areas in Salmās region will be studied regarding other available data, including warm springs, travertine deposits, faults and gravity data.

5.1. Altered areas and warm springs

There are 8 warm springs in Salmās region which are located in two separated spots that are in the east and the west of the region. Actually, there are 6 warm springs in the southwest of Ābegarm village and two warm springs in the southeast of Shurgol village, figure (4-a). There are not any altered rocks around eastern warm springs, at least for a circle around warm spring whose diameter is 1200 m. It is believed that the following reasons are responsible for not forming altered minerals around warm springs.

- Self-sealing: Ascending geothermal fluid affected adjacent rocks and accumulated altered minerals can fill the flow path.
- Single fault/fracture: Fault or Fracture which allow geothermal fluid to flow to the surface doesn’t have any network of smaller fractures. In other words, the fault just created warm springs at the surface.
- Salmās geothermal resource's cap rock properly protects the reservoir in this part of the Salmās region and doesn’t allow the hot fluid to reach the surface.

  However, the western warm springs have Fe-oxide (Hematite) altered rocks which are formed along NE-SW direction. No doubt, this task shows dual effects of the faults in the formation of both warm springs and altered rocks in this part of Salmās region.

5.2. Altered rocks and Travertine deposits

Remote sensing investigations and field studies reveled that in the five parts of Salmās region altered rocks and travertine deposits are formed in the same places. They include in the south of Shurgol, northwest of Kānisefid, west of Tizkharāb, southeast of Porbayān and the northwest and the northeast of Alikān villages, figure, (4-b).

5.3. Altered rocks and Faults

In figure (4-c), altered rocks and major faults in Salmās region are shown. As it can be seen in the figure, in the south of Shurgol village, there is an area of altered rocks which is parallel to Shurgol fault. This area is elongated in the NE-SW direction. In the west of Kanisefid village, Zindasht fault divided into two parts, the northern and the southern ones. There are some altered rocks between them. In the east of Tamar-Shurgol and the north of Zindasht fault, there are some altered rocks in a relatively extensive areas. In the vicinity of these altered rocks there are some major faults which mainly have NE-SW and NW-SE strikes. It seems that there is a logic relationship between the faults and altered rocks.

In the southwest of Zindasht village, there is an altered area which relates to a major fault. In the northeast, north and northwest of Alikān village, there are three major faults which have N-S strike and altered areas near them. In the west of the village, there is a major fault which has E-W strike and also an altered area is formed over there. Both of the fault and altered area have been formed in a same direction.

5.4. Altered rocks and gravity data

In 2012, Niroo Research Institute (NRI) conducted a gravity survey in Salmās region as a part of a geothermal exploration program. The gravity data were measured in 110 stations. Residual gravity anomaly map and altered areas in Salmās region are shown in Figure (4-d). As it is shown, there is a large area with negative gravity anomaly between Zindasht and Kānisefid villages from the east and Shurgol village in the west of Salmās region. Due to the lack of gravity data, thr southern border of gravity anomaly isn’t very clear. This extensive anomaly can be related to the activity of a geothermal resource. The main reasons for this theory are as follows:

- There is an altered area between Kānisefid and Shurgol villages which is completely concise with negative gravity anomaly.
- In the south of Zindasht village and also in the south and west of Kānisefid village, there are some travertine outcrops that are superimposed to the negative anomaly area.
- Precisely, Shurgol warm springs are appeared in the northwestern border of negative anomaly area.

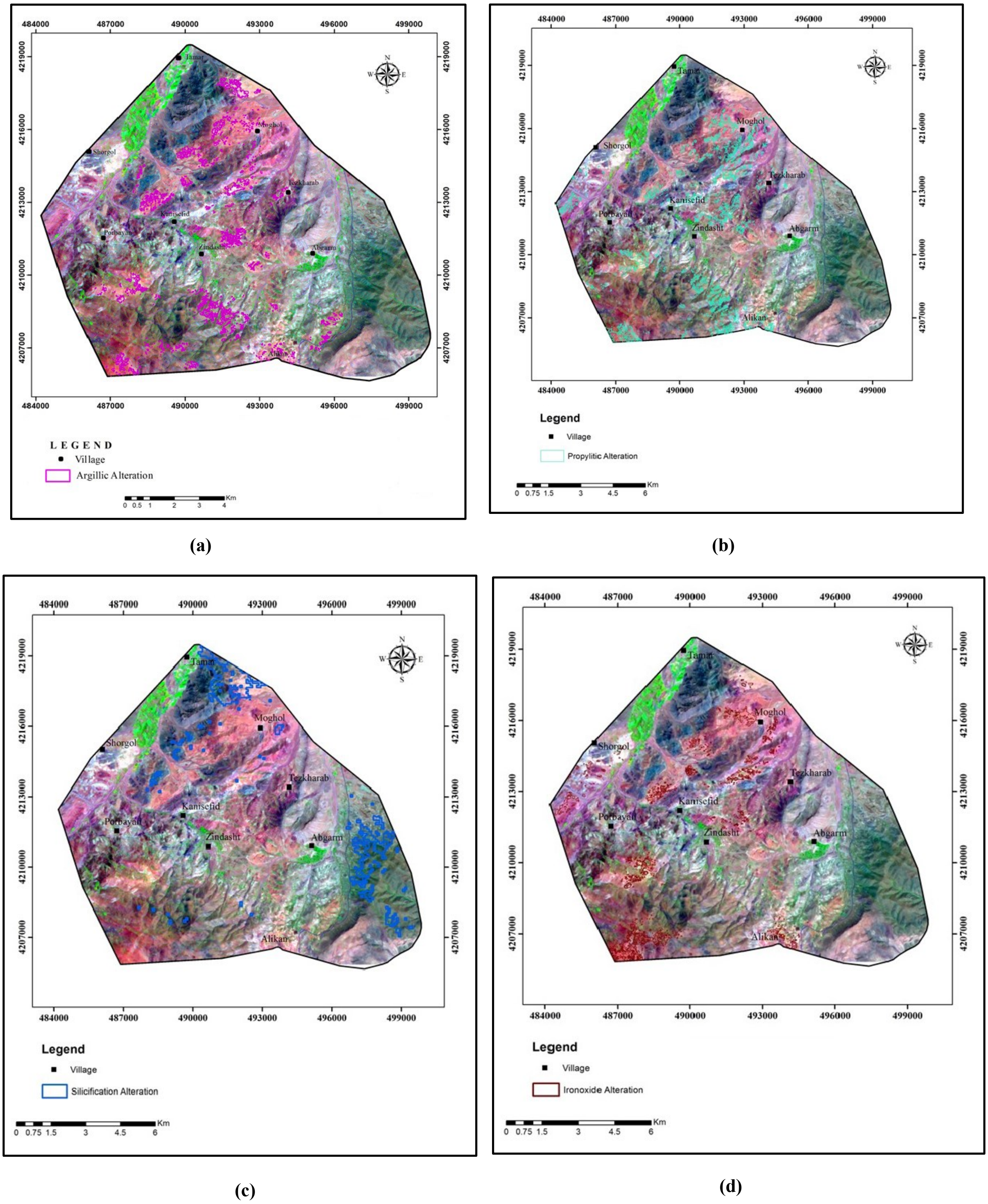
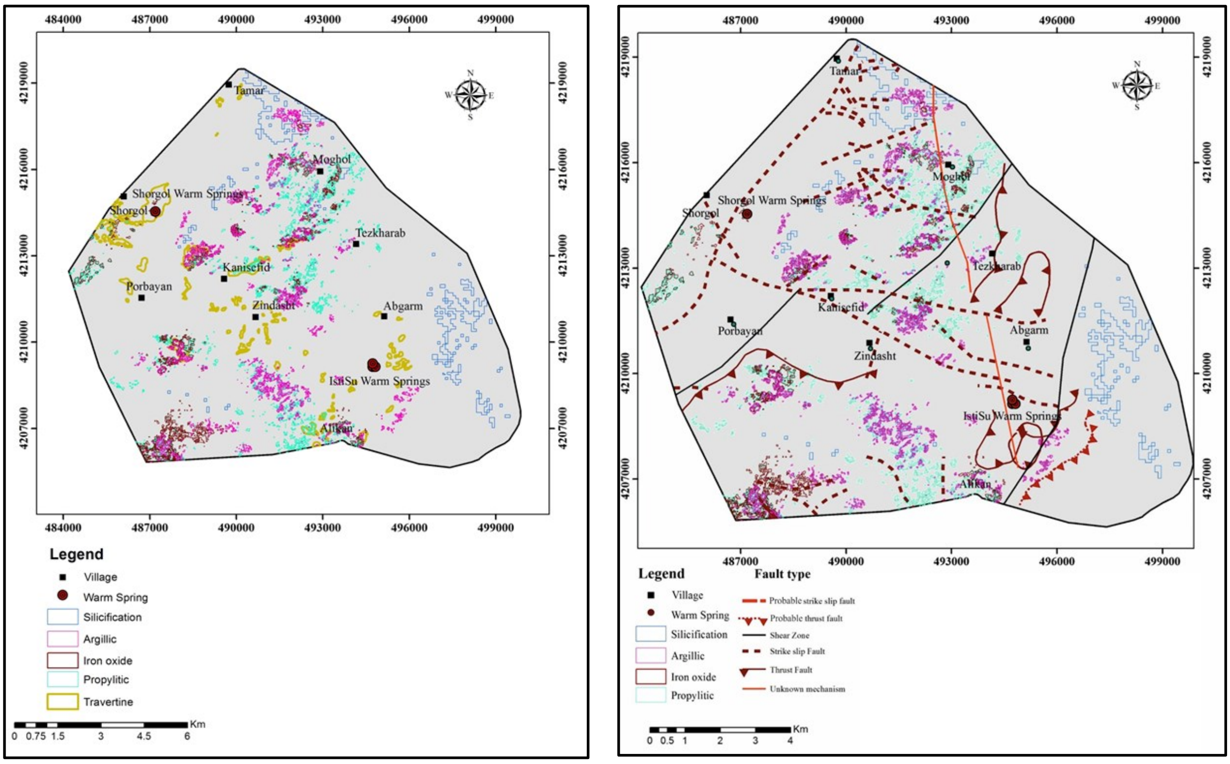


Figure 3. Hydrothermally altered areas in Salmās geothermal region. (a) Argillic altered rocks (b) Propylitic altered rocks (C) Silicic altered rocks (d) Fe-oxide altered rocks



(A) (B)

Figure 4. (A) Comparison of hydrothermally altered areas with travertine deposits and warm springs in Salmās geothermal region. (B) Comparison of hydrothermally altered areas with the main faults in Salmās region

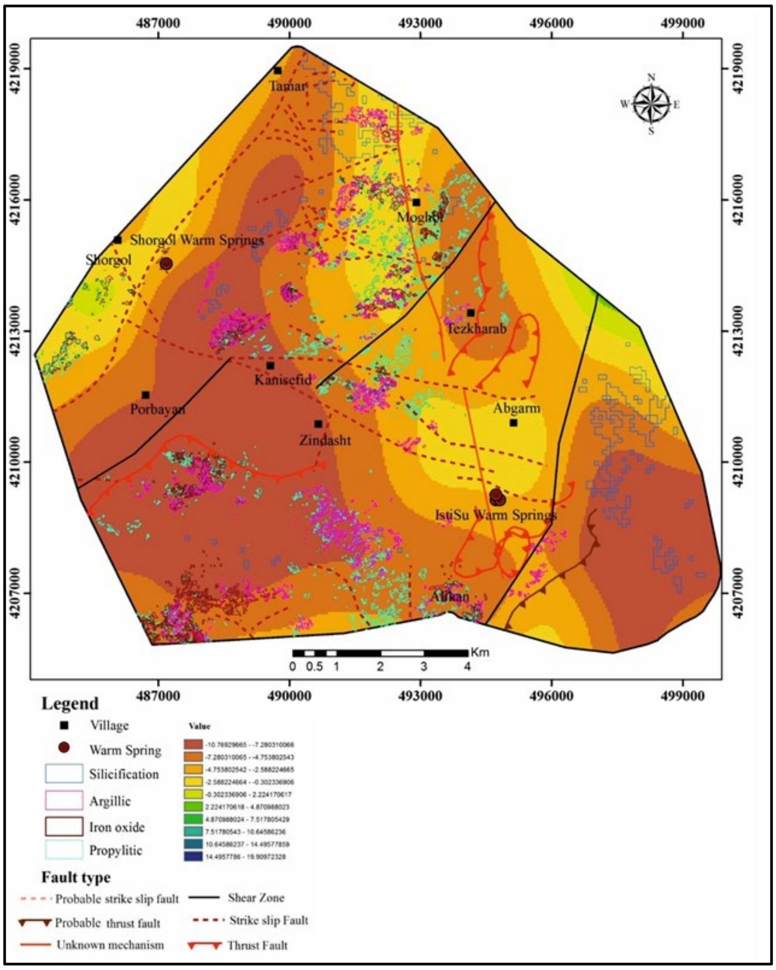


Figure 5. Comparison of hydrothermally altered areas with the gravity data in Salmās geothermal region

6. Conclusions and Recommendations

Due to the presence of some geothermal surface manifestations such as warm springs, travertine deposits and altered areas it is found that there is a geothermal resource in Salmās region in the west Azarbaijan province of Iran. As an exploration program, a detailed geological map of the region was generated. Also, altered areas in Salmās region were studied in detail. By using of ETM and ASTER satellite images, four altered areas including argillic, propylithic, silicic and Fe-oxide altered areas were recognized in this region. In order to evaluate the remote sensing results about hydrothermally altered areas in Salmās region, during the field check, some rock samples were picked up from it. In many cases, hydrothermal altered minerals were determined in the samples. In the next step, altered areas were studied and compared with the location of warm springs, travertine outcrops, major faults and available gravity data. Finally, based on the results of the present research it is revealed that an area between Shurgol and Kānisefid villages has a reasonable geothermal energy potential. This prospect is located in the northwest of central part of the Salmās region. Indeed, it is very probable that there is a geothermal resource in this part of Salmās region. There is not any outcrop of young volcanic rock in the study region so it is believed that Salmās geothermal region is a low –temperature geothermal resource.

In order to get more information about the nature of the Salmās geothermal resource, it is strongly recommended to conduct the following studies: Detailed geochemical investigations, geophysical surveys including detailed gravity surveys (with more denser grid), electromagnetic method (MT) and thermal surveying. Implementation of these exploration methods will be very useful to find chemical characteristics of the reservoir, subsurface structural features, distribution of electrical resistivity and temperature in the deep parts of Salmās region and consequently it would possible to construct the first detailed conceptual model of the geothermal system in Salmās region.

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