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Geological Classification of Proposed Geothermal Areas of Iran

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ABSTRACT

A geology-based classification of geothermal resources can significantly help required exploration and utilization strategies and overall management of the geothermal fields/projects. Although Iran owes its high geothermal potential to its special geological characteristics and active volcanic-tectonic nature, but none of geothermal prospecting studies consider geological environments and features of the proposed geothermal areas. The eighteen previously introduced geothermal areas of Iran are situated in different sedimentary basins and tectonic zones. By comparing the general but remarkable geological signatures of each structural zone and by applying the most important geological parameters, including geological environments, geological features, crustal heat source, resource category and rock type, a geology-based classification of geothermal areas is proposed. In this scheme, the geothermal areas can be categorized based on their geological features into at least five groups; a) Quaternary Volcanoes-associated geothermal prospects, including Sabalan, Sahand, Khoy-Maku, Taftan-Bazman areas/volcanoes all belonging to the UDMA. b) Quaternary Volcanics-Major Faults- associated geothermal prospects, including Damavand, Ferdows, Tabas, Takab-Bijar, Kashmar areas that except Damavand area that is Quaternary volcano in Alborz zone and formed in an transformational regiment and pull-apart basin, are all pertinent to the transformational tectonic regimen and their related young volcanism predominantly in Central Iran/Domain and Eastern Iran zones, c) Faults-associated geothermal prospects, including Khur-Biabanak, Avaj, Amol, Baft areas that except Amole, all the remained areas are located in the faulted and fractured regions in different tectonic zones zones, d) Thrust-Fold Belt-associate geothermal prospects, including Minab, Kazeroon, Lar-Bastak areas that are situated in the Zagros Fold Belt and tightly engaged with deep thrust faults, and e) Plutons-associated geothermal prospects, including Ramsar and Isfahan-Mahalat areas which have no relationship with young volcanism, but are relevant to local and regional buried intrusions. Thrust-Fold Belt-associate geothermal prospects are the only ones that geologically occurred in inter-plate environment, whereas all the other areas and classes belong to plate margin environment. In other scope, proposed geothermal prospects can be classified on the basis of nature and geological settings, where Quaternary Volcanoes-associated geothermal prospects, in addition to Damavand area from Quaternary Volcanics-Major Faults- associated geothermal prospects group are volcanic type of geothermal systems and are high-temperature resources, while Khur-Biabanak, Avaj, Amol, Minab, Kazeroon, Lar-Bastak, Ramsar and Isfahan-Mahalat, Kashmar areas are convective systems. Other areas, including Tabas, Ferdows, Takab-Bijar and Baft could be derived from a combination of both volcanic and convective geothermal systems.

1. INTRODUCTION

Iran is located in one of the most active volcanic-seismic belt in the world. There is a large number of geothermal manifestations in Iran created by several orogenic phases and various subordinate geological phenomena such as extensive young volcanism, active tectonic events and deep major faults. Wide variety of geothermal resources in Iran first appealed geologists and engineers in 1975 to explore and exploit Iran's geothermal resources within a cooperative program between the Ministry of Energy, Tehran-Boston Company and ENEL Company (Italy). It resulted in recognition of at least four areas in northern Iran, including Khoy-Maku, Mt. Sabalan, Mt. Sahand and Mt. Damavand (shaded areas of 1 to 4 in Fig. 1). During 1993 to 1996, EPRS (Electric Power Research Center) investigated these four main geothermal prospects in detail, and introduced Meshkinshahr as the most potential geothermal area in Iran (northwest Sabalan, area 1in Fig. 1). More extensive studies were also carried out by CRERA (Center of Renewable Energy Research and Application) in 1995-1996 and ultimately ten more promising areas were introduced and published in 1998 (solid line areas of 5 to 14 in Fig. 1) by SUNA (Renewable Energy Organization of Iran).

Since 1998, SUNA has put emphasis on detailed exploration of NW Sabalan geothermal prospect and in 2002 to 2004 three deep exploration and two shallow injection wells were drilled in the most prospective region; Moil Valley, south Meshkinshahr, northwest Mt. Sabalan. From 2007 to 2011, exploratory drilling continued and six extra production and injection wells were drilled. Within this period, detailed exploration and development studies such as geological mapping, sampling and analysis of all surface geothermal exposures, MT geophysical surveys, discharge tests, extensive logging operations, hydrological modeling of the area, and numerical modeling of the reservoir have been undertaken to acquire a precisely assessed reservoir. It can be claimed that the most up to date and serious geothermal activities in Iran is being performed by SUNA in NW Sabalan Geothermal Field which is ready to generate power in the coming years. Some minor geological studies on geothermal potential in Iran have been conducted by the Geological Survey of Iran (GSI), and a number of universities and institutions, aiming to achieve and develop geothermal technology in Iran.

Identification of geological setting of a geothermal system can be a critically important interpretive tool in evaluation, exploration, and assessment of geothermal resources. Regarding lack of a comprehensive and well-studied map of geothermal potential in Iran, this paper initially plans to review available maps and examine Iran's geothermal prospects, and define a primary geology-based classification of these prospects. The general geology of each tectonic zone and/or sedimentary basin is expected to be noticeably valuable to understand the main geological phenomena affecting every geothermal area. This would lead to a better understanding of geological identity and characteristics of every introduced geothermal prospect in Iran. The geological phenomena influencing occurrence of geothermal prospects and abnormal thermal gradients caused by volcanic terrains have been considered as criteria for geologically classifying the geothermal prospect. In addition, this purpose-based classification, as an essential primary step for providing geologists, geothermalists, engineers and managers with a valid applicable framework, would be a road map to prioritize the available geothermal resources. It is important to remember the wide diversity of characteristics, therefore detailed investigation by applying modern exploration techniques such as remote sensing, geochemistry, airborne geophysics, MT, etc is an inevitable preference for further development stages of a geothermal field.

2. BACKGROUND

The geothermal prospect map which was first published by ENEL (1975) and completed later by SUNA-CRERA (1998) was considered as the base map for initiation of all geothermal exploration activities in Iran (Fig. 1). Fotouhi et al., (2000) plotted hydrothermal ore deposits on the volcanic belt of Iran to show the identical origin of these underground resources in terms of hydrothermal fluids. Yousefi et al., (2007) utilized Geographic Information System (GSI) and applied the available digital data layers that are essential in determination of geothermal resources on the map. The layers include geological data set (volcanic rocks, volcanic craters and faults), geochemical data set (hot springs and acidic hydrothermal alteration zones), and geophysical data set (micro-seismic and shallow intrusive bodies). With the aim of minimizing human error in analyzing the data, they let GIS make decision on target potential so as to choose the most appropriate and promising sites as geothermal fields. Consequently, they updated Iran's geothermal potential map by specifying the exact area of 14 previously determined geothermal areas, as well as introducing 4 new geothermal potential, including Avaj, Amol, Kashmar, and Baft (dotted line areas of 15-18 respectively, Fig. 1).

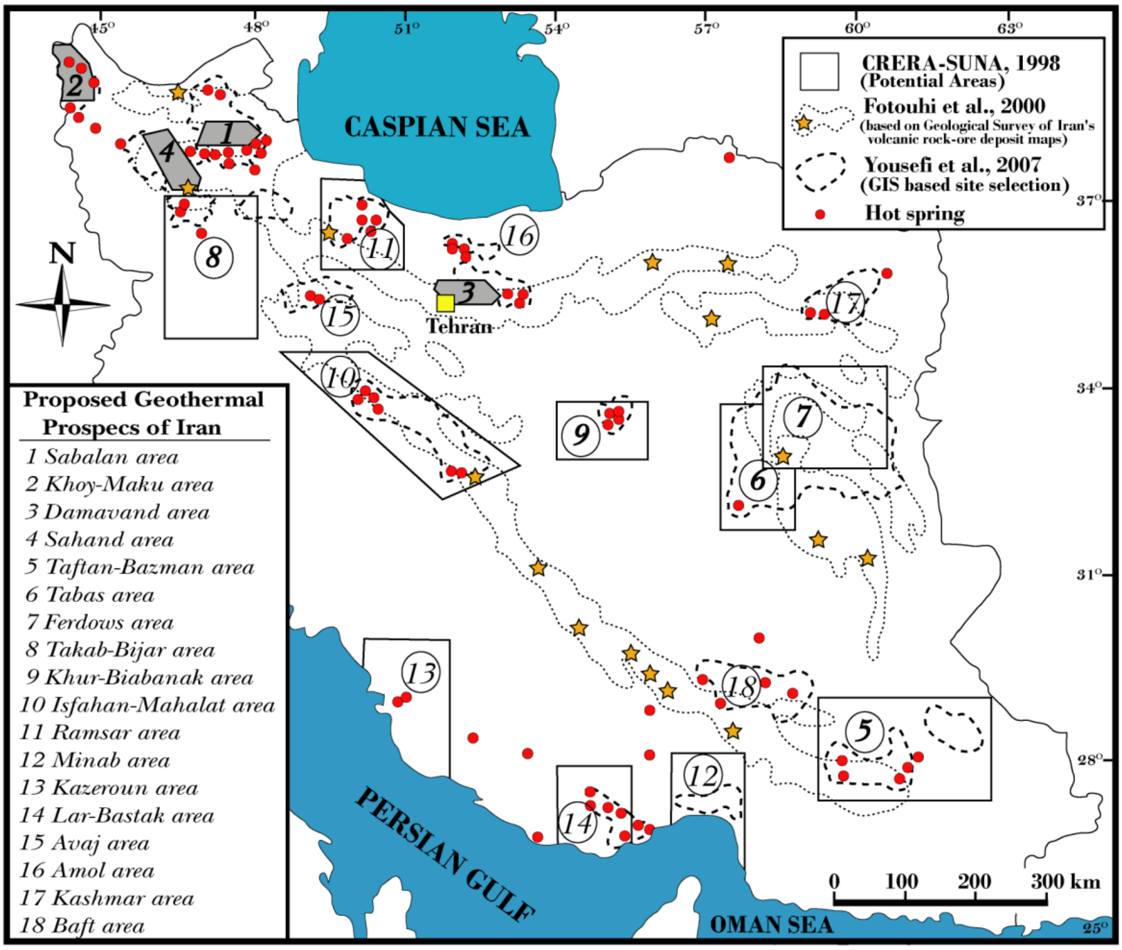

Figure 1: Combined geothermal prospect maps of in Iran

2. GEOLOGY

2.1 Geological History and Tectonic of Iran

Iran, as a segment of the Alpine-Himalayan orogenic system, has a complex pattern of crustal series, tectonic blocks and different structural zones. The geodynamic evolution of Iran's crust and its geologically dynamic nature is obvious from various evidences such as present earthquakes, semi-active volcanoes, uplifted coasts, continuous rise of salt domes, etc. A part of this tectonic chaos is associated with the different phases of Alpine orogenic system (Cimmerian event), starting from the late Triassic to the late Cretaceous, and bringing about the current features and morphology of Iran. Present compressional tensions arising from the opening of the Red Sea and the Indian Ocean that caused northward motion of the Arabian plate, has been imposing different tectonic movements on continental and oceanic crusts and varied blocks of Iran. Hypocenter position of the twentieth century earthquakes along Iran's major faults demonstrates that most faults of Iran are still active. Owing to this active tectonic history, Iran is considered to be seismically very active and is at high risk (Aghanabati, 2004).

Faults have played effective roles in the evolution of various tectonic events (unconformity, thrusting, folding, magmatism, etc.). For instance, many of the volcanic activities occurred in Iran have reached the surface through faults and openings. They have had also major impacts on the formation of structural-sedimentary zones of Iran. In addition, thrust and reverse faults and to a lesser extent strike-slip faults, have given rise to crustal deformation. The major faults, therefore, could be classified according to their time of formation, movement, and geographical distribution. Three major fault trends are distinguishable in Iran (Nogol Sadat, 1978): a) Northwest-southeast which has the same trend as Zagros Zone, Sanandaj-Sirjan Zone (SSZ), Urumieh-Dokhtar Magmatic Assemblage (UDMA) and western Alborz, b) Northeast-southwest, which is parallel to eastern Alborz, and north of Kavir-e Bozorg (Great Kavir) (north of Central Iran Zone), c) North-south with the same trending as Kavir-e Lut (Lut Desert), east of Naiband Fault, and north of Bazman, all in the east of Iran (Eastern Iran Zone) (Figs. 2 and 3).

2.2 Structural Zones-Sedimentary Basins

Iran was primarily divided into several structural-sedimentary basins by Stöcklin (1968). Subsequently, with more sweeping information, other divisions/subdivisions were proposed by many geologists. Aghanabati (2004) took various factors into account to introduce the latest and the most comprehensive structural-sedimentary zones map of Iran (Fig. 2), including types of crust (continental-oceanic), events occurred in paleo-sedimentary basins, variation between identical bio-litho facieses in different places, geological processes like magmatic activities, metamorphism, and intensity of folding system, etc. In his new modification of the structural-sedimentary zones of Iran, evolution of Paleo-Tethys and Neo-Tethys oceans and their impact on the history of Iran's geology was more precisely regarded (Table1).

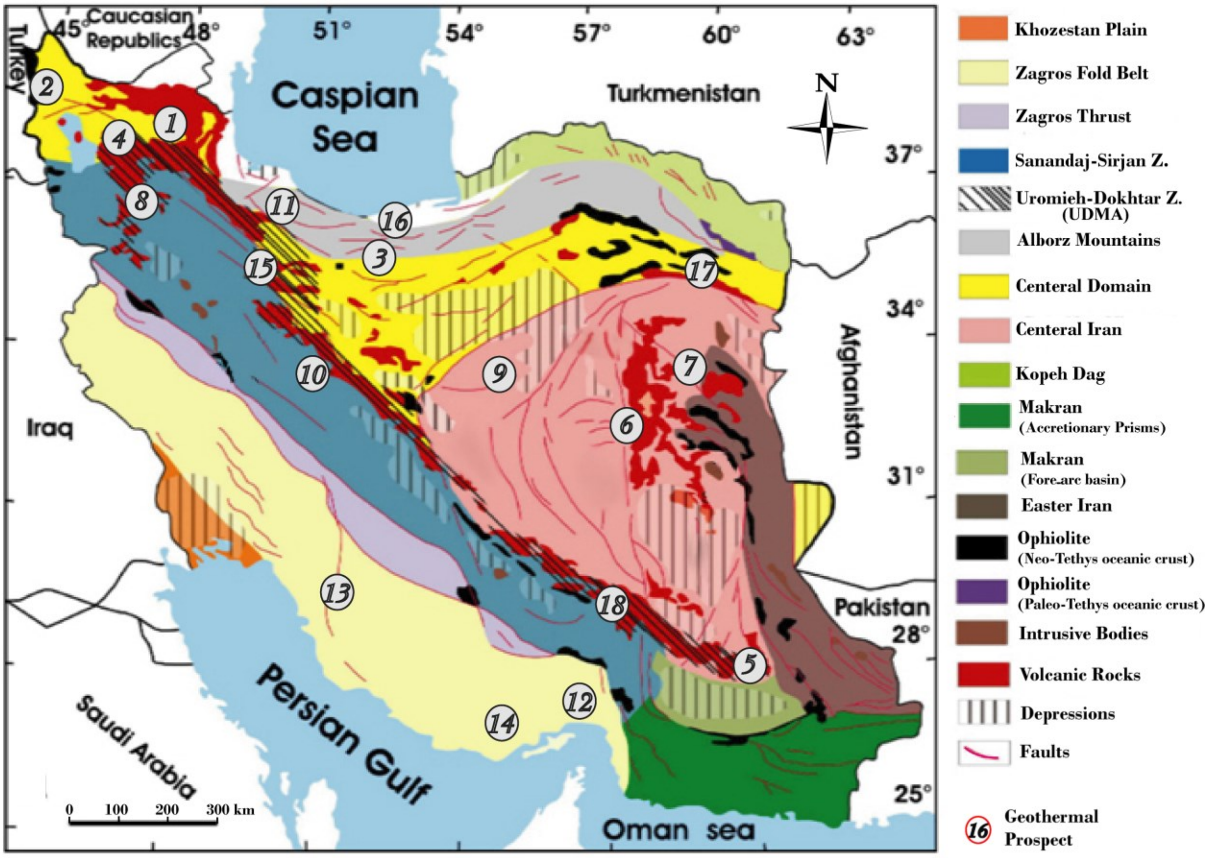

Figure 2: Major sedimentary-structural zones of Iran (Aghanabati, 2004) with the geothermal areas displayed on the zones.

Table1- Paleo-geographic classification of structural domain/sub-zones of Iran (Aghanabati, 2004)

Mega continents	Location	Major Domain	Sub-zone
Eurasia	Southern Margin of Eurasia (Turan Plate)	Northern Iran (Turan Plate)	South Caspian extensional basin
			Kopeh Dagh compressional basin
Paleo-Tethys Suture			
Gondwana	Northern Margin of Gondwana (Turan Plate)	Central Iran (Iran Plate)	Sanandaj-Sirjan
			Alborz-Azarbayjan
			Tabriz-Saveh Zone, Central Iran micro-plate (Yazd block, Poshte-h Badam block, Tabas block, Lut block,)
			Eastern Mountains of Iran
	Neo-Tethys Suture		
	Southern Margin of Gondwana (Zagros Plate)	Southern Iran (Zagros Plate)	Trusted Zagros, Folded Zagros, Dezful Depression, Abadan Plain

Generally the structural-sedimentary basins of Iran include Zagros zone in south and southwest Iran, Makran zone in southeast Iran, Alborz and Caspian subsidence zone in north and northwest Iran, Kopeh Dagh zone in northeast Iran, Central Iran zone in central and northwest Iran and Eastern Iran zone. Sanandaj-Sirjan zone belonging to the Zagros orogenic belt is a mainly regionally metamorphosed belt in the south of the volcanic belt called Urumieh-Dokhtar Magmatic Assemblage (UDMA). The sequence of a fold-trust belt (Zagros zone), regionally metamorphosed rocks (SSZ) and magmatic belt (UDMA) indicate a typical subduction-related geological setting. Ophiolites, therefore, are located along major structural boundaries and Paleo-Tethys (in north Iran between Alborz zone and Central domain) and Neo-Tethys (along Zagros zone, SSZ, and UDMA) oceanic crust. Intrusive bodies have distributed in the most structural zones except Zagros. Table 1 represents the general classification of the structural-sedimentary zones in terms of their domains and tectonic location. It is worth mentioning that Zagros plate, including Zagros Thrust, Zagros Fold Belt and Khozestan Plain (Dezfoul depression and Abadan plain), is the only portion of Iran which is considered as a part of the Arabian plate and in a bigger scale as a part of the Gondwana mega-plate.

2.3 Plio-quaternary Volcanism

Cenozoic magmatism is the most extensive volcanic and plutonic activity in Iran which has played a significant role in the formation of the recent geological features of Iran. This magmatic activity is mostly referred to Eocene and earlier by different geologists. It represents different rock types and compositions all over the country, particularly in Volcanic Rocks belt of Iran. Despite the marine paleo-geographical environment in the Pre-Eocene time, the Quaternary magmatism is confined to volcanic activities and reveals the latest magmatism phase in Iran. Geographically, they expose in two main domains and are tightly linked with regional structures and sedimentary zones. They have mainly moderate composition (dacitic and andesitic-dacitic) and occasionally include granitoidic enclaves suggesting contribution of crustal partial melting in the evolution of ascending basic mantle and magma mixing phenomena. They are either semi-active (i.e. emitting sulfuric gases and water vapors) or dormant associated with sulfuric and hot water springs. Most quaternary volcanic rocks of Iran are geographically situated in the northwest and east-southeast of the country and are categorized as follows (Aghanabati, 2004):

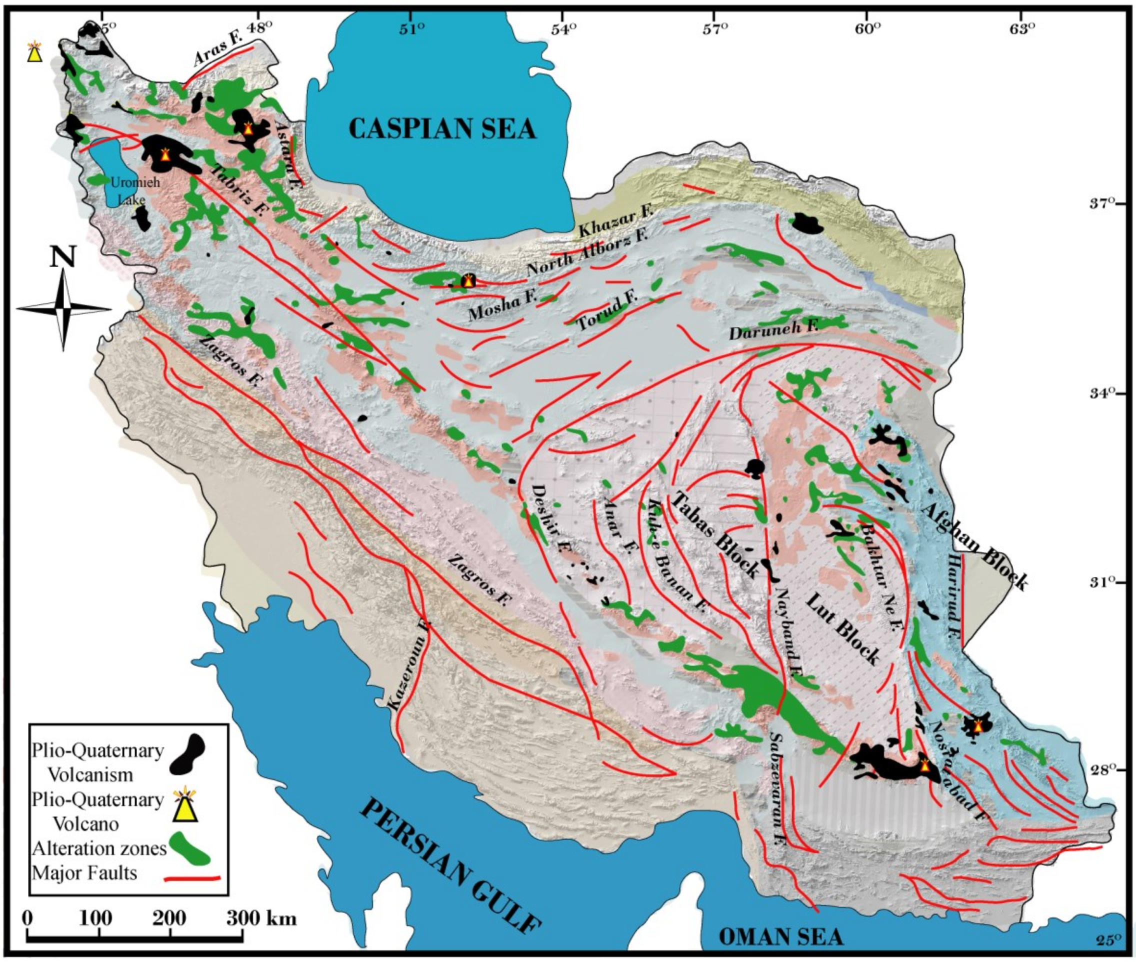

Figure 3: Modified distribution map of Plio-quaternary volcanic rocks and alteration zones (after Geological Survey of Iran's National Atlas, 2004) and major faults of Iran (after Aghanabati, 2004).

a) Azerbaijan Area (SE Turkey to NW Iran): In Azerbaijan Area, young volcanoes with general trending of NW-SE mainly consists of Sabalan Volcano, Sahand Volcano, and Azerbaijan Quaternary basaltic terrains, including Maku, Seru, Takab-Qorveh, Mahabad, Salmas and North Ahar basaltic rocks. Maku and Seru Quaternary basalts associate with Ararat Volcano in Turkey. In spite of having the same litological properties (basalt-olivine basalt), they display various compositions including alkaline porphyric basalts and olivine basalts.
b) Eastern Area (SSE Iran to SW Pakistan): Eastern Iran Quaternary volcanism (Eastern Area) includes some young volcanoes and volcanic deposits occurred in Sistan-Baluchistan and Lut Block in east and southeast Iran. It is composed of two main volcanoes called Taftan Volcano and Bazman Volcano and many local basaltic volcanism in Zahedan, Nehbandan, Takht-e-Rostam (south Taftan), Chah Shali (north Iranshahr), Gandom Beryan, Abark, Khaneh Khatoon and Nayband. Beyond Iran's

border in the southeastern boundary, Soltan Kuh Volcano in Pakistan is another member of this group of volcanoes all together representing a general trend of E-W and N-S. Gigantic Quaternary to Plio-Quaternary stratovolcanoes of Sahand and Sabalan in Azerbaijan Area, and Taftan and Bazman in Eastern Area represent a NW-SE linear trend, named "Sahand-Bazman Volcanic Belt" in Iran. This belt extends to the southeast in Turkey (Ararat Volcano) and to the southwest in Pakistan (Soltan Kuh Volcano). This volcanic belt overlaps the main important Cenozoic volcanic rock; Volcanic Rocks Zone (UDMA).

c) North and Central Iran Area: The extension of Quaternary volcanism, however, is not restricted only to Sahand-Bazman Volcanic Belt. Damavand Volcano (Alborz zone), Arnan (south Yazd, Central Iran zone), Arabshah (south Bijar, Sanandaj-Sirjan zone), Saveh (south Tehran, Central Domain), Aveh (west Tehran, Alborz zone), Kopeh Dagh (northwest Mashahd, Kopeh Dagh zone), Rayan (southeast Kerman, UDMA) are local outcrops of young volcanic rocks in North and Central Iran areas.

Correlation between geothermal prospect map (Fig. 1) and Plio-quaternary volcanic rocks distribution map (Fig. 3) imply that most of the prospects located in northwest and east Iran pertain to Plio-quaternary volcanism. It is noted that there are some Quaternary volcanic provinces in Iran which may also be accompanied by hot springs, but they are not considered as a geothermal potential. Such young basaltic areas include Mahabad and Salmas (south Urumieh Lake), North of Ahar (west Sabalan volcano), Rayan (southeast Kerman) and Saveh (south Tehran). The role of faults in magma ascent and its exposure to the surface and/or transferring the circulated hot water is undeniable (Moin Vaziri,, 1977).

2.4 Geological Classification of Geothermal Resources

The primary geothermal resources classifications have often mixed geological, engineering and heat transfer terminology due to their expected application in geothermal energy. The most common type of classification of geothermal resources is temperature (or enthalpy)-based one (low, intermediate and high temperature/enthalpy) with a long-lasting dispute over the arbitrary ranges of temperature introduced by many scientists. In general, the heat source for the most high-temperature resources (>150°C) appears to be a molten or recently solidified intrusion, whereas many of the low-temperature (<90°C) and intermediate-temperature resources (90°-150°C) seem to originate from deep circulation of meteoric water being heated in depth (Muffler and Cataldi, 1978). Geothermal resources are also grouped based on other factors such as mode of heat transferring system (convective and conductive), exergy (generation potential), physical state of high temperature fluids (vapour or liquid dominated system/reservoir), etc. The necessity of reviewing the geothermal resources classification is understood when new technologies such as EGS (Enhanced Geothermal Systems or Engineered Geothermal Systems) have dramatically been developing, brining about more economic geothermal potential than 30 years ago (Moeck, 2012). An all-inclusive and practical classification is also necessary for decision-makers and the public to understand the whole concept of geothermal systems. To provide a purpose-based classification, therefore, multiple classification schemes have been devised to explain and categorize geothermal energy systems.

Classification which is based on well-sorted geological data is the first step of identification of geothermal systems. How reliable and realistic the resource is classified is a key factor in valid assessment of reservoir and development of a geothermal field. Geothermal resources, therefore, should reasonably be categorized based on the geological features that directly and indirectly influence temperature range of the reservoir. The features include geology, heat source, applicability, power generation, etc., often being merged into a single classification system. Three main types of geothermal systems which are the main focus of this paper, based on their nature and geological settings are a) volcanic geothermal systems, b) convective systems, and c) sedimentary geothermal systems. Volcanic geothermal systems are definitely associated with volcanic activities. The heat sources for such systems are hot intrusions or magma. They are most often situated inside, or close to, volcanic complexes at or near plate boundaries or hot spots. Water flow in volcanic geothermal systems is controlled by permeable fractures and fault zones as well as permeable strata such as sediments, ignimbrites or lavas. In convective systems, the heat source is provided by the hot crust at depth in tectonically active areas, preferably with above average heat-flow. Here, the geothermal water circulates to considerable depth (> 1 km), through mostly vertical fractures, to extract heat from the rocks. Sedimentary geothermal systems are probably the most common type in East African Rift, where the area is filled by sediments and sparse volcanism has been occurring inside. Depending on regional geothermal gradient, primary or secondary permeability of the rock and fluid circulation at depth, the low- and medium- temperature geothermal fields can be produced in various geological basins /systems, including sedimentary basins, off-flow from volcanic systems, fault/fracture controlled convection system, distal part of fissure swarms, and active fracture zones (Saemundsson, 2009).

In the recently proposed geological classification of geothermal resources by Erdlac (2011) (Table 2), five important key parameters in defining a geothermal power system include a) geological environments b) geological features c) crustal heat source d) resource category, and e) rock type in which the geothermal resource is found. This systematic and descriptive method of classification is not necessarily the definitive answer to geothermal data categorization. For example, heat transfer mechanisms, presence or absence of other surface or subsurface features produced by geothermal activity in various geological environments permeability and porosity variations within the various target rock types have not been regarded in this method. Since the broad categories of igneous and sedimentary rocks were applied, a detailed description of the rock types (i.e. limestone, sandstone, andesite, rhyolite, etc.) can provide a more complete classification in future investigations.

3. DISCUSSION

The dominant tectonic regime that is initially caused by Arabia-Eurasia convergence, has been shortening nearly all structural zones and is mainly accompanied by distributed faulting in high mountain ranges in the south (Zagros belt), and in the north (Alborz, Kopeh Dag and south Caspian zones) of the country. Such a global tectonic regime builds a sequence of subduction-related zones with specific series of lithology; trust-fold sedimentary basin of Zagros in the south, regionally metamorphosed belt of SSZ beyond Zagros in the north and UDMA as the north band that overlays SS belt, Central Iran and Central Domain. Figure 2 indicates that the introduced geothermal areas of Iran are predominately located in four zones of Volcanic Rocks, Alborz Mountains, Central Iran and Zagros Fold Belt, even though geographically some parts of a prospect may extend to the adjacent zones such as Eastern Iran, Central Domain and SSZ (Fig. 2). Hereby, we classify the geothermal areas based on the structural-sedimentary basins of Iran and discuss their geology in detail to shed light on the type of geothermal resource in connection with geology.

Table 2- Proposed geothermal power system (Erdlac, 2011)

Geologic Environment		Geologic Feature	Crustal Heat Source	Resource Category	Rock Type
Plate Margin Environment	Convergent (Compressional)	Back Arc Basin	Magmatic	Stem Hydromagmatic	Igneous Sedimentary
		Volcanic Arc Complex			
		Continental Volcanism			
		Intrusive Complex			
	Divergent (Extensional)	Volcanic Spreading Centers	Magmatic	Stem Hydromagmatic	Igneous Sedimentary
		Rift Systems			
	Transform (Strike-Slip)	Pull-Apart Basin	Magmatic	Stem Hydromagmatic	Igneous Sedimentary
		Transformational Faults			
		Volcanic-Magmatic Centers			
Interplate Environment		Mantle Plumes (Hot Spot)	Magmatic	Stem Hydromagmatic	Igneous Sedimentary
		Extensional Terrain			
		Cratonic Basins	Thermal Gradient	Stranded	Sedimentary
		Passive Margin Basins		Geopressured	
				Hydrostatic	
				Co-Produced	
		Basement Complex	Radiogenic	Hot Dry Rock	Igneous

3.1. Geothermal Prospects in the UDMA part of Volcanic Rocks

Extensive part of Volcanic Rocks zone proposed by Aghanabati (2004) has been recognized as Urumieh–Dokhtar volcanic zone or Urumieh–Dokhtar Magmatic Assemblage (UDMA) by various geologists (e.g. Schroder, 1944; Alavi, 2004). This NW-SE trending zone is 150 km in width and is situated in the north of Sanandaj-Sirjan metamorphic belt. Berberian and King (1981) have proposed that this subduction-related Andean-type magmatic arc has been active from the Late Jurassic to the present. The Plio-Quaternary volcanic belt being known as Sahand-Bazman Quaternary volcanic belt extends across the UDMA. The UDMA and Sahand-Bazman Plio-quaternary volcanic belt host most of the geothermal prospects of Iran, including Sabalan, Khoy-Maku, Sahand, Taftan-Bazman, Takab-Bijar, Isfahan-Mahalat, Avaj, and Baft.

Sabalan Area (No.1): Sabalan volcano representing Sabalan geothermal area is located in Ardebil province, NW Iran. It is 4811 m high and its deposits covers an area of approximately 1200 Km^2. Volcanologically, Sabalan is similar to Sahand volcano (Stromboli-Plinian-Peléan composite stratovolcano) and consists of three cones that are extensively eroded by collapse of their craters. It has been active from the Eocene to Pliocene. Studies indicate that the stages of pre- and after caldera formation have occurred in Plio-Quaternary times. It has mainly andesitic, dacitic to latite-basaltic lavas and pyroclastics with minor rhyolitic-ignimbrite lavas. Sabalan volcano is the location of the most explored geothermal field in Iran.

Khoy-Maku Area (No. 2): Volcanic formations in the most NW regions of Iran such as Khoy, Maku and Seru pertain to Khoy-Maku geothermal area and are mostly comprised of basaltic flows relevant to Ararat volcano in Turkey and EW and NW-SE prolongation of the volcano series, including Ararat Volcano, Sufan Volcano, Namrud Volcano, and Tandurk Volcano in Turkey and Armenia. With up to 200 m thickness, they cover an area of approximately 700 Km^2 and compose a variation of volcanic rocks with different composition. They dominantly form flat structures and low topographic features in a way that can be classified as Hawaii-type volcanic activity.

Sahand Area (No. 4): Having an area of about 4500 Km^2 and a height of 3707 m, Sahand volcano is situated in 40 km south of Tabriz city, NW Iran. It is another classic composite stratovolcano that is fairly older than the Quaternary volcanic rocks (middle Miocene to late Pleistocene). Stromboli-Plinian-Pelean explosive features demonstrate a semi-marine environment for Sahand volcano at the time of explosion. It is composed of rhyolitic, dacitic, andesitic lavas and pyroclastics. Occurrence of pumice and volcanic ashes implies that it used to be an explosive volcano.

Taftan-Bazman Area (No. 5): Taftan volcano with andesitic summit is located in NE Khash, SSE Zahedan. It is a Quaternary-Plio-Quaternary non-marine strata-volcano with the volcanic deposits covering an area of approximately 1300 Km^2. Volcanic lavas are andesite, dacite and volcanic ashes in composition. Fumaroles occur on the peak and surrounding slopes as distinctive white steams suggesting recent activity of the volcano. There are some minor Quaternary volcanoes and volcanic rocks around Taftan volcano with the same magmatic origin. Bazman volcano is located at the southern end of Lut Block and the north of Jazmurian depression. It is a strata-volcano with a main central crater encircled by several minor craters. It is mostly composed of basaltic lava, ignimbrite, breccias and tuffs. In contrast to the other parts of the UDMA that are Neo-Tethys subduction-related volcanic arc complexes, Taftan and Bazman volcanoes are Makran-Oman (Indian Oceanic Plate) subduction-related volcanoes in the north of Jazmurian depression. The fumarole manifestations reported by the local people and extensive altered tuffs and lavas also confirm the interacting thermal fluids inside the volcano.

Takab-Bijar Area (No. 8): The Quaternary and older volcanoes and volcanic series related to Takab-Bijar geothermal area are located in Takab to Qorveh regions, and are chiefly trachyte-basalt and basanite in composition. It is suggested that they have been formed in relatively long period of Upper Miocene to Pleistocene. The volcanic series in south and a part of volcanic series in southwest Bijar are believed to be exposed in Quaternary and have restricted hot springs, fumaroles and sulfide manifestations. The impact of faults on transferring the heated ground water originated from Quaternary or older volcanic resources are undisputable, particularly in Takab area.

Isfahan-Mahalat Area (No. 10): It is one of the most extensive areas among all geothermal prospects which are geologically located in the Sanandaj-Sirjan metamorphic belt. Sanandaj-Sirjan metamorphic belt is an NW-SE trending zone parallel to Zagros region. Since these rocks cannot innately raise the normal thermal gradient and generate heat source, the geological processes creating Mahalat-Isfahan geothermal area can be associated with the UDMA and geological structures in the area. Presence of hot springs that have been forming thick travertine deposits around, exposure of numerous intrusions near the hot springs, occurrence of a seismically active major fault along the whole area (Qom-Zofreh fault that is an elongation of Tabriz fault, Fig.3), and lack of quaternary volcanism in the whole area imply that the heat source is hidden and pertain to an unexposed pluton. These types of intrusive bodies have outcrop in many other places along the UDMA such as Alvand pluton in 100 km NW Mahalat.

Avaj Area (No. 15): The two out of four geothermal prospects marked by Yousefi et al., (2007) as a geothermal potential, including Avaj and Baft areas are both located in the UDMA. Geologically, Avaj area is situated in the volcanic terrain of Eocene deposits. Occurrence of some hot springs and voluminous volcanic rocks (UDMA) in the area signify a magmatism-related potential, but on the other hand, special tectonic regime of Avaj area emphasizes that seismically active deep faults (particularly Avaj fault that is along Tabriz and Qom-Zofreh faults) are the main conductor of the earth's heat to the surface.

Baft Area (No. 18): Varied signatures of geothermal potential, including extensive altered volcanic rocks (Fig. 3) and seismic history of the area that are related to the major active faults of Naiband and Sabzevaran are chosen by the GIS (Yousefi, 2007) to consider Baft area as a geothermal prospect, while lack of hot springs and quaternary volcanism indicate that it can be revised by field investigations.

Four out of eight geothermal prospects in the UDMA part of Volcanic Rocks zone are associated with Plio-Quaternary volcanoes and volcanic rocks, including Sabalan, Sahand, Khoy-Maku, Taftan-Bazman areas, where the Plio-Quaternary volcanism play the main role in heating the circulating meteorite water in formations and transferring the fluids into the surface (convective transferring state). They can, therefore, be classified as volcanic geothermal systems, carrying high temperature (> 150ºC) hydrothermal resources. The heat source of Takab-Bijar, Isfahan-Mahalat and Avaj geothermal areas could be related to the magmatic sources and activities occurred in this belt. They occur in plate margin environment and have hydrothermal resource with different geological features/settings; Takab-Bijar area occurs in convergent and transform, Avaj area occurs in transform and Isfahan-Mahalat occurs in convergent settings. Since there are restricted outcrops of young volcanism in Takab-Bijar areas, it can be claimed that a combination of young volcanism-related heating source and major/minor faults has brought about the occurrence of this geothermal system. In case of Avaj area, regarding lack of Quaternary volcanism in the area, the influence of deep faults, particularly Avaj major fault which is a part of Tabriz fault (Fig.3) is undeniable. The Avaj area, therefore, can be categorized as a transform geological environment, where transformational fault(s) is/are the main factor in building deep thermal aquifers and exposure of hot springs. Outcrops of some granitic plutons and sub-volcanic intrusions and absence of Quaternary volcanic rocks in the area is convincing enough to consider Isfahan-Mahalat geothermal prospect as a convective system affected by covered plutonic formations. Regarding buried nature of plutones, it is presumed that the piercing meteoric water would be heated by both conversion and conductive heat transfer regimen. In this regard, Takab-Bijar, Avaj and Mahalat-Isfahan geothermal areas could not be classified as high temperature geothermal system and they can reach temperatures lower than 150 ºC (moderate-temperature geothermal system).

3.2 Geothermal Prospects in Central and Eastern Iran

Geological histories of Central Iran and Central Domain, as the largest sedimentary-structural zones, are basically in close relation with each other. They are comprised of narrow mountain ranges surrounded by Alborz region in the north, and Sanandaj-Sirjan Zone in the southwest. No clear border is observed with Eastern Iran in the east. Eastern Iran zone (Nehbandan-Khash domain), which is also called Sistan suture, Sistan flysch zone and Sistan shear zone, is a N-S trending belt, approximately 200 km in width and 800 km in length along eastern borders of Iran with Afghanistan and Pakistan. It represents a narrow, short-lived strip of the Neo-Tethyan lithosphere that is another identified basin with flysch deposits, analogous to Makran and ophiolitic basement.

In comparison with other zones, Arabia (Gondwana)-Eurasia convergence has differently exposed in Central and Eastern Iran zones. When shortening (thrusting and folding) was the dominant structural framework in nearly all structural zones, Central and Eastern Iran mainly experienced extratensional and transformational faulting. Major reorganization of faults between 3 and 7 Ma (Allen et al., 2004) and accommodating oblique NE-SW shortening across the N-S deforming zone, probably by anticlockwise rotations around the vertical axis of blocks are the main reasons for active deformation system in the late Cenozoic to recent times. A dominantly Oligocene to Tertiary magmatic event, caused by such plate movements, particularly between Lut and Afghan blocks, is represented by widespread alkali volcanic rocks and minor intrusions that appear to be related to major transcurrent faults, particularly in the northern regions of Central and Eastern Iran. They are all pointed out as Volcanic Rocks of Central and Eastern Iran and are obviously separated from the UDMA part of Volcanic Rocks (Aghanabati, 2004, Fig. 2). At least 70 km bedrock offsets in Eastern Iran, elevation changes along the anticline ridge suggesting displacement on the blind underlying thrust and faults' Quaternary movements, deformation and subsequent incision of Quaternary fan deposits, surface ruptures and large earthquakes are other indicators of long-term active tectonic in Central and Eastern Iran (Walker, 2006).

Four geothermal prospects of Tabas, Ferdows, Khur-Biabanak and Kashmar areas are geographically situated in Central Iran, Central Domain, Volcanic Rocks and Eastern Iran (No. 6, 7, 9 and 17, respectively). The regional structures that facilitate water convection and heat transfer in these areas are relevant to the major faults such as Miami, Kalmard, Troud, Naiband, Dorouneh, Nehbandan, Posht-e Badam and Harirud. Linear outcrops of Quaternary volcanic rocks, many small craters and dacitic sub-volcanic flows are vividly observed in Tabas and Ferdows prospects which extends along Naiband fault southward (Fig. 3). The volcanic rocks are basaltic in composition and presence of warm springs and fumaroles reveals that they aren't totally extinct. There are also restricted numbers of basic volcanic bodies related to the Quaternary in the north of Kashmar city (Nabavi, 1971). A combination of young volcanic activities and active tectonic imposed in the whole zones created many surface manifestations of thermal upflows in the form of hot springs, travertine deposits, fumarole and hydrothermally-altered terrains. In Khur-Biabanak area, though there are no quaternary volcanic deposits on the surface (Fig. 3), major deep transformational faults, particularly Daruneh fault, have given rise to the exposure of some hot springs and alteration zones.

Despite the fact that most of the geothermal areas proposed in different geological zones of Iran are associated with the convergent plate margins, the geothermal areas located in Central and Eastern Iran have dominantly been generated by transform (strike-slip) faults. In Tabas, Ferdows, and Kashmar areas, young volcanism, huge earthquakes and hot springs are all exposed along major faults obviously, confirming the inevitable contribution of active and deep tectonic regime in creation of geothermal prospects. These areas provide evidences of plate margin environment (micro-plates of Tabas block, Lut block and Afghan block), therefore, can be considered as a combination of convective and volcanic geothermal systems. Such volcanism, occurring in (micro-) plates' margin can provide magmatic source for geothermal resources. Since they are fault/fracture controlled geothermal systems which carry magmatic heat source, they can be classified as low to medium temperature geothermal systems (< 150ºC). Although the same active transextensional and strike-slip faults have been functioning in Khur-Biabanak area, but lack of young volcanic deposits and specifically Quaternary volcanism is cogent to regard it as a convection geothermal system where transformational faults play the main role in transferring the circulated heated fluids to surface and produce hot springs and other geothermal manifestations.

3.3 Geothermal Prospects in Zagros Fold Belt

Zagros Orogenic Belt of Iran, as a part of the Alpine-Himalayan orogenic belt, is a 2000 km long and NW-SE trending belt extending from the East Anatolian Fault of eastern Turkey to the Oman Sea in southern Iran. As figure 1 show, it covers south west of Iran and is practically composed of three main sub-zones; Khozestan Plain, Zagros Fold Belt and Zagros Thrust (High Zagros Zone) (Agard et al., 2005). The approximately 12 km thick folded and trusted sedimentary deposits overlays a Precambrian metamorphic basement. Minab fault (Zendan fault) separates the topmost southeast of Zagros zone from semi-flysch basin of Makran. Seismic studies demonstrate the existence of a number of major active blind thrusts, and basement to surface transverse faults being responsible for some of the hidden earthquakes in active Zagros Fold-Thrust belt. The morphotectonic units of Zagros are separated by deep-seated and discontinuous major thrust fault. On the other hand, most of the anticlines in Zagros are cut by salt domes (Lower Cambrian, Hormoz Salt domes) (Berberian, 1995). These evidences confirm that the faults are quite deep and salt migrates from depth, cutting at least the entire sedimentary cover. Zagros Belt is easily recognized by the NW-SE trending parallel anticlines and accordingly is the home of the world's largest hydrocarbon reservoirs. It is generally composed of marine deposits (Neo-Tethys) such as limestone, marl, sandstone, shale, conglomerate, evaporates, etc, and no magmatic and metamorphic rocks are exposed in this zone.

In Zagros Fold Belt all three geothermal prospects in south Iran, including Minab, Kazeroun and Lar-Bastak areas (Figs. 1 & 2, Nos. 12, 13 and 14, respectively) are situated at southwesterly boundary of Zagros near the Persian Gulf. The hidden and deep faults (thrusts), being accompanied by intruding salt domes can be considered as the main reason of hot springs occurrence in Zagros Fold Belt. The geothermal prospects located in this belt, therefore, differ exceptionally from all other geothermal areas in Iran. They can be regarded as interplate environment (Arabian plate) and passive margin basin. In this regard, deep-seated faults and salt domes are the main parameters in carrying naturally circulated and heated meteoric water by natural thermal gradient and manifestation of hot springs on the surface. This deep fault/fracture controlled aquifers in such a regional sedimentary environment can result in producing a sedimentary geothermal system with conductive heat resource which can create low to medium temperature geothermal resources (< 150ºC). The resource category of Minab, Kazeroun and Lar-Bastak geothermal prospects has never been investigated in detail and all types of thermal gradient resources in crustal heat source category, including stranded, geopressured, hydrostatic and co-produced (Table 2) can be applied to them by this time. The tight relationship between petroleum and sedimentary-type geothermal reservoir in Zagros makes this area attractive in geothermal exploitation, specifically simultaneous production of petroleum and hot brine from oil-gas drilling rigs.

3.4 Geothermal Prospects in Alborz Mountains

Alborz structural zone with general E-W trending is bounded to paleo-Tethys suture zone in the north and its border with the Caspian Sea is overlaid with the Caspian coastal plain. Alborz Mountain is divided into three sub-zones of eastern, central, and western. The most northwestern part of the UDMA part of Volcanic Rocks is considered as western Alborz by some authors, but in the sedimentary-structural zones map of Iran introduced by Aghanabati (2004), Alborz zone is limited to Astara fault (Figs. 2 and 3) and has not extended across the northwest of Iran anymore. Major volcanic activity of this zone started in the Eocene and varied widely in intensity during the Tertiary. Among all three geothermal prospects introduced in Alborz zone or Alborz-Binalud Quaternary volcanism, including Damavand, Ramsar and Amol areas, only Damavand area is entirely engaged with Quaternary volcanism. In Khalkhal region (the geothermal area proposed by Yousefi, et al., (2007) in Fig.1 that is located between geothermal areas of 8 and 11), west of central Alborz, there are evidences of fault-related thermal activities being proved by occurrence of few hot springs, while the similar source of fluids, originating from Sabalan volcano can also be considered.

<u>Damavand Area (No. 3):</u> The highest peak (5678 m) and youngest volcano (0.6-1.8 Ma, Davidson et al, 2004) in Iran plateau, Damavand Volcano is located in the east of central Alborz sub-zone. It is a composite stratovolcano with acidic-neutral alkaline composition. Since 10,000 years ago, its external activity has declined and it has been dormant ever since, however its internal underground activities have never stopped showing fumaroles emission from the summit. According to the international standards, such volcanoes can be categorized as active volcano and it is viewed as solfatara areas of Iran (Gansser, 1966). Damavand lavas and pyroclastics are predominantly porphyritic trachyte-andesite, while young basalts of Damavand region have alkaline composition. It represents chemical characteristics of a decompression melting-related magmatism in response to lithospheric

delamination beneath the Alborz Mountain. Moreover, the volcano indicates magmatism with uncertain tectonic affinity confirming the geophysical and geochemical constraints of a local hotspot/plume origin. Such a local nature of Damavand is possibly associated with lithospheric delamination, rather than any connection with subduction systems (Davidson et al, 2004). Sulfuric gases and rocks, hot springs and also occurrence of old and new earthquakes are pertinent to the underground activities of Damavand volcano in the recent years. All these parameters make Damavand a real potential of geothermal prospect.

Ramsar Area (No. 11): The actual Ramsar geothermal area is not restricted to Ramsar city where more than nine hot springs are known around. They are mainly discharging from Upper Triassic-Mid Jurassic limestone and dolomites and young sandy alluvial. They have various concentrations of radioactive components, different composition and temperatures displaying variety of functions interfering the heat and fluid transferring system. Linear pattern of hot springs highlights significant role of faults and fractures in linking the hot springs to the deep sources. Role of a deep N-S fault in leaching the radioactive elements and creating a geochemical aureole of U and Th around calcareous tuffs in the area was confirmed (Bolurchi, 1991). Thorium concentration in hot springs is strikingly more than uranium values, which is assumed to be relevant to the granitic plutons in the adjacent areas (Abdollahi, 1993). Lack of uranium-bearing veins in different types of host rocks, uranium placers and radioactively anomalous rivers also indicate an active and young underground source for both temperature and radioactivity of springs. It is claimed that the thermal and radioactive source of hot springs in Ramsar and surrounding areas in a regional scale is originated from a highly-differentiated granitic pluton (Abdollahi, 1993). Regarding occurrence of Alam Kuh granitic pluton in around 80 Km southeast Ramsar (Late Miocene-Early Pliocene, Axen et al., 2001) that is assumed to be a part of heat source in the whole region, a hidden plutonic source can supply the required heat for Ramsar geothermal area.

Amol Area (No. 16): It was first introduced by Yousefi, et al, (2007) and probably recognized based on the occurrence of a few hot springs, the abundance of some regional faults, and also earthquake epicenters in Amol area. The hot springs have been discharging from Mesozoic dolomite and carboniferous shale formations and there is no Quaternary volcanic rock in the whole nearby areas. Although Damavand volcano supposed to be heat source of these springs, their trends are different from the regional structural scheme and particularly from the trend of hot springs in Damavand. Rezaee (2011) referred to north Lavij fault zone and particularly Ghalandroud fault as the main factor to transfer heat from the depth.

All the three geothermal areas in Alborz show different source and function in creating a geothermal field. Damavand volcano is an exception in terms of geological setting among all volcanoes in Iran. While Sabalan, Sahand, Taftan and Bazman are all a subduction-related volcanism and are build in a back arc basin, Damavand volcano is formed by a regional lithospheric delamination and the consequent decompression melting of mantle, all due to a local extensional tectonic system. The volcanic geothermal system influenced by this process has the potential of creating a high temperature geothermal system (> 150ºC). Even though there is an assumption implying that Damavand volcanic system charges the heat source of Amol geothermal area, it is firmly believed that the minor faults in Amol area play the main role in creation of this geothermal prospect. This geothermal area, therefore, can be a fault/fracture controlled convection system, having low to moderate temperature resources (< 150ºC). Ramsar geothermal area displays different heat source; intrusive kind of magmatic heat source. This type of geothermal systems makes a low to medium temperature (< 150ºC) geothermal prospect and applies hydrothermal resource and fault/fractures convection system to heat the circulating meteorite water by a hidden pluton.

4. CONCLUSION

Table 3 represents the geological classification of geothermal areas in detail. In this table, the nature of prospects and anticipated temperature of each prospect is estimated and can be considered as a primary geological-based classification for further investigations. In this regard, all the geothermal areas are situated in plate margin environment except the one that are situated in Zagros fold belt (Minab, Kazeroon and Lar-Bastak areas); inter-plate environment. Except theses three geothermal areas in Zagros fold belt that has thermal gradient crustal heat source, hydrostatic type of resource and sedimentary type of deep aquifers, all the other areas have are magmatic heat source, hydrothermal (steam hydromagmatic) type of resource which both igneous and sedimentary rocks are anticipated to host the thermal fluids. Ten out of eighteen areas are formed in a convergent (compressional) tectonic environment, including Sabalan, Sahand, Khoy-Maku, Taftan-Bazman, Baft (with volcanic arc complex geological features), Isfahan-Mahalat, Ramsar (with intrusive complex geological features), Minab, Kazeroun and Lar-Bastak (with passive margin basin geological features), where transform (strike-slip) geological environment and transformational faults geological features in particular seem has the main role in occurring of four areas; Damavand, Avaj, Amol, and Khur-Biabanak. Among these four areas, just Damavand volcano completely represents the evidences of pull-apart basin geological features in addition to transformational faults. The three remained geothermal areas, including Tabas, Ferdows and Takab-Bijar, are formed in convergent tectonic settings where transformational faults have also influence their occurrence as geothermal prospects.

Figure 4 also illustrates the general form of geological classification, mainly based on geological features presented in table 3. In short, the proposed geothermal areas in Iran can simply be classified in the form of following categories, based on geological features and environments:

a) Quaternary Volcanoes-associated geothermal prospects; Sabalan, Sahand, Khoy-Maku, Taftan-Bazman areas (volcanic arc complex geological feature).
b) Quaternary Volcanics-Major Faults-associated geothermal prospects; Damavand, Ferdows, Tabas, Takab-Bijar, Kashmar areas (a combination of volcanic arc complex and transformational faults and/or pull-apart basin geological features).
c) Faults-associated geothermal prospects; Khur-Biabanak, Avaj, Amol, Baft (transformational faults geological features).
d) Thrust-Fold Belt-associated geothermal prospects; Minab, Kazeroon, Lar-Bastak areas (passive margin basin geological features).
e) Plutons-associated geothermal prospects; Ramsar and Isfahan-Mahalat areas (intrusive complex geological features).

The temperature-based classification of these geothermal areas indicates that Quaternary Volcanoes-associated geothermal prospects, in addition to Damavand area from Quaternary Volcanics-Major Faults-associated geothermal prospects group are high-temperature geothermal resource, while all the other areas can be categorized as low-medium temperature. Telling the proposed geothermal prospects apart can be based on the nature and geological settings of each prospect. In this scheme, Quaternary Volcanoes-associated geothermal prospects are all volcanic geothermal systems, while Khur-Biabanak, Avaj, Amol, Minab, Kazeroon, Lar-Bastak, Ramsar and Isfahan-Mahalat, Kashmar areas are convective geothermal systems. The remained geothermal areas, inluding Tabas, Ferdows, Takab-Bijar and Baft can be regarded as a combination of both volcanic and convective geothermal systems.

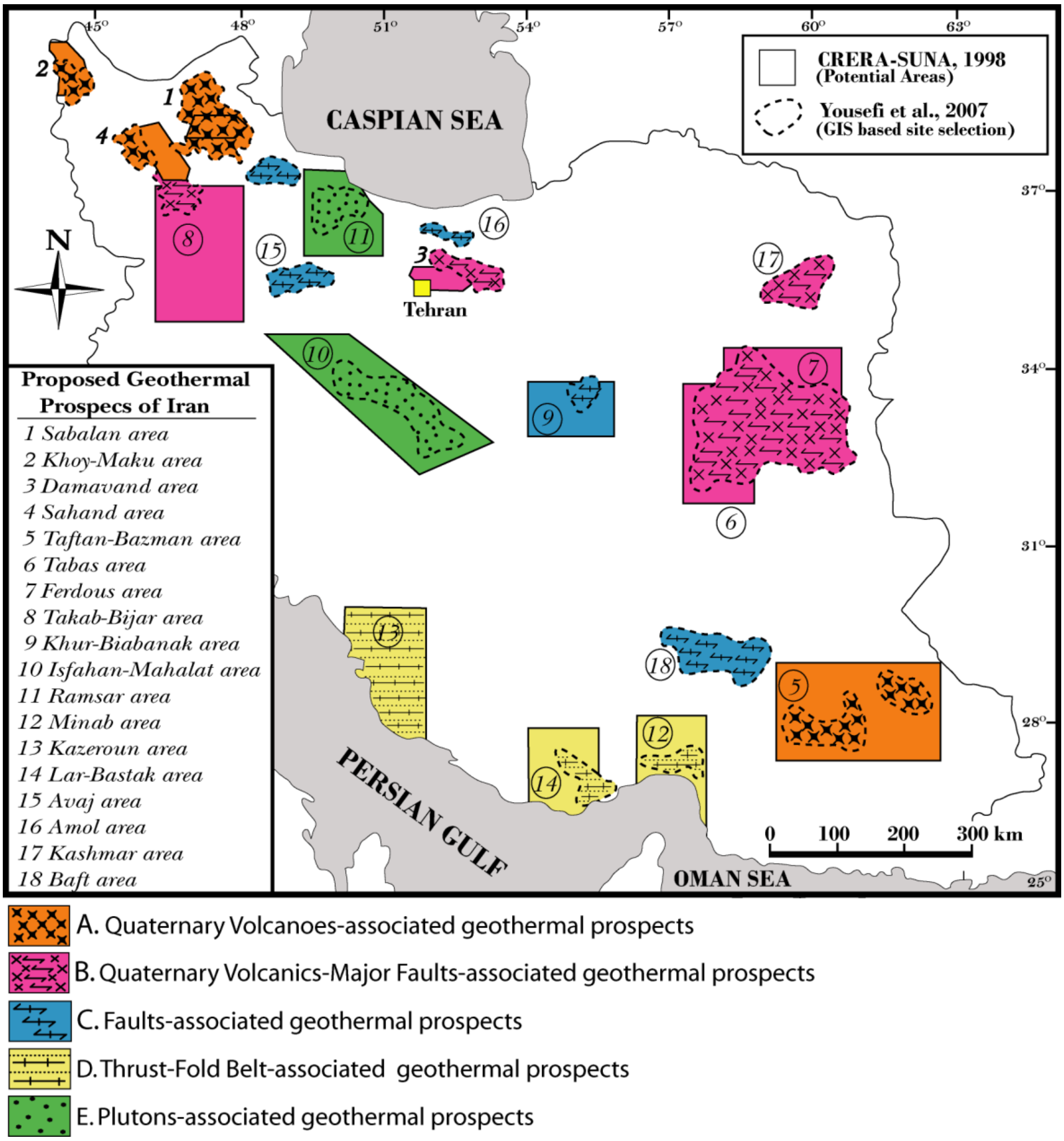

Figure 4: Geological classification map of Iran's geothermal prospects

Table3-Geological classification of Iran's geothermal areas

Geothermal Prospects (SUNA-CRERA, 1998 & Yousefi et al, 2007)	Structural – Sedimentary Basin (Aghanabati, 2004)	Nature and Geological Setting (Saemundsson , 2009)	Temperature-based Type (Saemundsson , 2009)	Geological Environment (Erdlac , 2011)	Geological Feature (Erdlac , 2011)	Crustal Heat Source (Erdlac , 2011)	Resource Category (Erdlac , 1109)	Rock Type (Erdlac , 2011)
(1) Sabalan	Volcanic Rocks (UDMA)	Volcanic Geothermal System	High Temperature	PME-Convg.	VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(2) Khoy-Maku	Volcanic Rocks (UDMA)	Volcanic Geothermal System	High Temperature	PME-Convg.	VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(3) Damavand	Volcanic Rocks (UDMA)	Volcanic Geothermal System	High Temperature	PME-Trsf	PAB & TF	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(4) Sahand	Volcanic Rocks (UDMA)	Volcanic Geothermal System	High Temperature	PME-Convg.	VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(5) Taftan-Bazman	Volcanic Rocks (UDMA)	Volcanic Geothermal System	High Temperature	PME-Convg.	VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(6) Tabas	Volcanic Rocks & Central Iran	Volcanic/Convective Geothermal System	Low-Moderate Temperature	PME-Trsf & PME-Convg	TF & VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(7) Ferdows	Volcanic Rocks & Central Iran/Domain & Eastern Iran	Volcanic/Convective Geothermal System	Low-Moderate Temperature	PME-Trsf & PME-Convg	TF & VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(8) Takab-Bijar	Volcanic Rocks (UDMA) & S-S Metamorphic zone	Volcanic/Convective Geothermal System	Low-Moderate Temperature	PME-Convg &PME-Trsf	VAC & TF	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(9) Khur-Biabanak	Central Iran/Domain	Convective Geothermal System	Low-Moderate Temperature	PME-Trsf	TF	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(10) Isfahan-Mahalat	Central Iran & S-S Metamorphic zone	Convective Geothermal System	Low-Moderate Temperature	PME-Convg	IC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(11) Ramsar	Alborz Mountains	Convective Geothermal System	Low-Moderate Temperature	PME-Convg	IC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(12) Minab	Zagros Fold Belt	Convective Geothermal System	Low-Moderate Temperature	IPE-Convg	PMB	Thermal Gradient	Hydrostatic	Sedimentary
(13) Kazeroun	Zagros Fold Belt	Convective Geothermal System	Low-Moderate Temperature	IPE- Convg	PMB	Thermal Gradient	Hydrostatic	Sedimentary
(14) Lar-Bastak	Zagros Fold Belt	Convective Geothermal System	Low-Moderate Temperature	IPE-Convg	PMB	Thermal Gradient	Hydrostatic	Sedimentary
(15) Avaj	Volcanic Rocks (UDMA) & S-S Metamorphic zone	Convective Geothermal System	Low-Moderate Temperature	PME-Trsf	TF	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(16) Amol	Alborz Mountains	Convective Geothermal System	Low-Moderate Temperature	PME-Trsf	TF	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(17) Kashmar	Central Iran & Kope Dag	Volcanic/Convective Geothermal System	Low-Moderate Temperature	PME-Trsf & PME-Convg	TF & PAB	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary
(18) Baft	Volcanic Rocks (UDMA)	Volcanic/Convective Geothermal System	Low-Moderate Temperature	PME-Convg	VAC	Magmatic	S. H. (Hydrothermal)	Igneous/Sedimentary

+ PME = Plate Margin Environment, + IPE = Interplate Environment, + Convg = Convergent (Compressional) , + Trsf = Transform (Strike-Slip),
+ VAC = Volcanic Arc Complex , + IC = Intrusive Complex, + PAB = Pull-Apart Basin, + TF = Transformational Faults , + PMB = Passive Margin Basin,
+ S. H. = Stem Hydromagmatic,

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