Revista Geoaraguaia
ISSN:2236-9716
Barra do Garças – MT
v.12, n.1. Jun-2022

Diagenesis and Tectonic Setting of The Varcheh Intrusive Masses in Sanandaj-Sirjan Zone, Iran

Diagênese e Ajuste Tectônico das Massas Intrusivas de Varcheh na Zona de Sanandaj-Sirjan, Irã

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Abstract

Varcheh intrusive masses of the Sanandaj-Sirjan zone (SSZ) are embedded in middle and upper cretaceous sedimentary rocks. The lithological composition of this complex is mostly olivine gabbro, monzogabbro, diorite, and monzodiorite with granular and ophitic textures. The clinopyroxene, plagioclase, and sometimes indigenized olivine are the major crystals of these rocks. Enrichment in LILE (i.e., Ba, Rb, and Th) and depletion in HFSEs (Ti and Nb) from spider diagrams show the characteristics of rift environment-associated rocks. The geochemical and petrogenetic studies indicate the common origin of the intrusive rocks in the region and the role of differential crystallization along with the contamination of magma with crustal rocks in the evolution of the source magma of the mentioned rocks. This magma has originated from the low-grade partial melting of an enriched garnet-spinel-lherzolite mantle source at a depth of 100 to 110 km. In general, small exposures from a large batholith are observed on the ground.

Keywords: Basic intrusive rocks; Tectonic environment; Varcheh; Sanandaj-Sirjan zone.

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Resumo

As massas intrusivas de Varcheh na zona de Sanandaj-Sirjan (SSZ) estão embutidas em rochas sedimentares originadas no cretáceo médio e superior. A composição litológica deste complexo é principalmente formada por gabro de olivina, monzogabro, diorito e monzodiorito com texturas granulares e ofíticas. O clinopiroxênio, o plagioclásio e, eventualmente a olivina indigenizada são os principais cristais dessas rochas. Enriquecimento em LILE (ou seja, Ba, Rb e Th) e depleção em HFSEs (Ti e Nb) analisada por diagramas mostram as características de rochas associadas ao ambiente de rifte. Os estudos geoquímicos e petrogenéticos indicam a origem comum das rochas intrusivas na região e o papel da cristalização diferencial junto com a contaminação do magma com rochas crustais na evolução do magma fonte das rochas mencionadas. Este magma se originou da fusão parcial de baixo grau de uma fonte enriquecida de manto granada-espinélio-lherzolita a uma profundidade de 100 a 110 km. Em geral, pequenas exposições de um grande batólito são observadas no solo da região.

Palavras-Chave: Rochas intrusivas básicas; Ambiente tectônico; Varcheh; Zona Sanandaj-Sirjan.

Introduction

Sanandaj-Sirjan Zone (SSZ) is a belt in the southwest of central Iran, which is located in the immediate northeast of the main Zagros thrust. The rock and structural features of this zone represent a deep trough or middle rift block in the Precambrian shield of Iran and Saudi Arabia. Therefore, its geological features are distinct from the adjacent areas. The special differences of this zone have attracted geologists for a long past. The length of SSZ is about 1500 and its width is 150 to 250 km. The zone starts from the west of Urmia Lake and continues in a northwest-southeast direction to the Minab fault, north of Bandar Abbas. Lake Urmia, Tuzlugol, Gavkhouni, and Jaz Murian are the boundary area between Sanandaj-Sirjan and Middle Iran (Stocklin, 1968).

The SSZ is indeed a part of the Zagros orogenic belt, which is the result of the opening and closure of the Neotethys Ocean. From northeast to southwest, it has three parallel tectonic zones including the Urmia-Dokhtar magmatic complex, the Sanandaj-Sirjan zone, and the folded Zagros belt (GhSemi and Talbot, 2005; Ullah et al. 2021, Jafari et al. 2021).

The boundary of SSZ with the Urmia-Dokhtar magmatic complex toward the east is formed by a series of structural embayments that are the result of compression. This zone is a pair of metamorphic bands mainly in the form of greenschist, amphibolite, and Eclogite facies, which has risen at the end of the Cretaceous due to the continental collision between the African-Arab continent and the Central Iranian subcontinent (Mohajjel and Fergusson, 2000; Barahouei et al. 2021; Pourabdollahi et al. 2021).

The most important metamorphic events that affect the SSZ are related to the tectonic events of the opening and closure of the Neotethys Ocean (Alavi, 1994; Mohajjel et al., 2003; Aghanabati, 2004; GhSemi and Talbot, 2005; Morovati et al. 2021). Indeed, the tectonic zone of the Zagros Orogen is the result of subduction and collision of the Arabian plate and Central Iran subcontinent during the Late Cretaceous to Tertiary (Laramid orogenic phase) (Mohajjel et al., 2003; Mohajjel and Fergusson, 2000; Rajabi et al. 2021).

Study Method

To investigate and determine the amount of main, secondary, and rare elements in the samples of the region, we made some field visits to choose rock samples with the least alteration from different rock units. Next, 14 rock samples were selected and analyzed using inductively coupled plasma mass spectrometry (ICP-MS) in Zarazma Company of Iran (Table 1).

Geology of the region

According to the 1:100,000 geological map of Varcheh, in the south and southeast of Arak, 30 small outcropped intrusive masses in the dimensions of 0.5-5 km2 have exposure between latitudes 49°45′ to 50°00′ E and 33°45′ to 34°00′ N (Figure 1). The intrusive rocks in the study area are pyroxene gabbro, gabbro-diorite, diorite gabbro, pyroxene diorite, diorite, Luco-diorite, and monzodiorite. At the point of contact of the intrusive masses with the host rocks, there is often no specific phenomenon other than the presence of limited alteration zones. Most of these rocks are in the form of small stocks or sills.

The studied intrusive mass has penetrated the Middle and Upper Cretaceous sedimentary rocks including limestone shale, marl, and siltstone. In the study area, the presence of various rocks with heterogeneous origins has created different morphologies in different parts of the study area.

In addition to the type of rocks, regional tectonics and volcanic eruptions have played a determining role in the shaping these areas.

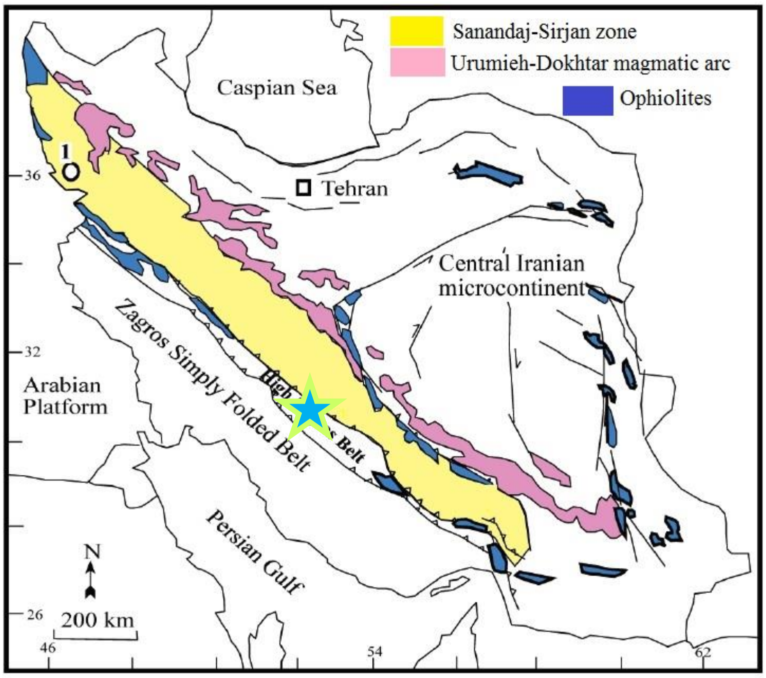


Figure 1 - The location of the study area in the map of structural zones of Iran
Source: Ghasemi; Talbot (2006).

The most important rocks in the study area include gabbro, monzogabbro, diorite, gabbro diorite, pyroxene diorite, diorite, and luco-diorite. In these studies, the shape and size of the hand specimens of the rock are massive and gray to dark green. Also, in terms of texture, they are holocrystalline and medium to coarse crystal and sometimes have ophitic and sub-ophitic textures. Intergranular, ophitic, and sub-ophitic textures suggest simultaneous crystallization of plagioclase and clinopyroxene (Vernon, 2004). The presence of ophitic tissue also indicates greater nucleation of plagioclase than clinopyroxene (Wager, 1960).

These rocks have a relatively simple mineralogical composition including plagioclase, clinopyroxene, opaque minerals, and ilmenite with ophitic and sub-ophitic textures. Plagioclase is the most important and abundant mineral in these rocks with a frequency of about 12% and is often euhedral to subhedral and in the form of fine to large blades with repetitive polysynthetic twins. Clinopyroxene is the second major mineral of these rocks with a frequency of about 45%. This mineral sometimes is oraliticized and has turned to amphibole (tremolite and actinolite) filled with chlorite.

Accessory and altered minerals include opaque minerals (iron oxide and titan), chlorite (from the decomposition of clinopyroxene), amphibole (from the decomposition of clinopyroxene), and calcite. The main marked alterations in this mass are sericitic, sussoritic, oralitic, and chloritic in plagioclase and clinopyroxenes (Figure 2).

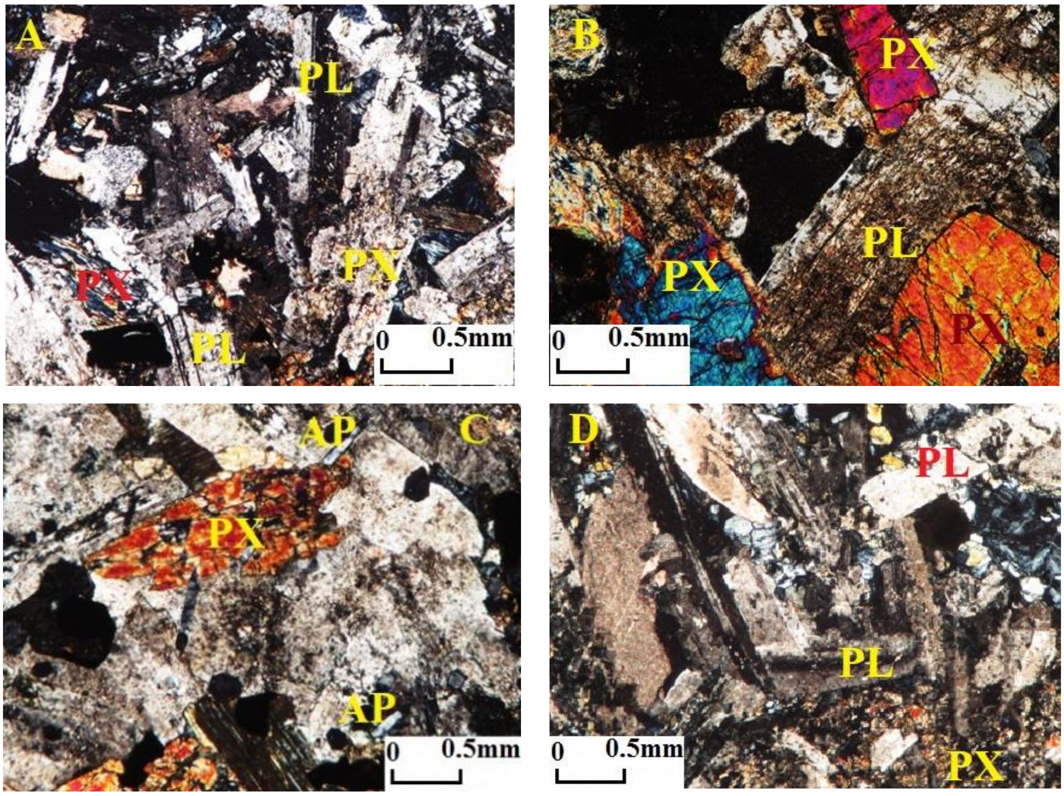


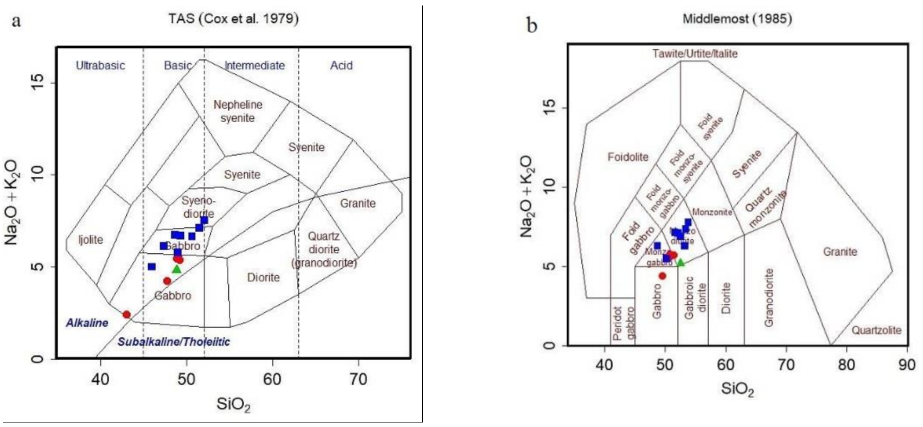
Figure 2 – (a) Granular subhedral texture in gabbro pyroxene; (b) View of gabbro with granular texture; (c) Granular subhedral texture in gabbro-diorite; (d) Anti-perthitic plagioclase and clinopyroxene in the luco-diorite sample.
Source: Authors (2021).

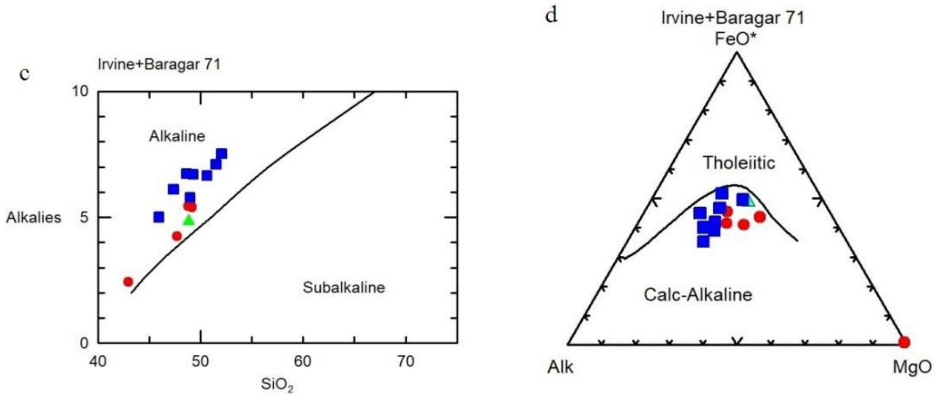
Geochemical studies of intrusive rocks in the region

Evaluation of the main elements of intrusive rocks in the Varcheh region according to the TAS diagram shows that the SiO2 values in these rocks are in the range of 43 to 53%. Also, these rocks are in the combined range of gabbro and quartz diorite (Fig. 3a and 3b). In addition, based on the boundary of semi-alkaline and alkaline series (Irvine & Baragar, 1971), the studied rocks are in the range of tholeiitic and alkaline (Figs. 2c and 2d).

The magnesium number of the samples (#mg) is between 41 and 53. According to Kelemen et al. (2004), the magnesium number less than 50 indicates the evolution of the parent magma, between 60 and 50 shows the parent magma (i.e., high magnesium), and more than 60 suggests the primary parent magma.

Most specimens are in the parent magma range. Generally, concentrations of MnO, CaO, P2O5, MgO, TiO2, Fe2O3, and Al2O3 oxides decrease with increasing silica content, while K2O and Na2O show an ascending trend. An increase or decrease in any oxide or element can be a sign of its presence or absence in the minerals making the igneous rock. In general, the variations of the main elements against SiO2 in the studied samples indicate a reproductive relationship in most of the different intrusive rocks in the Varcheh area (Fig. 4).





Gabbro: syenodiorite: Monzonite:

Figure 3 – (a) Diagram of Na2O + K2O vs. SiO2 (Cox et al., 1979); (b) Diagram of Middelmost et al., 1985; (c) Diagram of total alkaline versus SiO2 (Irvine & Baragar, 1971); (d) Diagram of AFM (Irvine & Baragar, 1971)

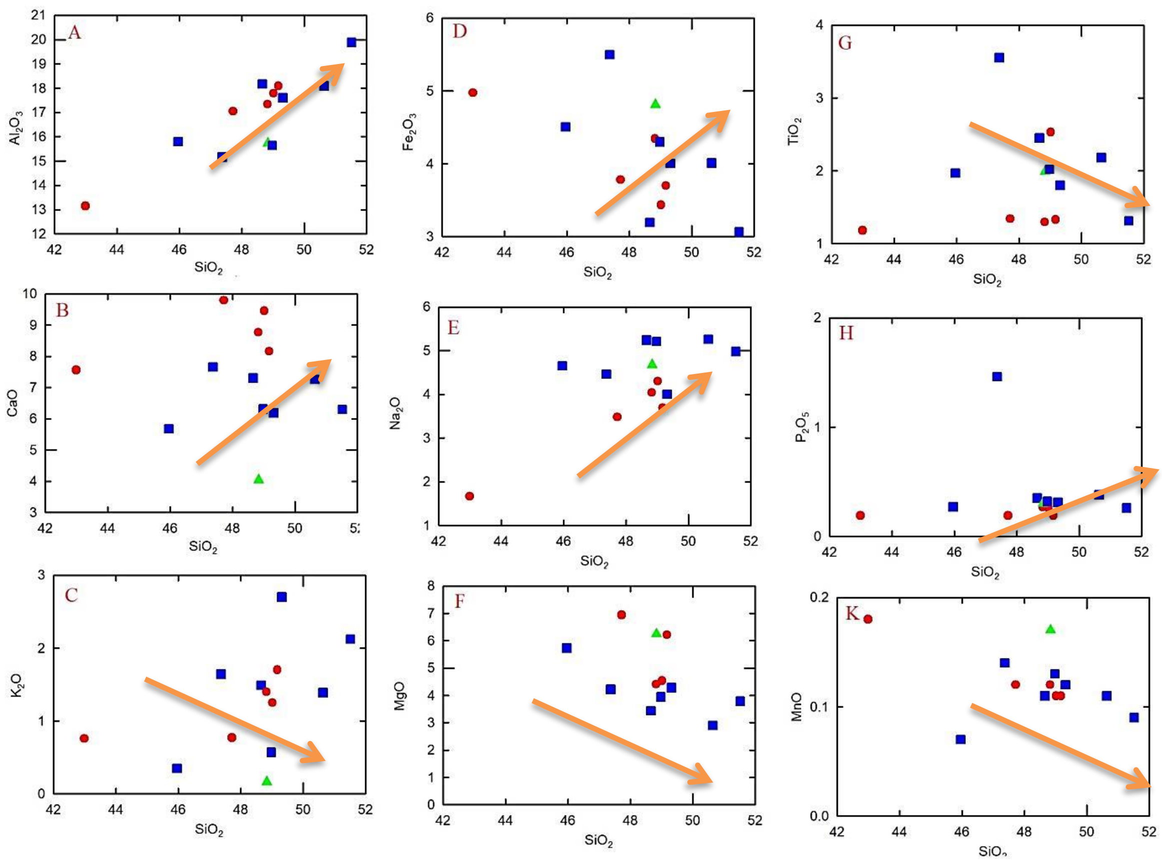


Figure 4 - Variations in the main elements in Harker diagrams
Source: Harker (1909).

Using diagrams of trace element changes versus Zr and Th is among the appropriate methods to understand the trend of magmatic evolution. The suitability of Zr for use in variation diagrams is due to the very low mobility of this element during alteration (Le Roex et al., 1983; Meng et al., 2012; Talusani, 2010; Widdowson et al., 2000; Widdowson, 1991) and the wide range of variations of this element in basic rocks. Also, this element exhibits completely incompatible geochemical behavior during melting and differential crystallization in basaltic melts (Talusani, 2010) and has a strong tendency to enter and remain in the melt phase.

As shown in Fig. 5, the trend of Ni is somewhat scattered but negative compared to Zr. On the other hand, Th is somewhat scattered but positive compared to Hf. The trends observed in these diagrams show the relationships of the rocks of the region and the origin of the magma that forms them from a source with almost similar geochemical properties. Furthermore, the main petrological control is related to the crystallization process in the basaltic magma of the region.

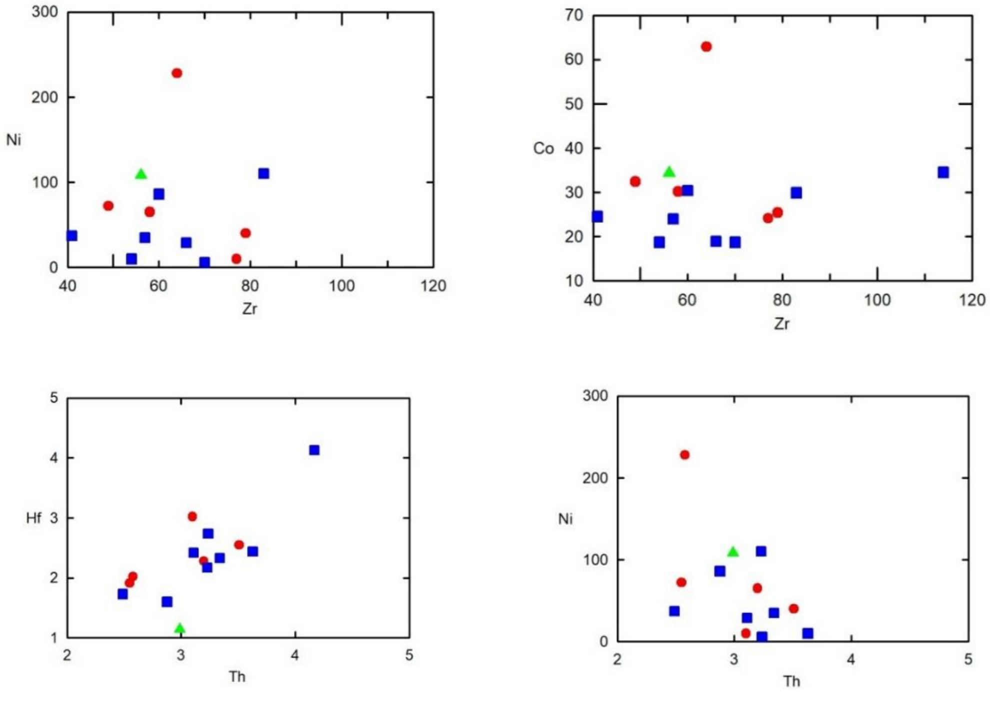
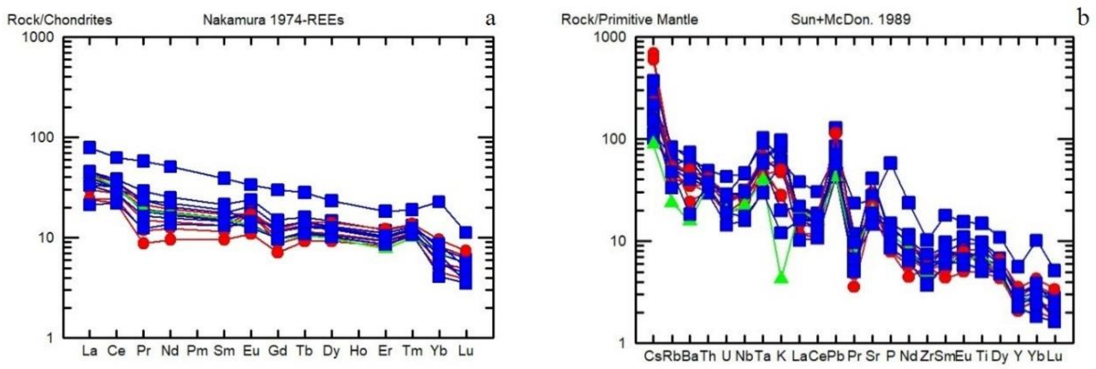


Figure 5 - Diagrams of changes in incompatible elements against each other
Source: Authors (2021)

The diagrams in Fig. 6 show the average of normalized rare and rare earth elements relative to the values of chondrite, mid-ocean ridge basalts (MORBs), primary mantle, and ocean island basalts (OIBs) for the rocks of the study area. These diagrams show similar patterns of element distribution in the rocks of the region. In the normalized diagram relative to the primary mantle values, some positive and negative anomalies are seen in the values of Sr, Rb, Nb, Pb, and Ba (Fig. 4a and b). Since Ti and P elements are in the group of elements with high field strength (HFS) and do not show mobility during secondary processes, the cause of the anomaly observed in them can be considered as petrological factors.

The presence of negative anomalies in Nb also indicates the role of magmatic contamination with the continental crust in the evolution of rocks in the region. Severe positive anomalies of Pb and Ba indicate continental crustal contamination and a positive Sr anomaly indicates the presence of plagioclase phenocrysts in the rock. The positive anomaly is related to the element Th, the increase of which indicates crustal contamination.



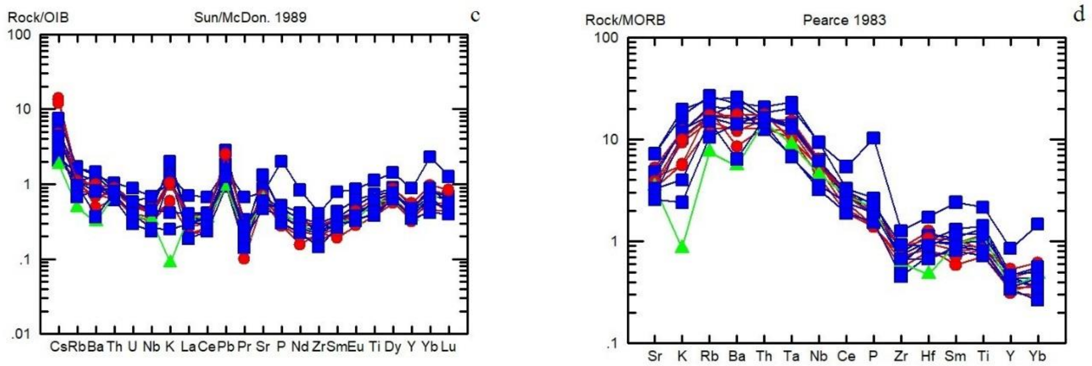
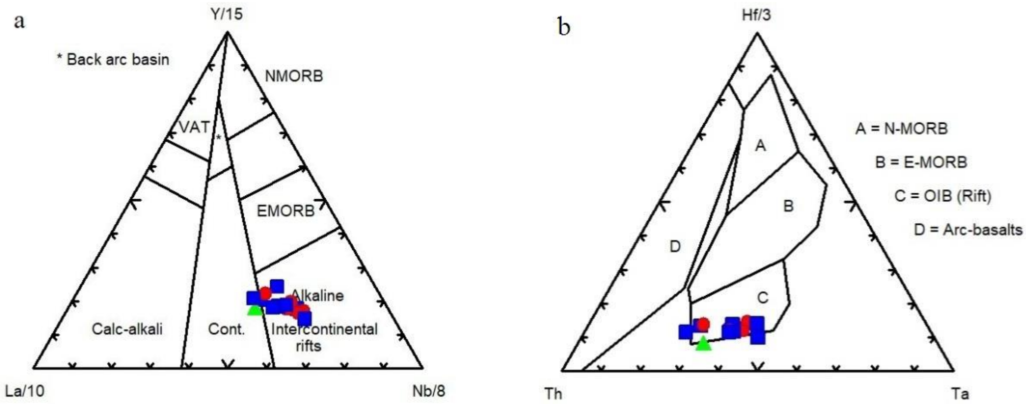


Figure 6 – (a) Normalized diagram of samples relative to chondrite (Nakamura, 1974); (b) Normalized diagrams of samples relative to the primary mantle (Sun and McDonough, 1989); (c) Normalized diagrams of samples relative to OIB (Sun and McDonough, 1989); (d) Normalized diagram of samples relative to MORB.

In the diagram of Gabanis and Lecolle (1989), the studied specimens are located in the intercontinental rift range (Fig. 7a). According to the diagram of Peacer (1982), Wood et al (1980), and Shervis (1982), the specimens are in the range of volcanic arc (Fig. 7b), rift (Fig. 7c), and in-plate basalts with alkaline nature, respectively.



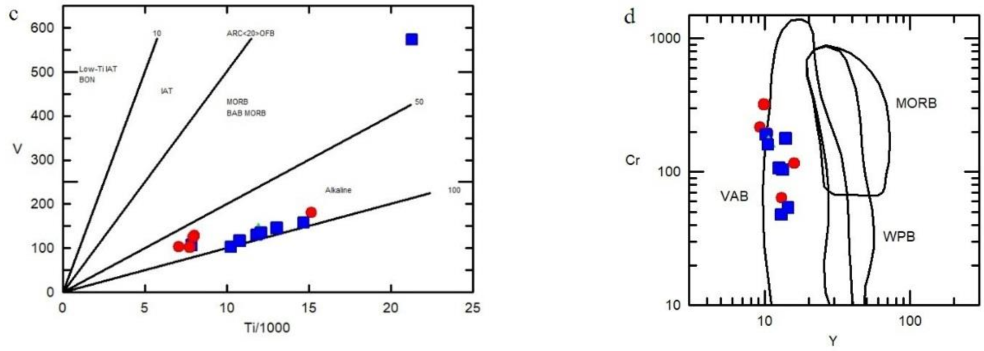


Figure 7 – (a) Position of the studied samples in the diagram of Gabanis and Lecolle (1989); (b) Ternary diagrams to determine the tectonic environment (Wood et al., 1980); (c) The position of the samples of the region in the diagram of Shervis 1982; (d) The position of the studied samples in the Cr diagram against Y (Pearce, 1982)

To determine the amount of crustal contamination and its role in the evolution of magmas forming rocks in the region, we used the trends presented by He et al. (2010) and rare element ratios presented by Hart et al. (1989). The trend of the analyzed samples on the diagram of changes of Th/Nb versus SiO2 shows the role of differential crystallization and the involvement of crustal contamination in the evolution of rocks in the region (Fig. 4-8). Moreover, according to Hart et al. (1989), La/Nb ratio greater than 1.5 and a La/Ta ratio greater than 22 indicate magma contamination with crustal compounds. These ratios in the intrusions of the study area are maximum 0.88 and 9.16, respectively.

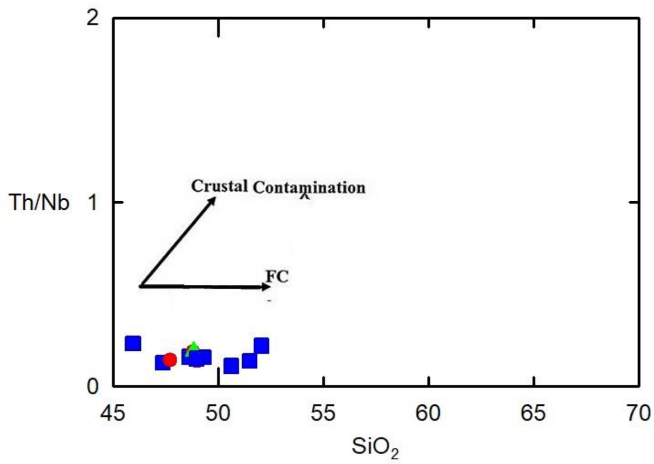
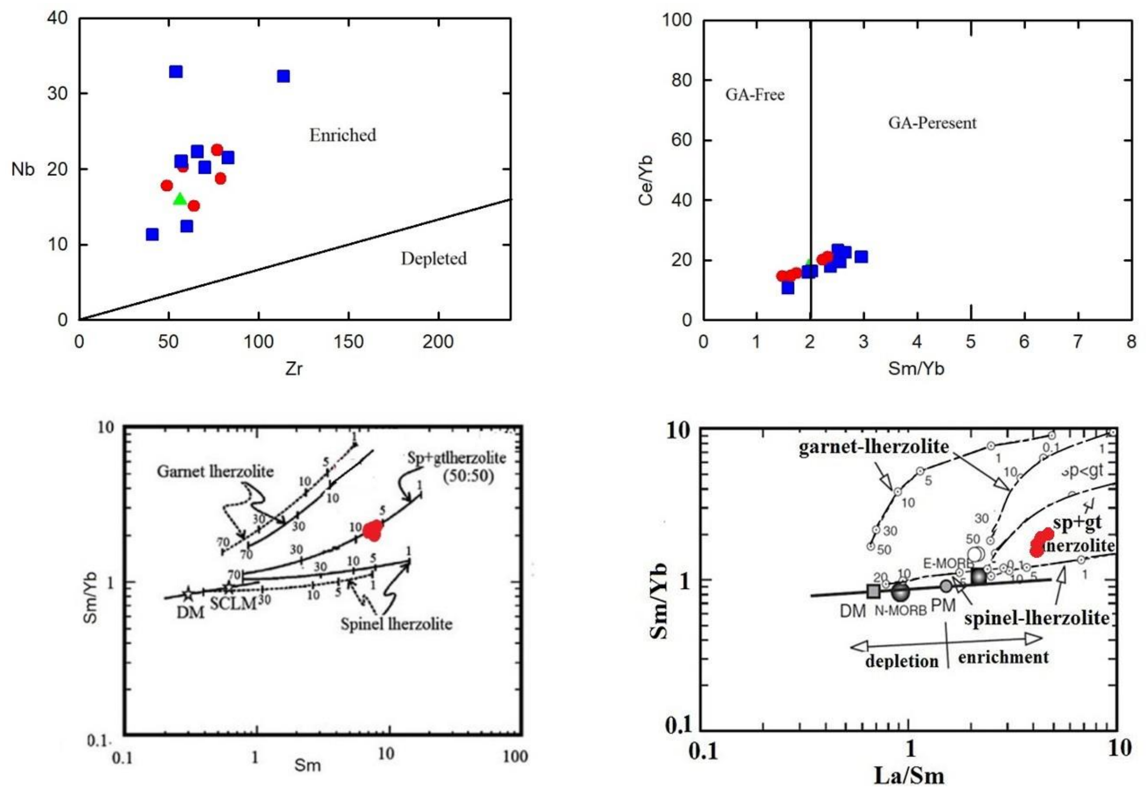


Figure 8 - Diagram of Th/Nb changes versus SiO2 to determine the amount of crustal contamination and its role in the evolution of magmas forming rocks in the region according to the trends presented by He et al. (2010).

The ratio of Ce/Yb can indicate the depth and melting rate of the parent rock. A small value of this ratio (less than 15) suggests that the magma originated from the upper parts of the mantle (low depth or high melting rate). In contrast, magmas with a high ratio of Ce/Yb (greater than 15) indicate that the magma originated from the deep depth (garnet stability field) and the low melting rate (high pressure) (Cotton et al., 1995). The ratio of Ce/Yb in the intrusive masses of the region is about 17.92 on average, suggesting the high depth and low melting rate of samples. Conly et al (2005) also believe that 0.12 < Rb/Zr indicates a mantle source affected by metasomatism, the average of this ratio in the rocks of the study area is about 0.56. To determine the degree of enrichment of the source of the studied rocks, the ratios of incompatible elements Zr/Y and Zr/Nb were used (McDonough, & Sun, 1989). The elements Zr and Nb during differential crystallization of olivine, pyroxene, magnetite, and plagioclase behaves inconsistently in basaltic magmas. Based on these ratios, all specimens studied are placed in the source of the enriched mantles (Fig. 9) . The element Sm behaves inconsistently compared to Yb in the mantle. Since this element is present in the pyroxene structure and sometimes in the amphibole structure, its values change dramatically compared to Yb during melting processes (Li & Che, 2014).

Therefore, the Sm/Yb ratio can be used to determine the chemical composition of the mantle (2000, Aldanmaz et al.). In the diagram of Sm/Yb versus Ce/Sm, which is designed to detect the presence or absence of garnet at the source of melt production, the specimens are in the garnet range and prove the presence of garnet at the source of these rocks (Fig. 9b). Geochemistry of rare earth elements is widely used to determine the degree of melting and depth of mantle origin of primary magmas (Rollinson, 1993; Furman, 2007; Zhao & Zhou, 2007).

The diagram of Sm/Yb versus Sm shows the changes in the degree of melting in the two mantle origins of peridotite spinel and peridotite garnet. In this diagram, the Sm/Yb and Sm ratio decrease with increasing partial melting rate. The basalt rocks studied in this diagram are located on the peridotite garnet melting curve with a melting point of 1 to 10% (Fig. 9f). The depth obtained for the melting point of the mother magma of the studied samples using the Ce diagram in relation to Ce/Yb is 100 to 110 km (Ellam, 1992).



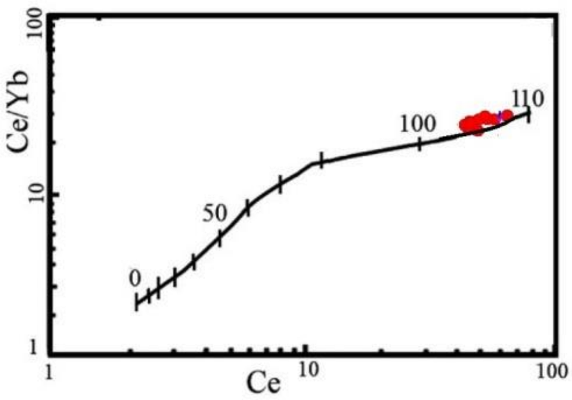


Figure - 9: (a) Graph of Sun & McDonough (1989); (b) Graph of Coban (2007); (c) Graph of Aldanmaz et al (2000). d) Green (2006), e) Graph of Ellam (1992).

Presenting a geodynamic model for the formation of igneous rocks in the study área

The post-impact environment basically involves a complex period. Various tectonic models including fracture and detachment of the subduction plate (Davies & Von Blankenburg, 1995), lithosphere delamination (Bird, 1979), slab rollback of the subduction zone (Lonergan and White, 1997), and of course the local tensile basin (Keary & Vine 1996: Einsele, 2000) have been used to justify post-impact tension.

Older magmatic activity in the Sanandaj-Sirjan zone includes Late Triassic and Early Jurassic tholeiitic mafic volcanic rocks (Alavi and Mah-davi, 1994), interpreted as remnants of Tethyan oceanic crust(Mohajjel et al., 2003), and Late Proterozoic to early Paleozoic mafic rocks formed during extensional events (Berberianand King, 1981; Rachidnejad-Omran et al., 2002).

The overall petrography, petrology, and geochemistry of the Vercheh rocks of Sanandaj in Iran, were derived from a lithospheric mantle source. The data indicate that the lithospheric mantle was affected by slab-related hydrous fluid resulting from the nearby subduction of the Neo-Tethyan Ocean under the SSZ. The fluid-related metasomatism was pervasive, and eventually led to the mantle becoming hybridized and highly enriched in compatible elements, with unusual elemental ratios. the metasomatized mantle source for Vercheh rocks had highly fractionated ratios of Rb/Cs, Nb/U, Ce/Pb, Rb/Ba, and Th/U. These observations support the hypothesis of dehydration associated with slab subduction at a convergent margin. Finally, it is important to acknowledge that the extensive development of volcanic and plutonic rocks of contrasting composition and tectonic settings in Iran cannot be interpreted in terms of a single, simple subduction zone (fig 9).

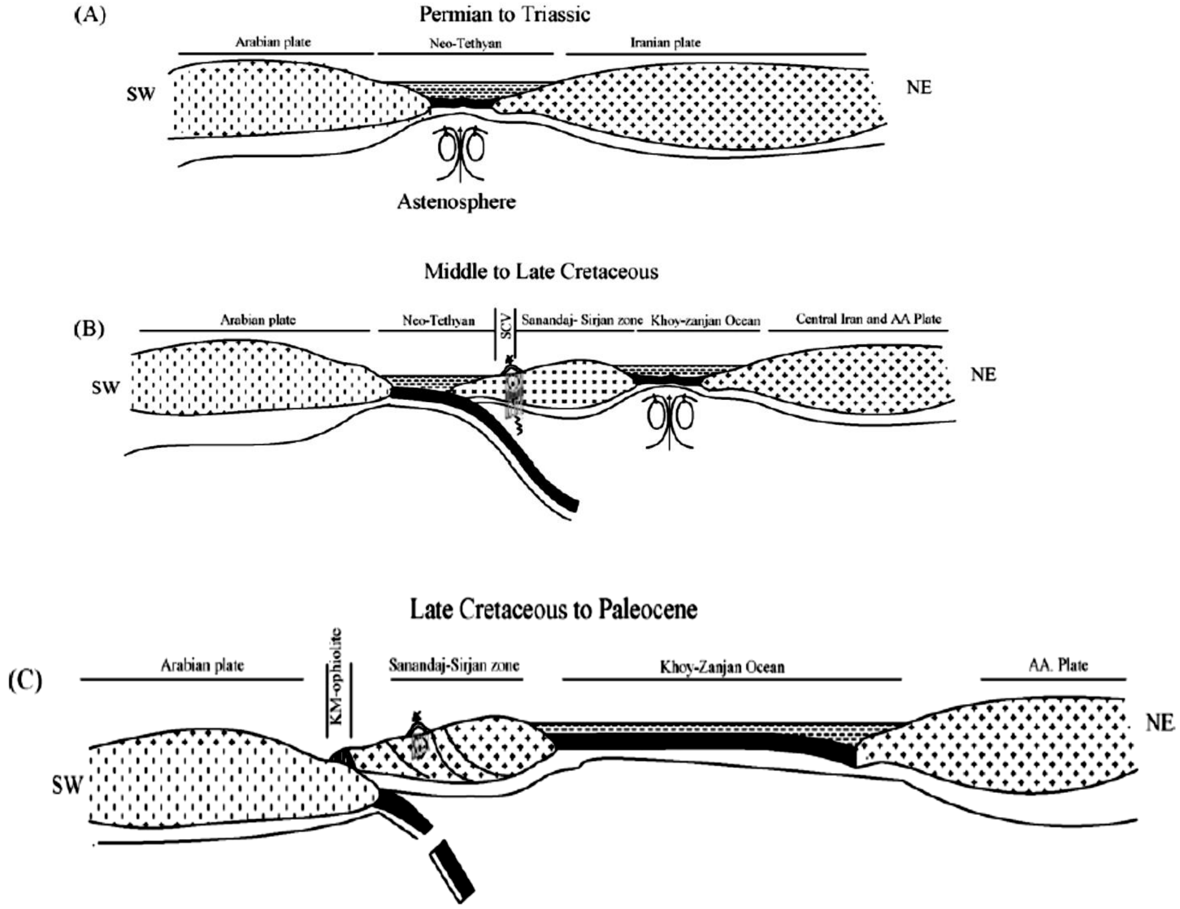


Figure 10 - Proposed model for evolution of the NW Iran. a) Drifted Iranian plate (include SSZ and central Iran) from Arabian plate in Permian to Triassic. b) Subduction of Neo-Tethyan oceanic plate beneath the SSZ and generation of the SCV(Cretaceous volcanic rocks) in active margin of the SSZ and developing a new fracture with NW–SE direction in the east of the SSZ which separated it from the central Iran (C.I.) and Albourz-Azarbadijan (AA) plate in the middle to late Cretaceous probably. c) Collision of Arabian plate with the SSZ and obuduction of NZ-ophiolite (such as Kermanshah) and developing of Khoy-Zanjan narrow oceanic crust in the upper Cretaceous-Paleocene(Azizi and Jahangiri, 2008).

Conclusion

According to studies, the rock units of the region include intrusive masses and have an alkaline nature. Based on lithographic studies, their texture is granular, intergranular, poikilitic and ophitic. Geochemical studies indicate that the magma forming these rocks was formed from the melting of 2 to 5% of a mantle source of garnet peridotite at a depth of 100 to 105 km. studies also indicate the role of differential crystallization as the main process in the formation of magma forming these rocks. According to tectonic diagrams and geostructural studies, the rocks of the region were formed in an intercontinental tensile environment.

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