Comparative review of the Northern Sanandaj-Sirjan Zone granitoids

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Abstract

The Sanandaj-Sirjan Zone is mainly composed of metamorphic complexes and granitic intrusions. These bodies are exposed and covered wide area of the Northern part of the zone. They are high potassium calk-alkaline felsic rocks and based on their Chondrite-normalized rare earth elements (REE) patterns, the LREE are enriched relative to HREE. The volcanic arc and within plate are the main tectonic environment of granite. The granitoids age of the Northern part of Sanandaj-Sirjan Zone are classified into three classes of Paleozoic, Middle Jurassic and Tertiary. The Sr-Nd isotopic ratios indicate a significant contribution of isotopically evolved components (older sedimentary material).

Keywords: Sanandaj-Sirjan, Granite, Neotethys, Subduction, Calk-Alkaline.

1- Introduction

The average composition of the continental crust is granodioritic (Clarke, 1992) and in some orogenic belts (e.g. Sanandaj-Sirjan) granitoids form as much as 30% of the surface outcrop and are an essential component of the continental crust. These rocks occur in the great belts which commonly extend for hundreds or even thousands of miles as individual bodies. They could be very large, or quite small, and which are invariably rather complex.

In Iran, generally, granite studies were mainly pursued on such bodies by individual geologists resulting in a patchwork of information which, while excellent in itself, but has not dealt with the regional geology problem as a whole.

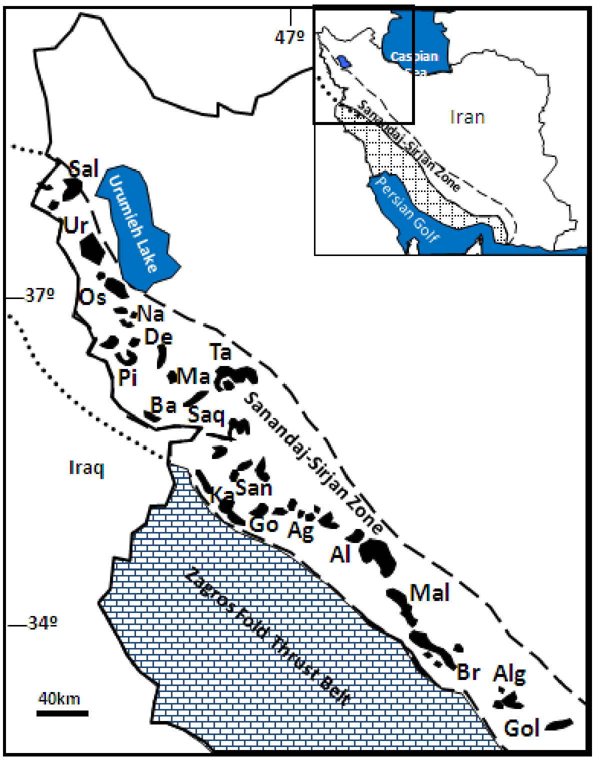
The Sanandaj–Sirjan Zone (SSZ) is one of the most important tectonic sections of Iran that include numerous plutonic bodies. It is a part of the Zagros orogeny and divided into an outer belt of imbricate thrust slices that includes the Zagros suture and an inner belt of mainly Mesozoic metamorphic rocks (Mohajjel *et al*, 2003). Because of the SSZ is suture zone between Afro-Arabian and Iranian plates (Alavi, 2007), understanding its geological history could unravel the regional geology of adjacent areas.

Geographically, the SSZ is subdivided into two parts in the Golpaygan area by Eftekharnejad (1981) (Fig. 1): (1) The southern SSZ which consists of rocks deformed and metamorphosed in Middle to Late Triassic; (2) The Northern SSZ that deformed in the Late Cretaceous and contains many intrusive felsic rocks.

The northern part of SSZ is composed of several plutonic bodies that cover approximately 30% of outcrops. The most important studied bodies from northwest to southeast are as follow (Fig 1): Sheidan-Siahkuh Salmas (Ghaffari *et al*., 2006); Goshchi (Advay *et al*., 2010); Urumieh (Ghalamghash *et al*., 2009a); Oshnaviyeh (Ghalamghash, 2002) Naqadeh–Khalifan–Pasveh (Mazhari *et al*., 2011); Piranshahr (Mazhari *et al*., 2009); Mahabad (Shahbazi and Valizadeh, 2000); Baneh (Mazhari, 2012); Khalifan (Bea *et al*., 2011); Shahin Dezh (Kholghi and Vossoughi Abedini, 2005); Saghez (Arian *et al*., 2011); Takab (Jamshidi-Badr *et al*., 2013); Almogolagh (Fayyazi, 1975; Amiri and Amini, 2004); Alvand (Shahbazi *et al*., 2010); Malayer (Ahadnejad *et al*., 2011a); Boroujerd (Ahmadi-Khalaji *et al*., 2007);

Aligoodarz (Esna-Ashari *et al.*, 2012); Hasanrobat Golpaygan (Alirezaei and Hassanzadeh, 2012).

This study compares petrological characteristics of the the Northern Sanandaj-Sirjan Zone Granitoids (NSSZG), which is its large proportion, to improve our understanding of the magmatic evolution in the SSZ and timing and fashion of the Afro-Arabian–Iranian collision.



Sal = Salmas
Ur = Urumieh (Ghalamghash et al., 2009a)
Os = Oshnavieh (Ghalamghash et al., 2008)
Na = Naqadeh (Mazhari et al., 2010)
De = Delkeh (Mazhari et al., 2010)
Pi = Piranshahr (Mazhari et al., 2009)
Ma = Mahabad (Shahbazi and Valizadeh, 2000)
Ta = Takab (Jamshidi-Badr et al., 2013)
Ba = Baneh (Mazhari, 2012)
Saq = Saqqez (Arian et al., 2011)
Ka = Kamyaran
San = Sanandaj
Go = Ghorveh (Zakariaee and Fakher, 2008)
Ag = Almogholagh (Fayyazi, 1975)
Al = Alvand (Shahbazi et al., 2010)
Mal = Malayer (Ahadnejad et al., 2011a, b)
Br = Boroujerd (Ahmadi-Khalaji et al., 2007)
Alg = Aligoodarz (Esna-Ashari et al., 2012)
Gol = Golpayegan (Alirezaei and Hassanzadeh, 2012)

Figure 1) Generalized tectonic map of Northern Sanandaj-Sirjan Zone and its plutonic bodies locations.

2- Lithology

The granitic and granodioritic rocks are the most abundant types of intrusive rocks in the studied area. Diorite and tonalite accompany with small stocks of syenite, monzonite and gabbro are exposed as well. The Urumieh plutonic complex is mainly composed of granite, diorite and small stocks of alkali syenite (Ghalamghash *et al.*, 2009a). Based on Ishihara (1977), they are mostly I-type granites and related to the magnetite series (Ghalamghash *et al.*, 2009b). The Oshnavieh Plutonic Complex (OPC) also has two suites of diorite and granite with I and S-type affinities, respectively (Ghalamghash *et al.*, 2008). The Naqadeh intrusive complex is composed of two different mafic and felsic units (Mazhari *et al.*, 2010a). The major components of Naqadeh pluton are granitic rocks. The small Delkeh (Mahabad-Pasveh) pluton includes two different dioritic and granitic units (Mazhari *et al.*, 2010b). The Piranshahr massif is bimodal, comprising approximately the same exposure of mafic (gabbro) and A-type felsic (syenite) rocks (Mazhari *et al.*, 2009).

Between Bookan and Mahabad, there are several felsic intrusive bodies. These peraluminous granitic rocks are related to so-called Doran-type granites (i.e., late Precambrian age- Shahbazi and Valizadeh, 2000). Based on their lithological features and different compositions, three suites of plutonic rocks of syenogranite (S-type), granodiorite to tonalite (I-type), and quartz porphyry (I-type) can be distinguished in the Takab area (Jamshidi-Badr *et al.*, 2013). The Baneh intrusives include both I-type (biotite-granite) and S-type (amphibole-granite) rocks (Mazhari, 2012). The biotite-granite is dominantly covered this area.

In the Saqqez area, some of intrusive masses with the composition of granite, granodiorte, quartz-monzonite and quartz-diortite have penetrated to older rocks such as Kahar formation sandstone (Arian *et al*., 2011). These felsic rocks belong to I-type granites. Hassanzadeh *et al* (2008) report biotite-hornblende granodiorite with abundant zoned plagioclase in the Sheikh Chupan and without hornblende and zoned plagioclase granodiorite of Bubaktan, west and east of Saqqez, respectively. The Hasan Salaran granitoid complex (SE Saqqez) consists of two distinct granitoid types with various geneses (Athari *et al*., 2006): The first type is mainly composed of alkali-feldspar granite, syenogranite and alkali-feldspar quartz syenite (A-type) and the second type is composed of monzogranite, granodiorite and tonalite (I-type).

Ghorveh Plutonic rocks outcropped at the south of Ghorveh city. These igneous bodies are composed of acidic (granite), intermediate (quartz-monzogabbro and Monzodiorie) and basic (Gabbro) (Sheikh-Zakariaee and Ghaffari-Fakher, 2008). In the northern part of Asad Abad city, there is a large intrusive body (Almogholagh). Amiri and Amini (2004) studies show that the syenogranite is an abundant rock in the area and it is attributed to the I-type granites.

The Alvand pluton is one of the largest plutonic bodies in Iran which is located in the northern part of the SSZ. Severeal studies were performed on the petrology and microtectonics of this pluton (e.g., Sepahi, 2008; Shahbazi *et al*., 2010; Aliani *et al*., 2012). This pluton consists of granites (monzogranite and syenogranite), leucocratic granitoids (leucocratic tonalite, leucocratic granodiorite, and leucocratic quartz monzodiorite), mesocratic granitoids (tonalite, granodiorite, and quartz diorites), and abundant aplitic and pegmatitic dikes. The mineralogical, lithological, and geochemical studies along with field observations indicate that the Alvand granites have S-type characteristics with minor H and I-type intrusions. However, Shahbazi *et al* (2010) referred them to the A-type granitoids.

To the southeast, the Malayer plutonic rocks are exposed next to the Malayer city. It is made up of different textural and compositional bodies including granite (monzogranite and syenogranite), granodiorite, tonalite and diorite with subordinate monzosyenite and gabbro bodies that occur in only a few places along the southeastern part of the pluton (Ahadnejad *et al*., 2011a). The contents of ammonium suggest S-type for most of the Malayer intrusive rocks (Ahadnejad *et al*., 2011b). Ahmadi-Khalaji *et al* (2007) report three main rock types for the I-type Boroujerd granitic Complex including granodiorite, quartz-dioritet and monzogranite accompany with locally acidic dikes. The Aligoodarz granitoid complex is located in the Sanandaj-Sirjan Zone (SSZ), western Iran and consists of quartz-diorites, granodiorites and subordinate granites (Esna-Ashari *et al*., 2012). Esna-Ashari report these rocks as I-type granites, although other studies shows hybrid character for the Aligoodraz granitoids (e.g. Rajaeiyeh, 2005).

In the most southeastern part of the northern SSZ, there is an intrusive body in the northeast of Golpaygan city. It is recently is studied by Alirezaei and Hassanzadeh (2012). The hasanrobat pluton consists of granite and mylonite granite and has intrepreted as an A-type granite.

3- Whole Rock Geochemistry

More than 210 analyzed bulk rock samples were gathered from other authors works including 18 samples of Urumieh (Ghalamghash *et al*., 2009a), 11 samples of Oshnavieh (Ghalamghash *et al*., 2008), 4 samples of Naqadeh (Mazhari *et al*., 2010), 2 samples of Delkeh (Mazhari *et al*., 2010), 3 samples of Piranshahr (Mazhari *et al*., 2009), 50 samples of Takab (Jamshidi-Badr *et al*., 2013), 20 samples of Saqqez (Arian *et al*., 2011), 16 samples of Almogholagh (Fayyazi, 1975), 11 samples of Alvand (Shahbazi *et al*., 2010), 16 samples of Malayer (Ahadnejad *et al*., 2011a), 22 samples of Boroujerd (Ahmadi-Khalaji *et al*., 2007), 18 samples of Aligoodarz (Esna-Ashari *et al*., 2012) and 9 samples of Golpayegan (Alirezaei and Hassanzadeh, 2012).

The assessing of whole rock geochemistry revealed that the NSSZG are broadly calc-alkaline to high-K calc-alkaline. The calc-alkaline chemistry of the rocks is illustrated in Figure 2, a plot of wt % K_2O vs wt % SiO_2, which includes the field boundaries of Peccerillo and Taylor (1976).

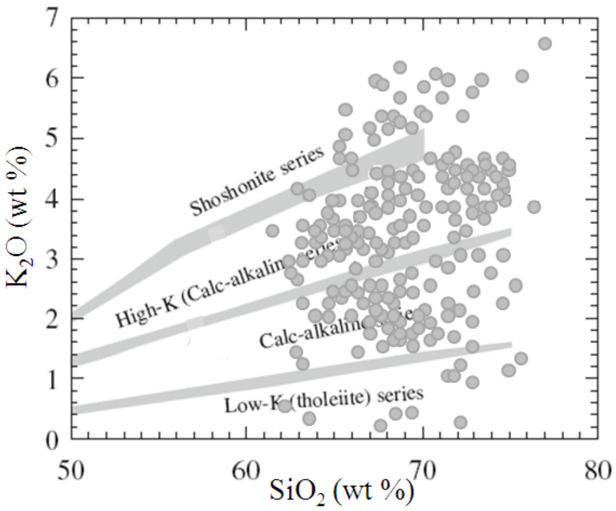


Figure 2) K_2O vs SiO_2 contents displaying the shoshonite, high-K, medium-K and low-K fields (from Peccerillo and Taylor, 1976; modified by Rickwood, 1989). The NSSZG are mostly located in the calk-alkaline fields.

The Figure 3 shows their plot of molar A/CNK vs wt % SiO_2. From this plot it is clear that there is a roughly linear trend of increasing A/CNK (range from 0.7 to 1.8) with increasing SiO_2 (62–78 wt%).

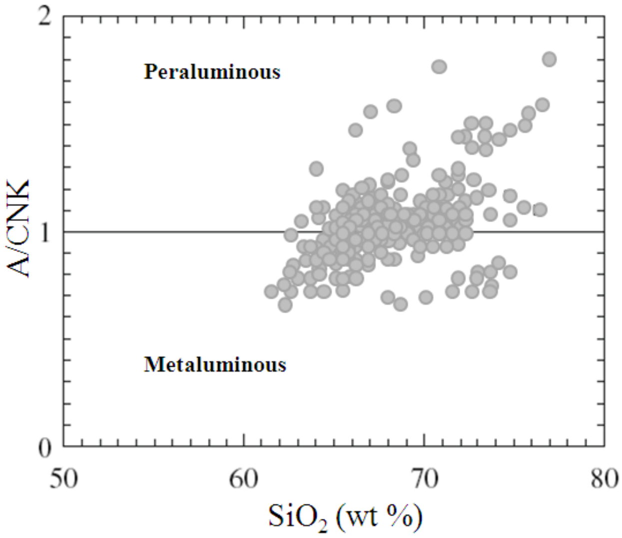


Figure 3) A/CNK vs. SiO_2 variation diagrams for the NSSZ granitoids: the suite are dominantly located between metaluminous (A/CNK < 1.0) and peraluminous (A/CNK > 1.0) border.

Here, the granites and granodiorits plot in the field that defines calc-alkaline to high-K calc-alkaline rocks, whereas the syenites (mostly includes almogholagh samples) straddle the boundaries between high-K calc-alkaline and shoshonitic series fields.

The intrusive rocks have a variable composition. Based on the degree of alumina saturation, the rocks are generally spread from a weakly metaluminous to strongly peraluminous. Based on Whalen *et al* (1987) diagram, because the NSSZG have mostly low contents in high field strength elements (HFSE), such as Zr and Nb, they have S and I-type nature rather than A-type as shown in the Figure 4.

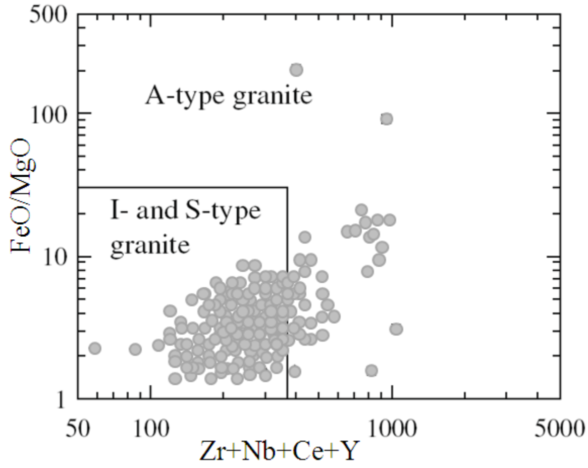


Figure 4) (Zr+Nb+Ce+Y) vs FeO/MgO discrimination diagrams of Whalen et al. (1987). The NSSZG are mostly I and S-type. Some bodies like Piranshahr, Saqqez, Alvand and Golpayegan have A-type characteristics.

In general, Chondrite-normalized REE patterns show that the NSSZG are enriched in light REEs (LREEs) relative to heavy REEs (HREEs), have a negative Eu anomaly, a flat HREE pattern (Fig. 5). However, the Hasanrobat granite is distinguished by considerably higher contents of REE relative to other plutons (Alirezaei and Hassanzadeh). The Takab granites show a steep LREE pattern (Jamshidi-Badr, 2013).

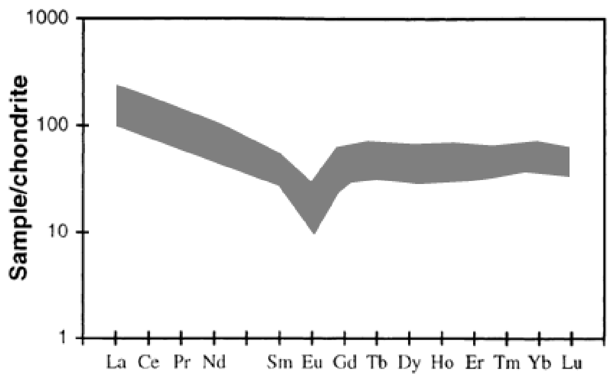


Figure 5) Chondrite normalized REE patterns of NSSZ granitoids (chondrite values from Boynton, 1984).

4- Sr-Nd Isotopes

The Sr isotopic ratios for the NSSZG have an average value ($^{87}Sr/^{86}Sr \approx 0.7093$). This indicates a significant contribution of isotopically evolved components (older sedimentary material) and/or seawater alteration across of the Northern Sanandaj-Sirjan Zone (Fig. 6).

In contrast, Nd isotope ratios of the NSSZG do not show a significant spread of values. However, the Piranshahr granites are more radiogenic and close to the MORB domain (Fig. 6). The Sr-Nd isotope ratios for the NSSZG samples plot within the field of oceanic sediments whereas the Piranshahr plot in the Continental Margin Arcs (Fig. 6).

5- Tectonomagmatism

In the Northern Sanandaj-Sirjan, felsic rocks make up the dominant lithologies (Fig. 1). Moreover, the rocks have mostly high K_2O (Fig. 2) and Rb contents and low contents of MgO and Ni (not shown), indicating that the primitive mantle liquid compositions are not their source and that the parental melts have undergone significant crystal fractionation prior to emplacement into the Northern Sanandaj-Sirjan crust.

Although, some of the NSSZG show A-type characteristics (i.e. Alvand and Golpayegan), they have mostly S and I-type tendencies suggesting their formation in a subduction related environment (volcanic arc). Pearce *et al*. (1984) tectonomagmatic discrimination diagram (Fig. 7) for the studied rocks displays Volcanic Arc and Within Plate as major tectonic environment for the granites.

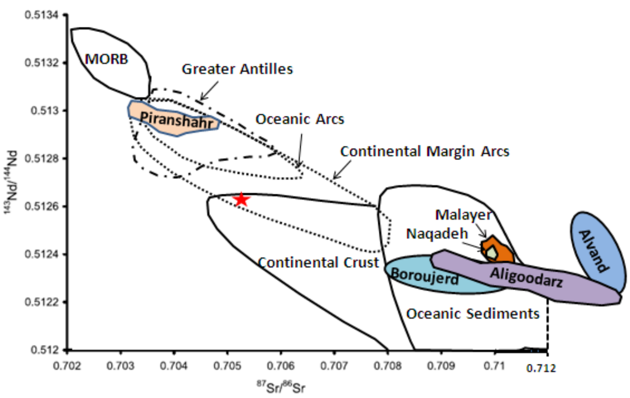


Figure 6) Measured Sr-Nd isotopic ratios for the NSSZG samples (references are as section 1), with comparisons. Data source: Greater Antilles field drawn from GeoRoc database. Other reference fields from Jolly et al (2006) and Wilson (1989). Star symbol represents Bulk Earth Composition. Most granitoids of the Northern Sanandaj-Sirjan Zone show evolved characteristics such as sediments.

The volcanic arc granites could be represent Neotethys oceanic crust Northeastern subduction under Iranian microplate during lower Triassic to Miocene. During this subduction, the oceanic crust and sea floor sediments were fragmented and accreted to the base of the Sanandaj-Sirjan Zone as a hanging wall. Following this event, the metamorphic and metasediment units were then accreted to the base of the Sanandaj-Sirjan during the progressive elimination of the northern Neotethyan oceanic basin. The metasediments have then lost most of their original water and lowers the melting point of the mantle rock and causes partial melting of mantle wedge of subcontinental lithosphere. The result is formation of metasomatised and enriched mafic arc magmas at variable water fugacity whioch could led to the formation of the granitoid rocks by crystal fractionation process. Therefore, these features were followed by the magmatism and intrusion of a volcanic arc granitoids (186 to 41 Ma) along the Northern Sanandaj-Sirjan active continental margin.

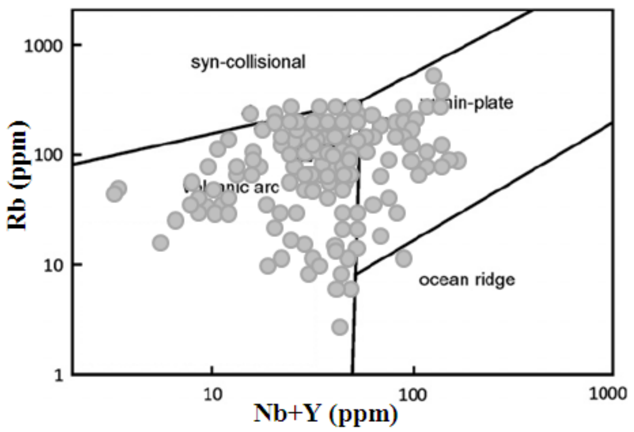


Figure 7) Most NSSZ granitoids with age range between 41 to 540 Ma, plot in a Volcanic Arc field in Pearce et al. (1984) Rb vs. (Nb+Y) diagram.

In the case of Takab area, the formation of its granitoids is referred to continent-continent collision in the late Proterozoic (Jamshidi-Badr *et al.*, 2013).

6- Summary and conclusions

In this paper, more than two hundred samples from the northern part of Sanandaj-Sirjan Zone were selected. These samples are studies by several authors for individual batoliths of the mentioned area. This research involved gathering analytical data (whole rock geochemistry), field work, isotopic data and geochronology. The results show that:

- The variation in geochemical characteristics of some intrusive bodies in the study area (e.g. Boroujerd and Golpayegan), suggests: a) the mixing of mafic and felsic magmas during the genesis of the bodies which could be examined by their association with mafic rocks (quartz-diorite and mafic enclaves), b) heterogeneity of the country rocks (metasedimentary, igneous or metamorphic types), c) different tectonic setting (volcanic arc, within plate, syn-collisional, post-collisional, …).
- The continuous geochemical trends between granitic bodies (e.g. Boroujerd and Malayer) argue for a syn-plutonic emplacement, with a clear crustal signature.
- The overall time for the crystallization and emplacement of the NSSZG was rather wide.
- According to geochronological age, the graniroids could be classified into three series: 1) Paleozoic series that related to Cadomian collision along the northern margin of Gondwana after its final amalgamation (e.g. Takab granitoids); 2) Middle Jurassic granitoids that include most plutons and are related to Netotethys subduction beneath Central Iran plate (e.g. Alvand, Malayer, Boroujerd, Aligoodarz); 3) The 40 to 60 Ma granitoids that are related to late stages of Netotethys subduction (e.g. Piranshahr, Turke Dare of Takab).
- The fractional crystallization was the main differentiation process during their formation.
- The felsic magmas probably formed from a heterogeneous crustal source and field data such as mafic enclaves suggest a link between melting process and the

emplacement of the mafic magmas in the crust.

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