PETROLOGY AND MINERALIZATION OF SEHEZAR VALLEY INTRUSIVE BODIES, TONOKABON, WITH EMPHESIS ON MINERAL POTENTIAL

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Abstract: Sehezar area is located in southern Tonokabon in Mazandaran province, north of Iran, near Tarom–Hashdtjin belt. Occurrence of granitoid masses in the region can be important in terms of mineralization potential. Geological units exposed in the study area mainly consists of Palaeozoic to Cenozoic rocks. In this research, microscopic and petrographic studies were performed on a number of samples from the region, as well as granite samples for intrusions classification. In reflected light microscopy pyrite, chalcopyrite and magnetite were identified in some samples. Igneous rocks have granular, hyaloporphyritic and vitrophyric textures. Porphyry textures indicates the coincident of intrusions with volcanics and clastics probably originating from a same magmatism. The major minerals in igneous rocks include quartz, K-feldspar, plagioclase, and in some cases, hornblende, biotite, and pyroxene. The minor minerals are sphene, iron oxides, apatite and opaque minerals. Petrographic studies showed that the intrusive rocks are granite, granodiorite, syenite to quartz-syenite and quartz-monzonite. The magmatic rocks are alkaline to calc-alkaline, magnesian rich and fit in metaluminous to peraluminous field. The granites are peraluminous and I-type of active continental margin tectonic settin. Variography of stream sediments samples showed that the spherical model is the best fit for the data, and spatial correlation range for Au, Cu and Fe are approximately 350 m. Evaluation of geostatistics results by calculating the root mean square error (RMSE) and the mean absolute error (MAE) indicates the acceptable accuracy of variography model. According to the Meinert diagrams and spatial correlation of the elements, it is may be concluded that these intrusive masses are associated with iron-gold-copper mineralization.

Keywords: Petrographic, calc-alkaline, Peraluminous, type I, Geostatistics.

INTRODUCTION

Sehezar area is located in southern Tonokabon in Mazandaran province, between 36^{o} 27' to 36^{o} 35' N latitude and 50^{o} 45' to 50^{o} 55' E longitude. In the studied area Sehezar granite is the most important intrusive body with a limited exploration studies. The studies were conducted mainly far prospecting, lithogeochemical and stream sediment geochemical survey by Madankav consulting company in 1999, and a semi-detailed exploration in Aroud area of Sehezar Valley by Kavoshgaran consulting company in 2009 and 2011. Also, Rezvani and Ghorbani studied the lithogeochemical and stream sediment geochemical survey of Sehezar valley granite. In previous works, a strong anomaly of iron (magnetite type) was spotted.

Chemical and mineralogical composition of igneous rocks are related to their magmatic composition. The magma composition changes during rising and major, minor and trace elements are affected by magmatic evolutions such as fractional crystallization, partial melting, assimilation, contamination and magma mixing (Karimpour and Adabi, 2007). The mineralization in each deposit depends on several physico-chemical and geological factors, which control characteristics of the associated deposit and are effective in mineralization process and elements distribution in different regions and horizons and ultimately its economic concentration. One of the factors affecting mineralization is characteristics of the host rock such as rock type, porosity and proportion of rock forming minerals. Study of changes and developments in magma and derived igneous rocks are based on geochemical data.

Preliminary study on intrusive bodies for determining the associated mineralization potential includes considering three main factors of, tectonic setting, geochemistry and physico-chemical properties of ore bearing fluids (Karimpour and Sa'adat, 2005). For this purpose, many researchers in economic geology and petrology field have focused their studies on relationship between intrusive bodies and magmatic deposits. The aim of this study is to determine the geochemical and petrological characteristics of the Sehezar granites and their relationship with mineralization using EXCEL, GCDkit and Igpet softwares.

METHODS

For petrographic purpose, studied rocks were separated based on field, textural and structural evidences, and using trace and rare earth elements geochemistry and normalization of data.
For evaluating geochemical characteristics of the studied rocks, major and trace elements and their ratios were used. For geochemical study, fresh granite samples from Aroud (Sehezar) region were selected and analysed. Mineralogical studies were carried out on thin and polished sections of selected samples using optical microscope.

DISCUSSION

Igneous rocks textures in studied samples include granular, hyaloporphyritic, and vitrophyric. Presence of porphyry textures indicates the coincidence of intrusions with associated volcanics and clastics rocks. The major minerals in rocks include quartz, K-feldspar, plagioclase and in some cases, hornblende, biotite and pyroxene which appear as major minerals. The minor minerals include sphene, pyroxene, apatite, iron oxides and other opaque minerals. In some samples, quartz crystals were formed as intercrystalline boundaries and amorphous forms. Associated alteration assemblages include carbonate, silica and sericite.
Opaque minerals are pyrite, pyrrhotite, chalcopyrite, iron hydroxides and titanium oxide. Pyrite occurred as 33 to 433 µ automorphs to semi-automorph grains dispersed or arranged in fractures, as well as in form of veins with 4 to 10% frequency. Pyrite crystals are fresh with rare alteration and weathering and only a few of them were replaced by iron hydroxide. Minor chalcopyrite of 13 to 23 µ was recognized in contact with pyrite crystals.
Streckeisen classification (1979) is one of the first classifications of igneous rocks based on their constituent minerals. By focusing on the difference in the frequency and composition of feldspars, a wide range of granitoids is identified. This classification is based on mineral frequency and texture. Normative classification i.e. CIPW is also common in volcanic rocks classification. Studied rocks based on QAP diagram are quartz monzodiorite, monzogranite, granodiorite, quartz monzonite, monzonite and monzodiorite.
According to the Middlemost classification, intrusive rocks of the studied area are granite, quartz monzonite, quartz and syenite. There is a sample plotted on the boundary of tonalite and quartz monzodiorite and a sample within the gabbro domain, which can be a monzodiorite rock according to field observations and optical microscopy.
One of the important features of Cox et al. diagram is the existence of a line that separates alkaline and subalkaline rocks and it is possible to infer the development process of magma (Miyashiro, 1974). If the silica content is raised and alkaline elements are also gradually raised, it indicates occurrence of fractional crystallization. If the silica content decreases or stays steady, and alkaline content of the samples show an ascending trend, partial melting can be considered for the magma origin. According to this diagram, intrusive rocks of the study area are more in the alkaline range near to the syenite and syenodiorite fields. Two samples are granite and based on the alkali vs. silica slope of the samples, it seems that partial melting has played a significant role in magma evolution, since alkaline changes against the silica have a steep slope.
De La Roche et al. classified igneous rocks by using the milli-cationic ratios presented as R1 and R2 parameters (De La Roche et al., 1980). In this classification, properties of rock chemistry are expressed as cationic parameters in terms of mineralogical constituents. According to De La Roche et al., this diagram is more practical than Norm-base classification, and Rollinson recommends its use for plutonic rocks, though with considering some items it is also applicable for all kinds of rocks, i.e. using chemical properties of the major elements of rock; comparing modal and chemical data and identification of feldspar compounds and silica

saturation degree (Rollinson, 1993). In the De La Roche et al. diagram, studied intrusive rocks are quartz monzonite, monzonite and granite.

Barker (1979), O`Connor (1965) and Abdel-Rahman (1990) classify granitoids by using normative An–Ab–Or diagram (Barker, 1979; O`Connor, 1965; Abdel-Rahman, 1990). According to this classification, studied rocks are granite, granodiorite and quartz monzonite.

Irvine and Baragar (1971) used the total alkali vs. silica and FeO, MgO, Na_2O + K_2O diagram to determine magmatic series of igneous rocks (Irvine and Baragar, 1971). This diagram separates alkaline from sub-alkaline samples. Then, sub-alkaline samples are separated by the AFM diagram into calc-alkaline and Tholeiite magma. The intrusive body of the study area is belong to alkaline to calc-alkaline (Irvine and Baragar) series.

Frost et al. presented a geochemical classification for granitoid rocks based on FeO / (FeO + MgO) = Fen, modified alkaline-calcic index (MALI) (Na_2O + K_2O-Ca) and the aluminium saturation index (ASI) (Frost et al., 2001) and proposed new diagrams for distinguishing tholeiite and calc-alkaline series. In these diagrams, iron number separates ferroan and magnesian granite. According to this diagram, studied rocks are magnesian magmatic series of calc-alkaline domain. The second variable of Frost et al. is the modified alkaline-calcic index which is based on, Na_2O + K_2O, CaO and SiO2, in which volcanic rocks are divided into; alkaline (alkaline-calcic index less than 51), alkaline-calcic (alkaline-calcic index between 51 and 56), calc-alkaline (alkaline-calcic index between 56 and 61) and calcic (alkalin-calcic index greater than 61). Frost et al. reduced these three variables to two variables, including Na_2O + K_2O-CaO and SiO_2, which is why they are called the modified alkaline-calcic index (Frost et al., 2001). Based on this diagram, studied rocks are alkaline-calcic and alkaline close to the border with alkaline magma. Based on K2O vs. SiO2 diagram of Peccerillo and Taylor the studied rocks are classified as high–K calc-alkaline to shoshonite series.

By using these diagrams, samples of the Sehezar area are fit in the domain of I- and S- type granites. It can be concluded that the granite in the Sehezar area is formed from magma contamination of both crust and subduction related process.

In Maniar and Piccoli classification, granitoids are divided into orogenic and non-orogenic granitoids, of which orogenic granitoids include the subgroups of islands-arc granitoids (IAG), continental-arc granitoids (CAG), continental-collision granitoids (CCG) and post-orogenic granitoids (POG). Non-orogenic granitoids are divided into two subgroups of rift-related granitoid (RRG) and continental epeirogenic uplift granitoids (CEUG). Maniar and Piccoli diagram have been used to identify tectonic setting by using SiO_2, FeOt and MgO values (Maniar and Piccoli, 1989). According to the Maniar and Piccoli diagram, the studied rocks can be considered as orogenic type granites. Since A/CNK is less than 1.4, orogenic granite has been associated with continental-collision granite (CCG).

In Batchelor and Bowden diagram, cationic criteria of R1 and R2 have been used which were introduced by De La Roche et al. One of the most prominent features of this diagram is the staging of tectonic processes from pre-orogenic to post-orogenic (Batchelor and Bowden, 1985). According to the Batchelor and Bowden diagram, studied granites can be attributed to the post collision uplift to the late-orogenic field. Two of these samples are in the syn–collision field, which indicate the tectonic setting associated with S-type granite. According to this diagram, it may conclude that the Aroud granite are formed in the subduction zone, which is subjected to magma contamination by the crustal contamination.

In Na_2O + K_2O vs. SiO_2 diagram (Middlemost), studied samples are alkaline and may be related to Cu and Zn skarn. According to the Irvine and Baragar diagrams (AFM), which are intended to separate sub-alkaline samples, this intrusive body is in the Cu and Fe skarn domain.

In K2O-SiO2 diagram, data are fit in the range of high-K, which are related to the Fe-Cu-Au skarn associated with high-K rocks.

Considering significant relationship between nature of granite intrusions and associated mineralization potential, for the Sehezar I-type peraluminous granite, it may draw the following assumption:

- ✓ Peralkaline granite can often produce tungsten-tin, zinc and boron deposits due to the high volatile elements of fluorine and chlorine. It is rare that these high-grade deposits be produced from I-type granitoids and most tungsten-tin deposits are found in association with S-type granitoids.
- ✓ Magnetite and hematite deposits along with minor copper and gold are also occurred in association with oxide granites (Sillitoe and Hedenquist, 2003). Field observations confirmed the presence of iron oxide minerals in the region.
- ✓ The oxide I-Type magmas of magnetite series have a set of chalcophile elements that can be an appropriate potential for copper and copper-molybdenum porphyry deposits. In optical microscopy of the polished sections, pyrite, chalcopyrite and magnetite minerals were observed.
- ✓ Mica, pyroxene and amphibole minerals contain the most metallic elements in silicate magmas. Tungsten may replace in the structure of biotite, zinc and manganese, in the structure of calcium-rich minerals, iron and magnesium in the structure of spinel, amphibole, mica and pyroxene minerals, and scandium and vanadium content are also high in pyroxene structure.
- ✓ According to Meinert's diagrams, these intrusive bodies can be related to the iron-gold-copper deposit.
- ✓ In general, Cu, Co and Pb are often concentrated in magma with sulfide minerals, as well as Nb and Ta elements that are in the structure of minerals such as rutile. Tin is also concentrated in F-, Li- and B-rich fluids.
- ✓ In the Sehezar area, amphibole, biotite, albite and orthoclase are considered as the most important mineral which may have some ore mineral elements in their structure, which is evident by presence of opaque minerals in microscopic sections of study area.

Considering that the Sehezar area is located in central Alborz region, it seems that intrusions in this area is an amalgamation of I and S type granite (of course, the evidence suggests that granite is of I-type, and there are some crustal impurities in it). The tectonic setting by using the standard diagrams of Pearce et al. (Pearce et al., 1984), Schandl and Gorton (Schandl and Gorton, 2002) and Müller and Groves (Müller and Groves, 2000) indicate that this region is on the boundary between the magmas associated with the continental and oceanic plates. Harker and Spider diagrams reveals that, studied granite is of I-type and related to the subduction zone. The ionic and elemental exchanges development in the subduction environments are affected by the fluids mobility and chemical interaction with the materials originating from subducting plate with mantle plume. According to Richards, iron, copper, gold, LILE and HFSE elements are produced during slab break out in the subducting zone which may enriched by the following means (Richards, 2011):

1) Their enrichment in transported fluid.
2) Their enrichment due to slab melting.

Siderophile and chalcophile elements such as copper, gold and iron are concentrated in partial melting magma due to the high content of oxygen fugacity in the environment and sulphur-phile elements, along with the large ion lithophile elements (LITE) that are injected into shallow crust. This emplacement mechanism creates iron oxide copper-gold (IOCG), skarn and epithermal ore deposits. The oceanic crust contains high amounts of iron (from crust orsediments), which has a strong oxidizing nature and leads to formation of Fe^{3+}. As a result, magma can desolve high amounts of iron and copper in itself and carry them to the surface

(Bonin and Bébien, 2005). One of the reasons for the presence of scattered magnetite in porphyry copper-gold deposits and IOCG iron deposits is occurrence of this phenomenon.

CONCLUSIONS

Based on Streckeisen (1976), Middlemost (1994), Cox et al. (1979), De La Roche et al. (1980) and O`Connor (1965) classifications, the Sehezar intrusive rocks are granite, granodiorite, syenite to quartz syenite and quartz monzonite. In general, classification of these rocks in different diagrams have almost show the same results.

According to Irvine and Baragar diagram, the Sehezar area intrusive rocks are belong to alkaline to calc-alkaline series. In the Frost et al. diagrams, these rocks are magnesian, alkaline-calcic to alkaline type. According to the Cox et al. diagram, the parent magma is alkaline to subalkaline, but close to the alkaline magma. Based on Peccerillo and Taylor diagrams, studied rocks are high–K calc-alkaline to shoshonite rocks. According to the Piccoli and Maniar diagrams, the samples are peraluminous and metaluminous type. The A/CNK index value in these samples is between 0.6 and 1.2. Using these diagrams, we conclude that the parent magma is of alkaline to calc-alkaline types of magnesian series in the metaluminous to peraluminous domain.

The geostatistics studies for selected elements indicated that Au, Fe and Cu had a spatial correlation of about 350 m., which could be due to the similar origin for these elements. However, tungsten has a spatial correlation of about 700 m., which differs significantly from other elements. The validation procedure indicate an acceptable accuracy of the variogram.

According to geochemical studies such as origin of magma and its tectonic setting the Aroud granite is of I-type and formed in active continental margin. Important outcome of this study is that some of these data show intermediate behaviour of both S-type and the I-type granite properties obtained according to the Maniar and Piccoli diagrams, which can be accepted according to their tectonic setting.

Magnetite and hematite deposits along with minor copper and gold, are also found in association with oxidic granites. Field observations in the region have confirmed the presence of iron oxide minerals. The oxide I-Type magmas (magnetite serie) are associated with chalcophile elements that can be considered as a potential for copper and copper-molybdenum porphyry deposits. According to microscopic study, pyrite, chalcopyrite and magnetite minerals occurred in the region. Based on the Meinert's diagrams and our studies, it may be concluded that these intrusive bodies are related to the iron-gold-copper deposits and have a potential to form an ore deposit, which is consistent with geochemical survey carried out in the region.

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