Petrogenesis of Delkeh Pluton, Sanandaj-Sirjan Zone, NW Iran

Mazhari[*1] S.A., Amini[2] S., Ghalamghash[3], J.

*1 Correspinding author Address: Department of Geology, Payame Noor University (PNU), Sabzevar, Iran.
Tel: +985712644012-14; e-mail: ali54894@yahoo.com

2 Department of Geology, Tarbiat Moallem University, 49 Mofatteh Avenue, Tehran 15614, Iran

3 Geological Survey of Iran, P.O. Box 13185-1494, Tehran, Iran

Abstract
The small Delkeh pluton includes two different dioritic and granitic units. These units are coeval, so that U-Pb SHRIMP data shows 40.74±0.56 Ma and 41.33±0.63 Ma for felsic and mafic rocks, respectively. Dioritic rocks are composed of plagioclase and pyroxene as major components. They are calc-alkaline with LILE/REE and HFSE/REE compatible with arc magmas. Isotopic characteristics ($^{87}Sr/^{86}Sr40_{Ma}$= 0.704088, εNd_{40Ma}= +4.70) suggest they are mantle derived. With regards to tectonic setting, dioritic melts should be originated from sub-continental mantle. Granitic unit involves biotite monzogranites with $^{87}Sr/^{86}Sr40_{Ma}$= 0.704515 and εNd_{40Ma}= +2.0. Geochemical characteristics suggest that partial melting of metabasic or mafic igneous rocks could generate magmas with similar compositions to Delkeh granites. With regards to petrologic features of Delkeh pluton, partial melting of mafic rocks at lower crust or upper mantle would lead to generation of granitic magma in Delkeh area. With regards to the existence of xenocryst aggregates in monzogranites, after the generation of primitive granite magma, some assimilation may cause small modification in chemical composition.

1- Introduction
The Sanandaj-Sirjan Zone (SSZ), also named as Zagros Imbricated Zone[1], is a part of Zagros orogen, which resulted from the opening and closure of Neothethys ocean between Eurasia and Arabia (e.g. [2], [3], [4]). The Sanandaj-Sirjan Zone contains multiple plutonic assemblages, the age of which is poorly known yet. The plutons cropping out in the NW part of the zone are generally thought as consisting of arc-related calc-alkaline rocks formed during during the Mesozoic because the northeasterly subduction of Neo-Tethys underneath the Iranian plate ([5], [6]). Recent data, however, reveal that the plutonic activity in the Sanandaj-Sirjan Zone spanned, at least, from the Late Carboniferous [7] to the Eocene ([7], [8]), and it was not limited to calc-alkaline magmas but also produced alkaline rocks including peralkaline granites and felsic nepheline-bearing syenites.

This paper presents new the results of the first comprehensive study of the Delkeh pluton, one small calc-alkaline pluton in North SSZ, carried out with modern igneous petrology research techniques. The following sections describe the field relationships, mineralogy and texture, mineral composition, whole-rock composition of major and 40 trace elements, whole-rock Rb-Sr and zircon SHRIMP U-Pb ages, and the Sr-Nd isotope geology of the different rock facies that form Delkeh pluton.

2- Local geology and field relations
The Delkeh pluton is a small plutonic body located on 45º 27´- 45º 30´ E and 36º 41´- 36º 43´ N between Pasveh and Mahabad towns in West Azerbaijan province, NW of Iran. These

plutonic rocks intruded in assemblage of mixed deposits attributed to different ages (Fig. 1). Enclosing rocks in northern half are Cretaceous limestones which are more common formation in whole region; while in southern half host rocks related to Precambrian mixed deposits composed of phyllite, gneiss, acid volcanic rocks and amphibolite [9]. Contact metamorphic rocks are exposured in some area especially in east and southeastern of body which hornfelse thickness reaches up 500 meters (Fig.1).

The Delkeh body is bimodal consist of two distinct mafic and felsic phases which outcrop unevenly on the west and east of body, respectively (Fig.1). The mafic rocks have more extension (~60%) and unfortunately, the contact of these two phases is covered. All samples are massive and neither mafic nor felsic rocks show no signs of magmatic foliation or structural deformation. Most occurrences are fresh and metasomatism or other alterations are not extensive.

3- Sample selections and analytical methods

6 samples were selected for petrographical study and different chemical analyses. These samples include 4 mafic and 2 felsic rocks. XRF and ICP-MS analyses were done on all samples. SEM and EPMA analyses performed on 1 granitoids (N54) and one diorite (N56). Rb-Sr and Sm-Nd analyses performed on these two samples, too. Zircon was separated from two rocks: one felsic and one mafic rock; and SHRIMP analyse were done on them (The complete analytical procedure is presented in [8]).

4- Petrography and mineral chemistry

4.1- Mafic rocks

The mafic rocks consist of medium grained dioritic rocks include of plagioclase, clinopyroxene, orthopyroxene as major minerals; and K-feldspar, amphibole and biotite present as minor. Plagioclase is the most abundant mineral which appears as euhedral to subhedral crystals and makes up to 37-40% modal of the rock. Most of these crystals show normal zoning but occasionally oscillatory and reverse zoning can be seen and sieve-textured cores are common. In the normal zoned plagioclases chemical composition changes between Ab_{45-80} An_{20-55}; while in the most complex oscillatory zoned plagioclases there are more calcic plagioclases. Clinopyroxenes (17-25% modal) appears mostly as anhedral crystals with diopside-augite composition. Orthopyroxene forms 15-20% modal of dioritic rocks and has enstatite composition. Pyroxenes occasionally rimmed by amphibole. These amphiboles are magmatic magnesio-hornblende. The volume of amphiboles reaches up to 7% modal in a rock. Biotite (<5% modal) occurs as subhedral to anhedral in association with amphiboles and magnetite. These biotites have high F and Cl indicating the role of late magmatic fluids in their formation. Alkali-feldspars (up to 10% modal) are orthoclase or perthitic and appear mostly interstitial but there are individual anhedral crystals, too. Quartz forms <3% modal of diorites and has formed as fine grained (Ø<0.5mm) crystals.

Fe-Ti oxides, apatite, titanite and zircon are the main accessory minerals; thorite can be seen rarely, too. Dioritic samples are fresh and alteration processes did not affect extensively on these rocks except rare secondary chlorite, epidote and sericite.

4.2- Felsic rocks

Modal composition of Delkeh felsic rocks defines them as monzogranites. Major components of these monzogranites are alkali-feldspar, plagioclase and quartz. Biotite is the major mafic mineral. K-feldspars are mostly orthoclase with rare perthitic crystals and their composition change from Ab_4 An_8 Or_{88} to Ab_8 An_0 Or_{92}. In large euhedral to subhedral K-feldspar porphyritic crystals, they include other feldspar, quartz and apatite grains. Plagioclase in Delkeh granites exhibits two forms: crystals with the same size of matrix are unzoned or show normal zonation (Ab_{75-88} An_{12-25}); but large plagioclases display more complex zonation which normally high calcic cores mantled by sodic plagioclase. Quartz appears as anhedral fine grained (Ø<1mm) crystals without undulatory extinction. Biotite is the only primary mafic mineral in Delkeh granites. It shows strong red-brown pleochroism with subhedral to anhedral habits. Its composition contains high Fe (Mg# <0.35). There are some aggregates of fine-grained areas in granitoids converted to biotite, magnetite-titanomagnetite and mixed minerals. EPMA data of unaltered points shows they are orthopyroxene with rare clinopyroxenes exsolution lamellas. These evidences point to probably entrance of xenocrysts from foreigner material.

Accessory minerals of Delkeh granites include Fe-Ti oxides, apatite, titanite, zircon and allanite. Small alteration has impacted on granites and caused some secondary minerals comprise of sericite, chlorite, epidote and hematite.

5- Zircon U-Pb SHRIMP dating

Zircons from two intrusive rocks of Delkeh body (one diorite, one granite) were extracted, mounted and polished by standard techniques and then analysed by SHRIMP method. U-Pb SHRIMP analyses of diorite zircons show 40.74±0.56 Ma intercept age of ^{207}Pb-^{235}U/^{206}Pb-^{238}U with MSWD= 0.94; and 207-corrected ^{206}Pb-^{238}U= 39.8± 0.4 Ma and 204-corrected ^{206}Pb-^{238}U= 38.0 ± 1.4 Ma ages. For Delkeh granite intercept age of ^{207}Pb-^{235}U/^{206}Pb-^{238}U, 207-corrected ^{206}Pb-^{238}U and 204-corrected ^{206}Pb-^{238}U are 41.33±0.63 Ma (MSWD= 1.8), 40.5 ± 0.6 Ma and 39.7 ± 1.2 Ma, respectively (Fig.2). These data reveals that all intrusive rocks in Delkeh include felsic and mafic, are coeval; although it should be conclude that diorite rocks can be somewhat younger.

6- Chemical composition and Sr and Nd isotopes

Chemical composition of Delkeh plutonic includes major elements, trace elements and Sr and Nd isotopes. These data show limited chemical variation for each phase in this unit so that SiO_2 changes only in the range of 56.09- 56.53 and 67.14- 67.46 wt% in diorites and granites, respectively. All rocks are silica-saturated and classify as high-K calc-alkaline plutonic rocks. Chemical composition of diorites and granites relates to different groups without any intermediate constituents.

N-MORB normalized patterns display similar trends for diorites and granites except higher LILE and lower HFSE contents for granites. All samples show troughs at Nb, Ti and P and spikes at Pb, K characteristics of arc magmas and have LILE/REE and HFSE/REE ratios similar to them.

Diorites and granitic rocks in Delkeh have relatively similar ^{87}Sr/ $^{86}Sr40_{Ma}$= 0.704088 and 0.704515, respectively; while εNd_{40Ma} values are somewhat different: +4.70 and +2.00 in diorite and granite, respectively. The Nd model ages are 0.633 Ga in diorite and 0.695 Ga for granite.

7- Petrogenesis

Dioritic rocks in Delkeh pluton are calc-alkaline with LILE/REE and HFSE/REE compatible with arc magma. Isotopic characteristics ($^{87}Sr/^{86}Sr40_{Ma}$= 0.704088, εNd_{40Ma}= +4.70) suggest they are mantle derived. With regards to tectonic setting of this region, melts derived from sub-continental mantle could yield dioritic magma in Delkeh body.

As discussed before, chemical composition variations in Delkeh plutonic rocks are restricted and mafic and felsic samples show completely distinct composition. Moreover, they are petrographically unrelated and there are no transitional components between diorite and granites. These characteristics make it difficult to consider probability of parental magma relation between diorites and granites.

Initial Sr ratios in Delkeh granite (0.704515) are similar to diorite (0.704088) but diorite has higher positive εNd value (+4.7 vs. +2.0). These isotopic features confirm that granite doesn't contain notable crustal components. Although, different Nd composition between diorite and granite can be ascribed to different sources, but by considering of granite texture and the existence of xenocrysts aggregate minerals which could be formed by assimilation of foreigner materials, the possibility of common parental magma can not be failed. Regarding petrographical and geochemical features of Delkeh granites two evolution history can be considered: fractional crystallization of a mafic mantle-derived magma; and partial melting of mafic rocks with mantle characteristics.

In the first situation Delkeh granites can be generated by some plagioclase and pyroxene crystallization from dioritic magma plus a little assimilation by strange rocks contain more enriched Nd values. But chemical composition of granites doesn't confirm crystal fractionation of dioritic rocks; for example high plagioclase and pyroxene fractionation of diorites should yield high HFSE and more Eu anomaly than Delkeh granite contents. Furthermore, there are basic problems about the proposal of common parental magma for felsic and mafic rocks in Delkeh body. Firstly there are no transitional rocks and then if crystal fractionation were important in the Delkeh generation, there should be remarkable volume of cumulative rocks but in Delkeh there is not any sign of cumulates. Therefore, the generation of granites by diorite fractionation is unlikely.

The second history may be more reliable. Partial melting of metabasic or mafic igneous rocks could generate magmas with similar compositions to Delkeh. Juvenile isotope composition of Delkeh granites (low initial $^{87}Sr/^{86}Sr_{40Ma}$ and high εNd_{40Ma}) fails high contamination of crustal material. So, they should be resulted by partial melting of rocks with mantle origin. Respecting to post-collisional setting [8], partial melting of lower crustal or upper mantle mafic rocks would lead to generation of granitic magma in Delkeh area. Afterwards, some assimilation may cause small modification in chemical composition with regards to the existence of xenocrysts aggregates.

8- Conclusion

Delkeh pluton is composed of two different felsic and mafic rocks. Mafic rocks are diorites include of plagioclase, clinopyroxene, orthopyroxene as major minerals; and K-feldspar, amphibole and biotite present as minor. They have geochemical and isotopic composition indicative mantle origin. They could originate from arc magmas. Felsic rocks are monzogranites with feldspar, quartz and biotite as major minerals. With regards to petrological evidence, partial melting of lower crustal or upper mantle mafic rocks and some assimilation to crust materials would lead to generation of granitic magma in Delkeh area.

References

1- Alavi, M. 2004. Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. American Journal of Science 304, 1-20.

2- Berberian, M.; and King, G. C. P. 1981. Towards a Paleogeography and tectonic Evolution of Iran. Canadian Journal of Earth Sciences 18, 210-265.

3- Mohajjel, M.; Fergusson, C. L.; and Sahandi, M. R. 2003. Cretaceous-Tertiary convergence and continental collision, Sanandaj-Sirjan Zone, western Iran. Journal of Asian Earth Sciences 21, 397-412.

4- Ghasemi, A.; and Talbot, C. J. 2006. A new tectonic scenario for the Sanandaj-Sirjan Zone (Iran). Journal of Asian Earth Sciences 26, 683-693.

5- Ghalamghash, J. (2002). Petrology and emplacement of Urumieh-Oshnavieh plutons. (in Persian) Ph. D. thesis, 259 p., Shahid Beheshti University.

6- Ahmadi-Khalaji, A.; Esmaeily, D.; Valizadeh, M. V.; and Rahimpour-Bonab, H. 2007. Petrology and geochemistry of the granitoid complex of Boroujerd, Sanandaj-Sirjan Zone, Western Iran. Journal of Asian Earth Sciences 29, 859-877.

7- Mazhari, S. A., 2008, Petrogenesis Naqadeh- Sardasht plutons (in Persian) PhD thesis, 215 p., Tarbiat Moallem University.

8- Mazhari, S. A.; Bea, F.; Amini, S.; Ghalamghash, J.; Molina, J. F.; Montero, M. P.; Scarrow, J.; and Williams, I. S. 2009. The Eocene bimodalPiranshahr massif of the SanandajSirjan Zone, NW Iran: a marker of the end of the collision in the Zagros orogen. Journal of the Geological Society 166, 53-69.

9- Eftekharnejad, J., 1973, (1:250000) geological map of Mahabad, Geological Survey of Iran Press.

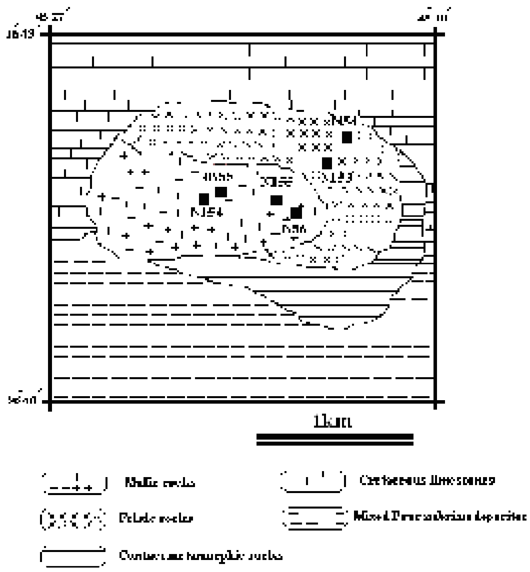

Fig.1- Simple geological map of Delkeh plutonic body. Analysed samples are plotted and shown by filled rectangulars.

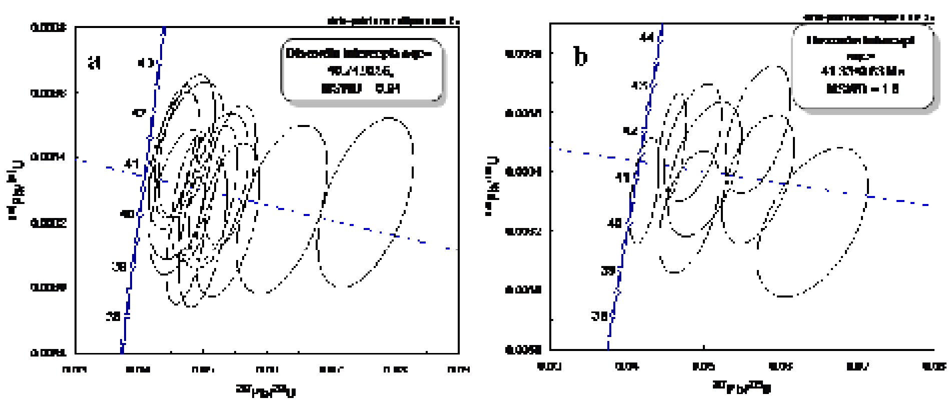

Fig.2- Wetherill concordia plot of analysed zircons of Delkeh pluton. (a) diorite; (b) granite.