CO_2-H_2O, Highly Saline and Carbonic Fluids From the Mesozoic Mashhad Granitoids, NE Iran

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Abstract

The Mesozoic Mashhad granitoid plutons have intruded into ophiolite complexes, meta-sediments and pyroclastics in the Binalood región, located in SW of Mashad city in NE part of Iran. Based on petrography and geochemistry, the Mashhad granitoids have been classified into 1) grey granite, 2) pink granite, 3) muscovite granite, 4) granodiorite and 5) pegmatite and quartz veins. Granitoids show typical igneous micro-textures with the mineral assemblage of quartz, plagioclase, K-feldspar, biotite, muscovie, amphiboles, clinopyroxene and garnet. Base on two-feldspar thermometry and hornblende-plagioclase thermometry / barometry, igneous temperatures of 750 to 770^oC and pressures of 4.6 to 5.5 kbars for the emplacement of granitoids have been estimated. The granitoids of Mashhad are have been classified as moderately peraluminous, S to I type granitoids of sub-alkalines to calcic type.

Fluid inclusion study was caried out on Mashhad granitoids which show presence of Isolated Fluid Inclusions (IFI) as well as Trail Bound Inclusions (TBI). Based on distribution pattern of inclusions, the isolated inclusions are classified as Group of Synchronous Inclusions (GSI). Good number of fluid inclusions have been recorded in five rock types viz., grey granite, pink granite, muscovite granite, granodiorite and pegmatites exposed around Mashhad. Four types of fluid inclusions have been recorded in Mashhad granitoids viz., Type I CO_2-H_2O inclusions, Type II Low salinity aqueous inclusions, Type III, high salinity inclusions and Type IV Carbonic inclusions.

Fluid inclusions occur as rounded, oval and negative crustal shape varying in size from 5 to 16 μm. CO_2-H_2O fluids are the most common fluids recorded in Mashhad granitoids. The volume proportion of CO_2 in CO_2-H_2O inclusions vary from 20 to 80 percent, suggesting highly varying mole fraction of CO_2 in inclusions. Minor, bi-phase, low salinity aqueous inclusions occur coeval with CO_2-H_2O inclusions. Fluid inclusion petrography and chronology of fluid entrapment data indicate the presence of Type I, CO_2-H_2O occur coeval with low salinity aqueous, represent the earliest fluids trapped in Mashhad granitoids. Presence of Type III, Halite bearing, highly saline fluids are found mainly in a quartz vein which cross cut granodiorite. Type IV, carbonic fluids occur along late fractures which cross-cut the early Type I, CO_2-H_2O fluids whihc are classified as TBI.

CO_2 in CO_2-H_2O inclusions show melting temperatures (Tm, CO_2) around -56.8 ^oC, indicating almost pure carbonic inclusions. TmClath vary from 4 to 8^oC. Temperature of homogenization of CO_2 into liquid phase range from - 9 to 22^o C, indicating density of 0.92 to 0.68 g/cc. And the total homogenization of CO_2-H_2O inclusions range from 205 to 320^oC, indicating XCO_2 values varying 0.75 to 0.20 mole fraction. The bi-phase fluid inclusions show Tm from - 5 to - 2^o C with low salinity values of from 4 to 8 wt.% NaCl equivalent and temperatura of homogenization into liquid phase varying from 120 to 160°C, indicating density of 1.03 to 1.96 g/cc. Type-IV, late

carbonic inclusions show Th ranging from 20 to 25°C with density of 0.82 to 0.78 g/cc. Tye III, halite bearing fluids show temperatura of melting at 315 to 335°C, indicating high salinity values of 38 to 40 wt. % NaCl equivalent.

Based on the intersection of density data of these fluids, entrapment temperatures ranging rom 590 to 650°C at pressures of 4.1 to 5.2 Kbar is estimated which nearly coincide with the mineral P-T estimates. Baesd on micro-textural studies combined with fluid inclusion petrography, fluid present process has been inferred. There are stron evidecnes that indicate fluid-present partial melting process has taken place, during the formation of S-type and I-type granitoids in Mashhad area. Presence of predominantly CO_2-H_2O fluids in granodiorites as well as both CO_2-H_2O and highly saline fluids in late quartz veins suggest fluid evolution with the enrichment of saline fluids during late magmatic stage in Mashhad granitoids. The low denstiy, carbonic fluids in quartz grains are chronologicaly late fluids trapped in granitoids. These fluids have formed due to peferential leakage of water from the early CO_2-H_2O inclusions along micro-fractures and is related to ductile shear deformation along thrust zones in Mashhad granitoids.

1. Introduction

Presence of different types of fluids like H_2O, H_2O-NaCl, CO_2 and CO_2-H_2O and CH_4 have been reported in many granitic rocks. Fluid inclusion study in granites are important as they provide necessary information on the nature and composition of fluid phase associated with felsic magmas. Experimental work on granitic rocks have shown the significant role of volatiles in the generation, mobility and crystallization of granitic melts. H_2O fluids were thought to be the most dominant fluid phase in felsic melts. However, the recent fluid inclusion studies in many deep seated granitic intrusions, particulalry from the Precambrian terranes have shown the presence of not only H_2O bearing fluids but also presence of CO_2, mixed CO_2-H_2O and halite bearing fluids in granitic rocks [1, 2, 3]. The origin of S- and I-type granitic rocks has ben discussed in detail [4]. The S-type granites have been formed by partial melting of crust dominated by metasediments with few igneous rocks and I-type granites have been formed due to partial melting of crust dominated by meta-igneous rocks with minor meta-sediments. The process of partial melting leading to formation of granites could be either by fluid-present or fluid-absent process [4,5]. Fluid inclusion studies in granites is significant not only to characterise the nature and composition of fluids associated with granitic magmas but also to understand the fluid-absent or fluid present process during the formation and accent of granitic magma.

Data on the type of fluids present is Mesozoic granitoids from Mashhad, Iran is not available, although geology of the area around Mashhad have been well documented [6,7,8,9,10]. Petrographic and few mineral chemical data has been reported on the Mashhad granite [8,9]. Except for the preliminary report of low salinity and CO_2-H_2O fluids in a quartz vein, intruding Mashhad granitoids [11], information on the nature and composition of fluids associated with Mashhad granitoids is completely lacking.

In this paper, we report for the first time presence of four different types of fluids like CO_2-H_2O, low saline, highly saline and carbonic fluids in Mashhad granitoids.

2.Geology of the area

The Mesozoic Mashad granitoid plutons (MMGP) are situated in the Binalood region located in SW of Mashad city in NE part of Iran [6,7]. The paleo-tethys remnantes consistan of racks like three types assemblage of rocks viz.,(1) ophiolites consisting of peridotites, pyroxenite, isotropic gabbros, and basalts. Metacherts interbedded with thinly bedded marbles whihc interlayered with metabasalts, (2) metamorphosed sedimentary sequence consisting of slates, phyllites, schists, carbonates and metaconglomerates and (3) pyroclastics – a distinctive assemblage of interlayered metamorphosed lapilli-tuffs and tuffs in the Binalood region form a long and narrow belt which extends for several of kilometers in a NW-SE direction [7]. The granioids have intruded the ophiolite complexes and meta-flysh during Mesozoic period [7,8]. There are two main varieties of granitoids viz., 1) S-type, continental collision / syn-collisionnal muscovite granite and pegmatite and 2) I-type, within the plate, post-collisional hornblende and green biotite bearing granite. Based on the isotopic ages, mineral composition and bulk rock composition [8,9] three varieties of granitoids viz., 1) Biotite granodiorite and biotite quartz monzodiorite which represent the oldest intrusives, 2) feldspar-granite and 3) Biotite- muscovite granite and aplite granite which represent final stage of magmatic activity. On the basis of petrographic study [9] the granitoids have been classified into five major groups viz., 1) Biotite granite 2) muscovite granite 3) hornblende granite 4) pegmatite 5) aplite. Three episodes of magmatism has been identified in Mesozoic Mashhad granitoid pluton (MMGP). The first episode of magmatism is recorded near Dehnow, where evidecnes of hornblende-biotite bearing tonalite and granodiorite have intruded after the first regional metamorphism before late Triassic to early Jurassic period. These rocks were classified as moderately peraluminous, S to I type granitoids of sub-alkalines to calcic type. They have also suggested that biotite bering granodiorite exposed around Vakilabad and Kuhsangi area belong to oldest member of the granitoid suite. During the second phase of igenous activity which occurred during late Triassic period, feldspar monzogranite exposed near Sangbast area were intruded. Field and structural relations show that these intrusives are younger than granodiorite and older than biotite-muscovite leucogranite. They are moderately peraluminous, k-rich calc-alkaline type. The last stage of magmatism took place during Jurassic time. This indicates an episodic plutonism from the early Triasic to Cretaceous period. Four main types of encalves have been identified in biotite-muscovite leucogranite viz, feldspar- monzogranite, metamorphic rocks, biotite-granodiorite and micaceous rich grey intrusive in this granitoid pluton. The Khajehmourad, biotite-muscovite leucogranite and late pegmatite dykes are highly felsic peraluminous S-type granitoids in the area [8,9].

A major NW-SE trending thrust fault (shear zone), demarcate the western margin of the Mashhad graniotoids. Granitoids are relatively undeformed with the exception of ductile shears cutting granitoids near Dehnow. Near Dehnow, N-W to SE trending ductile shears with the development of mylonitic to ultramylonitic fabric is observed. These features suggest considerable reactivation along NW-SE trending thrust zone, along the westren margin of the granitoids near Dehnow.

For the purpose of fluid inclusion study, based on petrography the Mashhad granitoids have been classified into 1) grey granite, 2) pink granite, 3) muscovite granite, 4) granodiorite and 5) pegmatite and quartz veins. Granitoids show typical igneous micro-textures with the mineral assemblage of quartz, plagioclase, K-feldspar, biotite, muscovie, amphiboles, clinopyroxene and garnet.

Quartz show straight to lobate grain boundaries. Quartz grains show flash figures and does not exhibit undulose extinction. These features suggest that quartz grains are largely undeformed. Few quartz grains show presence of intragranular fractures. Euhedral plagioclase grains are generally fresh. They often contain euhedral grains of muscovite. In some granites, plagioclase show alteration to sericite and talc mainly in the central portions with margins of the grains free from any alteration. Flaky biotite occur between quartz and plagiolcae grains and is pleochroic from brown to yellow brown . Undeformed microcline occur as tabular grains exhibiting typcial cross-hatched twinning. Within the bigger microcline grains, presence of smaller, euhedral grains of twinned plagioclase is commonly observed.

Base on two-feldspar thermometry and hornblende-plagioclase thermometry/ barometry, igneous temperatures of 750 to 770^{o}C and pressures of 4.6 to 5.5 kbars for the emplacement of granitoids have been estimated.

3.Fluid Inclusions Petrography

Fluid inclusions studies were carried out for 15 rock samples. However, in only five rock samples good number of fluid inclusions have been recorded in the matrix quartz grains.

Very small fluid inclusions were noticed in plagioclase feldspar and fluids were absent in microcline.

Fluid inclusions were classified based on orientation of fluid inclusions within the mineral into primary and pseudosecondary inclusions , following (l2). Fluid inclusions were classified into Isolated Fluid Inclusions (IFI), which are primary inclusions in minerals and Trail Bound Inclusions (TBI), which are intragranular, fracture bound secondary inclusions in minerals. Based on distribution pattern of inclusions, the isolated inclusions are classified as Group of Synchronous Inclusions (GSI) [13]. In this paper, we use the term GSI to describe the trail bound inclusions in quartz grains. Care has been taken to record the textural relationship between fluid inclusions and the host mineral to document the relative timing of fluid entrapment which is a prerequisite for meaningful interpretation fluid inclusion data [14].

Chronology of fluids inclusions: Based on microtextural features of the matrix quartz grains and the shape, size and orientation of different types of fluids recorded in Mashhad granites, relative timing of entrapment of fluid inclusions have been established

Fluid inclusion study: Fluid inclusion study was carried out on five rock types viz., grey granite, pink granite, muscovite granite, granodiorite and pegmatites exposed around Mashhad. Following three types of fluid inclusions have been recorded:

Type I CO_2-H_2O inclusions

Type II Low salinity aqueous inclusions

Type III High salinity inclusions and

Type IV Carbonic inclusions

Fluid inclusions occur as rounded, oval and negative crustal shape. They are either irregularly distributed within the quartz grains or occur as intragranular trail bound inclusions. They vary in size from 5 to 16 μm. CO_2-H_2O fluids are the most common fluids recorded in quartz grains in Mashhad granitoids. They appear bi-phase at room temperature. The volume proportion of CO_2 in CO_2-H_2O inclusions vary from 20 to 80 percent, suggesting highly varying mole fraction of CO_2 in inclusions. Minor, bi-phase, low salinity aqueous inclusions occur coeval with CO_2-H_2O inclusions. Fluid inclusion petrography and chronology of fluid entrapment data indicate the presence of Type I, CO_2-H_2O which is the most common fluids which occur with low salinity aqueous. These Type I and Type II fluids represent the earliest fluids trapped in Mashhad granitoids. Presence of Type II, Halite bearing, highly saline fluids are found mainly in a quartz vein which cross cut granodiorite. Halite bearing inclusions are randomely distributed within the quartz grains with size varying from 14 to 18 μm. These inclusions are classified as GSI.
Type IV, carbonic fluids occur along late fractures which cross-cut the early Type I, CO_2-H_2O fluids (Fig.3). These CO_2-rich fluids appear as dark inclusions, show negative crystal shapes to highly irregular shapes. Their size vary from 10 to 15 μm. These inclusions are the only inclusions which occur along an intragranular trail within the quartz grains and are classified as TBI.

Microthermometric results: Microthermometric measurements on fluid inclusions were obtained on a LINKAM -THMS 600 and CHAIXMECA apparatus mounted on a LEITZ LABORLUX-12 microscope with a 40X objective at university of Mysore, Mysore. Cooling experiments was carried out before heating of doubly polished sections to avoid the possibility of loss of inclusions during heating due to decrepitation. The stage was calibrated using different standards and the precision was ± 0.1°C at low temperatures and ± 1.0 °C at high temperatures.
CO_2 in CO_2-H_2O inclusions show melting temperatures (Tm, CO_2) around -56.8 ^oC, indicating almost pure carbonic inclusions (Table 1). TmClath vary from 4 to 8^oC. Temperature of homogenization of CO_2 into liquid phase range from - 9 to 22^o C, indicating density of 0.92 to 0.68 g/cc. The total homogenization of CO_2-H_2O inclusions range from 205 to 320^oC, indicating XCO_2 values varying 0.75 to 0.20 mole fraction [19]. The bi-phase fluid inclusions show Tm from - 5 to - 2^o C with low salinity values of from 4 to 8 wt.% NaCl equivalent. They show homogenization into liquid phase varying from 120 to 160°C, indicating density of 1.03 to 1.96 g/cc. Type-IV, late carbonic inclusions show Th ranging from 20 to 25°C with density of 0.82 to 0.78 g/cc. Few halite bearing type III fluids in quartz vein cross cutting granodiorite show temperature of melting at 315 to 335^oC, indicating high salinity values of 38 to 40 wt. % NaCl equivalent.

4.Conclusions

Mashhad granitoids and pegmatites are largely undefomed igneous bodies intruding into meta-ophiolites and metamorphosed flysch during Mesozoic period. Mashhad granitoids are undeformed igneous bodies and show typical igneous micro-textures. Quartz grains in all the rock types studied show no signs of deformation and is considered to represent igneous mineral. However, quartz in mylonites and ultramylonites show the process of recovery and recrystallization features with the development of quartz neo-balsts.

The most common type of fluids recorded in all the granitoids as well as in pegmatite and quartz veins is the CO_2-H_2O fluids. These fluids occur co-eval with low saliny aqueous fluids within quartz grains. The CO_2-H_2O inclusions show varing volume proportions of CO_2 indicating mole fraction of CO_2 varying from 0.75 to 0.20. In quartz veins, cross cutting granodoirite, presence of primary halite bearing fluids have been recorded with high salinity values of 38 to 40 wt.% NaCl equivalent. Based on the intersection of density data of these fluids, entrapment temperatures ranging from 590 to 650^{o}C at pressures of 4.1 to 5.2 Kbar is estimated. Slighly lower pressure and temperature estimates obtained based on fluid inclusions study when compared to P-T data obtained based on Two-feldspar and hornblende-plagioclase thermometers is due to moderate reequilibration of fluids probably during uplift of the granitoids. Based on these observation the primary CO_2-H_2O, low salinity aqueous fluids as well as high salinity halite bearing fluids are interpreted to represent magmatic fluids trapped in Mashhad granitoids. All these evidences indicate fluid-present partial melting process during the formation of S-type granites in Mashhad area. Presence of predominantly CO_2-H_2O fluids in granodiorites as well as both CO_2-H_2O and highly saline fluids in late quartz veins suggest fluid evolution with the enrichment of saline fluids during late magmatic stage in Mashhad granitoids. The present fluid inclusion study brings into light the significance of CO_2-H_2O and highly saline fluids in understanding the petrogenesis of granitic rocks, and particulalry the origin and evolution of S-type granitoids [6].

Presence of low denstiy (0.78 to 0.82 g/cc) carbonic fluids along intragranular fractures in quartz grains indicate that these are the chronologicaly late fluids trapped in granitoids. The carbonic fluids have formed due to peferential leakage of water from the early CO_2-H_2O inclusions along micro-fractures. This process is related to ductile shear deformation along thrust zones, which led to formation of carbonic fluids in Mashhad granitoids.

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6. References

1. Konnerup-Madson, J., (1979). Lithos, v. 12, pp.13.23

2. Frezzotti, M.L., Di Vincenzo, G., Ghezzo, C., Burke, E.A.J, 1994,Evidence of magmatic CO2-rich fluids in peraluminous graphite-bearing leucogranites from Deep Freeze Range. Contrib. Mineral. Petrol., v.117, p.111-123.

3. Nabelek and Ternesm., 1994. Evidence of magmatic CO2-rich fluids in peraluminous graphite - bearing leucogranites from Deep Freeze Range. Contrib. Mineral. Petrol., 117: 111-123.

4.Clemens, J.D., 2003, S-type granirtic magmas - petrogenetic issues, models and evidences. Earth. Science reviews, v. 61, p. 1-18.

5. Clemens, J.D., and Droop, G.T.R., 1998, Fluids, P-T paths and fates of anatectic melts in the Earth's crust. Lithos, v. 44, p. 21-36.

6. Alavi, M., Thrust tectonics of the binaloud región; NE Iran. Tectonics, v. 11(2), p.360-370.

7.Alavi, M., 1991, Sedimentary and structural characteristics of the Paleo-Tethys remnants in

northeastern Iran. Geophysical unión,Geol. Soc. America Bull., v.103, p. 983-992.

8. Karimpour, M.H., Farmer, L., Ashouri, C. and Saadat, S., 2006, Major,Treace and REE geochemistry of the collision-Related Granitoids from Mashhad,Iran. Jour. Sciences, Islamic. Republic. of Iran,v. 17(12), p.127-145.

9.Karimpour, M.H., Farmer, L., Ashouri, C. and Saadat, S., 2002, Petrogenesis, aleotectonic setting, metallogeny of Mashhad paleo-tetys granitoids, Iran, Denever anual meeting Colorado convention centre.

10. Iranmanesh, J. and Sethna, S.F., 1998, Petrography and geochemistry of the Mesozoic

Granite at Mashhad, Khorasan Province, Northestern part of Iran. Jour. Geol. Soc. India, v.52, p. 87-94.

11. Tecca, F., Masoudi, F., Shabani, A.A.T., and Tarokh, A, 2009, CO2-bearing fluids in quartz 'Veins intruding the Mashhad granitoids, NE Iran. European Curr. Research on fluids Inclusions, 245-246 (ECROFI 2009)

12. Roedder, E, 1984, Fluid inclusions, Reviews in Mineralogy, volumen 12, Mineralogical Society of Ameruca. P. 644..

13.Touret, J.L.R., 2001, Fluid inclusions in the Metamorphic racks. Lithos,v.55, p.1-25.

14. Srikantappa, C. and Malathi, M.N., 2008, Solid inclusión of magmatic halite and CO_2-H_2O Inclusions in Closepet granite fromRamanagaram, Dharwar Craton, India. Ind. Min., v. 42(1), p.84-98.

15.Diamond, L.W., 2001, Review of the systematics of CO_2-H_2O fluid inclusions. Lithos, v.55, p. 69-99.

Table 1 Microthermometric result of fluid inclusions from Granitoids of Mashhad, NE-IRAN

Rock Type	CO_2-H_2O inclusions			O_2 inclusions			H_2O-NaCl inclusion			
	T_m CO_2 (GSI)	Th CO_2	Th_{total}	T_m	T_h (TBI)	d	Tm (GSI)	Salinity (wt% NaCl equiv.)		$d_{g/cc}$
M-6/1 Granodiorite	-57.8	-10 to -14								
M-6/3 Pink Granite	- 57.8	-4 to -2	255 to 290	-57.9	20 to 25	0.82 to 0.78	-2 to -5	4 to 8	120 to 160	1.03 to 1.96
M-4/1 Muscovite Granite	-57.8 to -57.5	-9 to -2	190 to 275							
M-5/2 Tourmaline Pegmatite	-57.9	10 to 16	290 to 320							
M-7/2 Garnet –bearing Pegmatite	-57.8	10 to 21	260 to 295							
M-11/4 Quartz vein .	57.9	10 to 22	170 to 245	Tm of Halite vary from 205 to 220°C						

Abbreviations used in the table:
GSI:Group of synchronous fluid inclusions TBFI:Ttrial bound fluid inclusions
Tm: Temperature of melting Th:Temperature of homogenization (Tm &Th are represented in degree centigrade; ^{0}C) Th($_{tot}$) :Total homogenization of CO_2-H_2O; d:density represented in g/cc . CLA:Clathrate melting.

M-6/1: Granodiorite, Qtz+Kfels (perthite) +Pl+Bt+Amp. Oldroad - Torbat. GPS – 36^o 5' 12.1" E 59^o 38'47.4"
M-6/3: Pink Granite, Qz+Kfels (perthite) +Pl+Bi+Mus+Opq+Ser. GPS – 36^o 5' 12.1" E 59^o 38'47.4"
M-4/1: Muscovite Granite Qtz+Kfelds (perthite) +Pl+Bt+Mus, Robat Khakestar GPS– N 36^0 09 1'17.5" E 59^o 37' 50.2"

M-5/2: Tourmaline Pegmatite, Qtz+Pl+Ms+Tur, Khakestary GPS – N 36^o 06' 27.7" E 59^o 38' 43.9"
M-1/1: Tourmaline Granite, Qtz+Kfls+Pl+Mus+Opaq+ Tur, Khajemorad. GPS – N36^O 09' 01.4", E059^o 41' 31.2"
M-6/4: Garnet –bearing Pegmatite, Qtz+Pl+Kfls+Bt+Ms+Grt+Chl+Ser, old road-torbat. GPS – N 36^o 5' 12.1" E 59^o 38'47.4"

M-7/2: Garnet –bearing Pegmatite, Qtz+Pl+Kfls+Mus+Grt new road(high way). GPS – N 36° 08' 59.8" E 059° 42' 21.9"

M-11/4: Quartz vein, Dehnow. GPS – N 36° 21' 43.9" E 59° 24' 42.1"

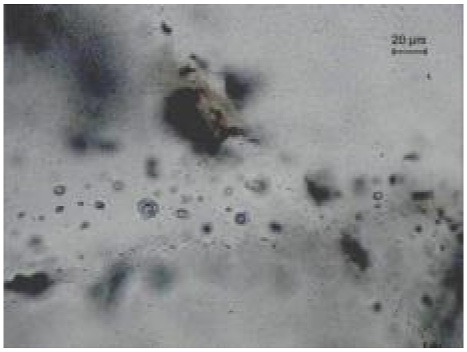

Fig. 2. Bi-phase CO_2-H_2O inclusions in quartz from Granite

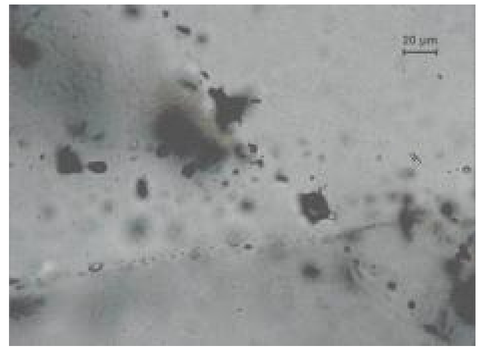

Fig. 3. CO_2-rich inclusions along late fracture cross cutting CO_2 - H_2O inclusions in quartz.

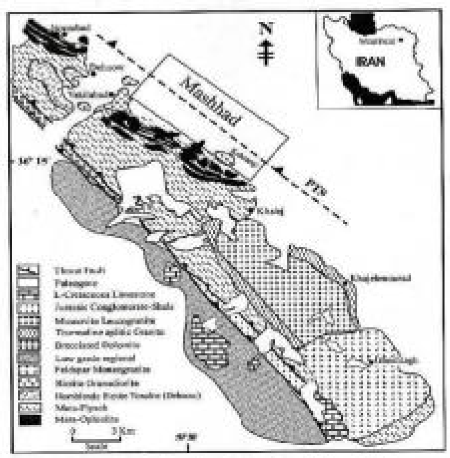

Figure 1a. Geological map of the study area. PTS refers to the Paleo-Tethys Suture zone.

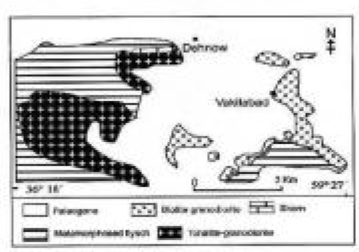

Figure Ib. Geological map showing the tonalite (Dehnow) and the granodiorite (Vakilabad).
Karimpour.M.H (2006)