Investigation of metamorphic zonation and isogrades of Garnet rocks in Hamadan area

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Abstract
The study area is a part of the Sanandaj- Sirjan metamorphic belt. We can divide Hamadan metamorphic rocks in three groups: regional metamorphic rocks, contact metamorphic rocks and migmatites. In this area we can't completely divide zonation of contact and regional metamorphic. In some places that contact metamorphic has influenced to low degree regional metamorphic rocks, contact metamorphic zonations are clearly appear, but when contact and regional metamorphic have a same degree or regional metamorphic has high degree than contact metamorphic, we can't distinguish them easily. In Hamadan area regional metamorphic zones are Chlorite± Biotite zone (we haven't garnet rocks in this zone), Biotite± Garnet zone (divided in two sub zone, Biotite and Garnet zone), Andalusite zone, Staurolite zone, Staurolite± Andalusite zone, Sillimanite- Muscovite zone and Sillimanite- Potassium feldspar± Cordierite zone, also contact metamorphic zones are Cordierite zone and Cordierite- Potassium feldspar zone.

1. Introduction
Garnet crystallizes in cubic system and mostly in dodecahedron (rhomb-dodecahedron) and trapezohedron (tetragon-trioctahedron) crystal forms. General chemical formula of this mineral is: $R_3R'_2(SiO_4)_3$, which bivaliant cations (i.e. Mg^{2+}, Fe^{2+}, Mn^{2+}, Ca^{2+}) lie in R site and trivaliant cations (i.e. Al^{3+}, Cr^{3+}, Fe^{3+}) in R' site. Commonly, more than one cation lies in R and R' sites and therefore garnet crystals give rise to isomorphous (solid solution) series of minerals. If Al^{3+} is located in R' site, the pyralspite group $[(Fe^{2+},Mg^{2+},Mn^{2+})_3 Al_2(SiO_4)_3]$ with almandine $[(Fe^{2+})_3 Al_2 (SiO_4)_3]$, pyrope $[(Mg^{2+})_3Al_2 (SiO_4)_3]$ and spessartine $[(Mn^{2+})_3Al_2(SiO_4)_3]$ end members will form. If Ca^{2+} is located in R site, the ugrandite group $[(Ca^{2+})_3(Al^{3+},Fe^{3+},Cr^{3+})_2(SiO_4)_3]$ with grossularite $[Ca_3Al_2(SiO_4)_3]$, andradite $[Ca_3(Fe^{3+})_2(SiO_4)_3]$ and uvarovite $[Ca_3(Cr^{3+})_2(SiO_4)_3]$ end members will form. Some other cations may also be emplaced in R and R' sites (Locock. 2008). The garnet minerals chemistry in the study area are rich in almandine.

2. Geological Setting
The study area is a part of the Sanandaj-Sirjan metamorphic belt. The Alvand plutonic complex is the most important plutonic body that regional and contact metamorphic rocks with low to high grade are located around it. The metamorphic sequence comprises pelitic, psammitic, basic, calc-pelitic and calc-silicate rocks. Pelitic rocks are the most abundant lithologies. Pelitic sequence is mostly made up of slates, phillites, micaschists, garnet schists, garnet andalusite (± sillimanite, ± kyanite) schists, garnet staurolite schists, mica hornfelses, garnet hornfelses, garnet andalusite (± fibrolite) hornfelses, cordierite (± andalusite) hornfelses, cordierite K-feldspar hornfelses and sillimanite K-feldspar hornfelses. Major

plutonic rocks of this area are granitoids, diorites and gabbroids, which intruded by aplo-pegmatitic and silicic veins (figure 1).

3. Metamorphic zonation and isogrades of Garnet rocks in study area

In this area we can't completely divide zonation of contact and regional metamorphic. In some places that contact metamorphic has influenced to low degree regional metamorphic rocks, contact metamorphic zonations are clearly appear, but when contact and regional metamorphic have a same degree or regional metamorphic has high degree than contact metamorphic, we can't distinguish them easily.

The metamorphic reaction and thermobarometric studies of metamorphic rocks have shown that garnet mica schist forming at 4.3 ±0.5 Kbar and 568-586 ºC and garnet hornfelses at 2.5 ± 0.1 Kbar and 539-569 ºC (Sepahi et al. 2004)

3-1- Regional metamorphic rocks

Low grade rocks (Chl zone): the lowest-grade rocks are very fine grained black,green or cream colored slates and phyllites, interlayered with carbonate rocks and quartzites. Slates contain Quart, Sericite, Chlorite, Graphite, Iron oxides. Phyllites contain Quart, Muscovite, Chlorite, Plagioclase, +/-Garnet, +/- Biotite, as well as accessory Tourmaline, Calcite and Iron oxides. Samples of metamorphic reaction that have shown in this zone are:

$Kln + 2Qtz \rightarrow Prl + H_2O$ (Thompson. 1970)

$2Ms + 6Qtz + 2H^+ \rightarrow 3Prl + 2K$ (Frey. 1978)

Biotite and garnet zone: These rocks are medium to coarse grained and their common texture is lepidoporphyroblastic with a usual crenulation cleavage. This zone divided in two sub zone, biotite and garnet zone. They are composed of Quartz, Biotite, Garnet (up to 10 mm in size), Muscovite, Chlorite, with accessory Plagioclase, Graphite, Tourmaline, Apatite, Calcite and Iron oxides (Fig 2). Common porphyroblasts are Garnet, Muscovite and Chlorite. Garnet crystals have complex relationship to deformation, i.e. they are pre-, syn- and post-tectonic. The metamorphic reaction and thermobarometric studies of metamorphic rocks have shown that garnet mica schist forming at 4.3 ±0.5 Kbar and 568-586 ºC (Sepahi et al. 2004).

$Chl + Ms \rightarrow Grt + Bt + Qtz + H_2O$ (Whitney et al. 1996)

$2Chl + 4Qtz \rightarrow 3Grt + 8H_2O$ (Kretz. 1994)

Chiastolite zone: These rocks are medium to coarsed grained with a common lepidoporphroblastic texture. Their common minerals are Quartz, Biotite, Andalusite (up to 20 cm length), Garnet, Muscovite and minor Graphite, Chlorite, Plagioclase, Tourmaline, Apatite, Sillimanite and Iron oxides (Fig 3).

$Grt + Ms + Qtz \rightarrow And + Bt + H_2O$ (Yang and Pattison. 2006)

Staurolite zone: These rocks are composed of Quartz, Staurolite, Garnet, Biotite, Muscovite, Chlorite, Plagioclase, Graphite and Tourmaline (Fig 4). Their common texture is lepidoporphyroblastic with porphyroblasts of garnet, staurolite (up to 15 cm in legnth)**.**

$Grt + Chl + Ms + Qtz \rightarrow St + Bt + H_2O$ (Yang and Pattison. 2006)

Sillimanite muscovite zone: Sillimanite andalusite schists contain Quartz, Sillimanite (± andalusite), Biotite, Muscovite, Garnet, Plagioclase and Opaque minerals (Fig 5).

Grt + Ms + Qtz → Sil + Bt + H_2O (Yang and Pattison. 2006)

Sillimanite- potassium feldspar zone: High grade schists and Migmatites are in this zone. The high grade schists in the regional metamorphic sequence contain Sillimanite, Quartz, Biotite, Muscovite, Garnet, Plagioclase, Potassium feldspar, ±Andalusite,±Kyanite, ±Staurolite (Fig 6).

Migmatites are a sequence of metatexite-diatexite rocks with various structures such as stromatic, schollen, schlieric and massive. The melanosome mineralogy of the most of the metatexites is very similar to high grade Garnet sillimanite (± andalusite and kyanite) schists but Cordierite-bearing interlayers occur, too (Fig 7). Leucosome of migmatites have granoblastic texture and contain Quartz, Plagioclase, Muscovite and ±Garnet.

Bt + Ab + Sil + Qtz → Grt + Kfs + L (Norlander et al. 2002)

3-2- Contact metamorphic rocks

Protoliths of the contact metamorphic rocks are similar to those in the regional metamorphic sequence and include abundant metapelitic rocks. Two metamorphic zones are widespread around plutonic bodies.

Cordierite zone: The major rock types in this zone are Cordierite hornfelses. This rocks have porphrogranoblastic texture that containing Quartz, Biotite, Muscovite,contact Cordierite (± andalusite), Plagioclase, Garnet, Tourmaline and Opaque minerals (Fig 8). garnet hornfelses forming at 2.5 ±0.1 Kbar and 539-569 ºC (Sepahi et al. 2004)

Chl + H2O → Grt + H_2O (Kretz. 1994)

Cordierite potassium feldspar zone: The typical mineral assemblage of these rock is Quartz, contact Cordierite (Crd_2), orthoclase, Biotite, minor Plagioclase, Garnet and Opaque minerals (Fig 9).

Bt + Sil (± And) + Qtz → Crd + Kfs + H_2O (Kretz. 1994)

Minerals assemblage in metamorphic zonation are shown in table 1.

4. Conclusion

We can divide Hamadan metamorphic rocks in three groups: regional metamorphic rocks, contact metamorphic rocks and migmatites. In this area regional metamorphic zones are Chlorite± Biotite zone, Biotite± Garnet zone, Andalusite zone, Staurolite zone, Staurolite± Andalusite zone, Sillimanite- Muscovite zone and Sillimanite- Potassium feldspar± Cordierite zone, also contact metamorphic zones are Cordierite zone and Cordierite- Potassium feldspar zone.

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Table 1: minerals assemblage in metamorphic zonation.

Sillimanite zone	Staurolite zone	Andalusite zone	Garnet zone	Biotite zone	Chlorite zone	
....	....	....	....	....	....	Quartz
....	....					Chlorite
....	....	....	....	....		Biotite
....	....	....	....	....	..	Muscovite
....	....	....	....	.		Garnet
			....	....	....	Andalusite
	......	....				Staurolite
			....	....	....	Kyanite
....						Sillimanite

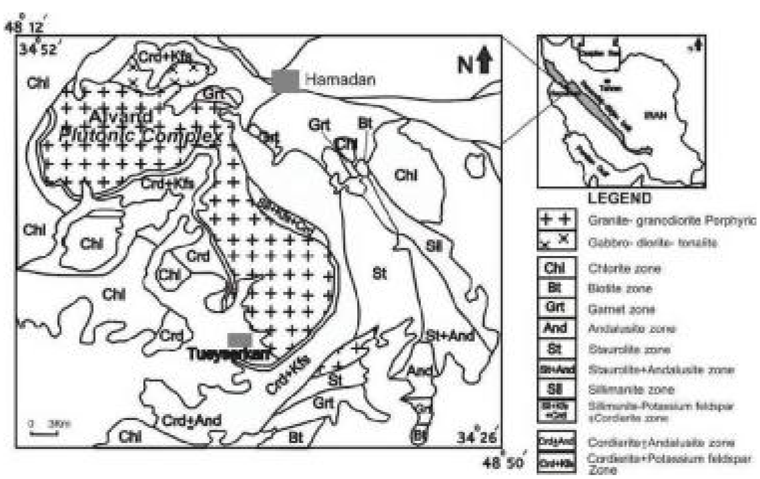

Fig 1: Simplified zonation map of the Hamadan area (modified after Sepahi, 2008).

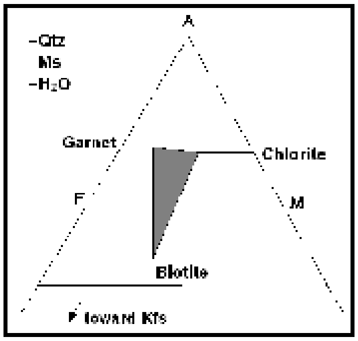

Fig 2: Mineral assemblage in Garnet zone.

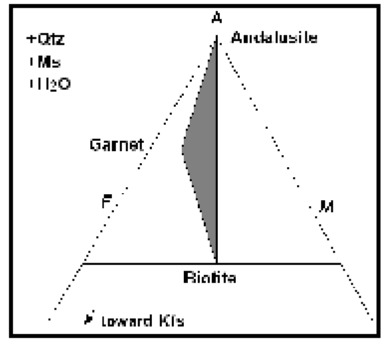

Fig 3: Mineral assemblage in Chiastolite zone.

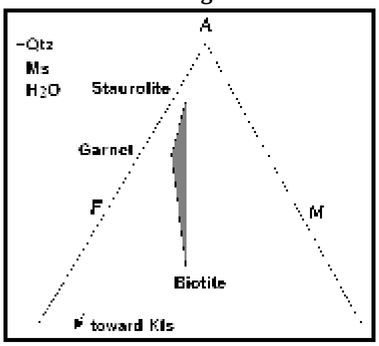

Fig 4: Mineral assemblage in Staurolite zone.

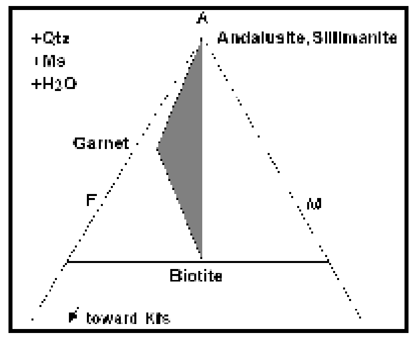

Fig 5: Mineral assemblage in Sillimanite muscovite zone.

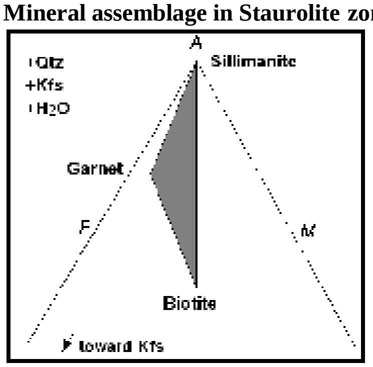

Fig 6: Mineral assemblage in
zone.
Sillimanite- potassium feldspar zone.

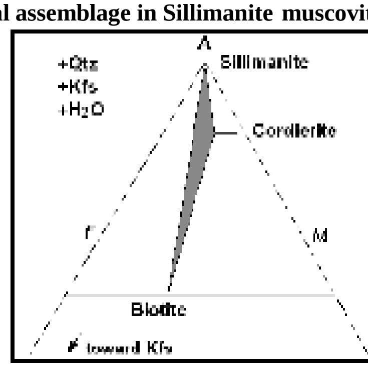

Fig 7: Mineral assemblage in Cordierite

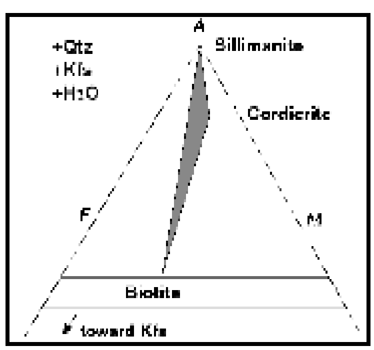

Fig 8: Mineral assemblage in Cordierite potassium feldspar zone.