Metamorphic Rocks in Ophiolitic Mélange Of Nain (Isfahan, Iran)

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Abstract

The Mesozoic ophiolitic Mélange of Nain, in Central-East Iran Microplate (CEIM) is composed of pelagic limestones, basalts and pillow lavas, plagiogranites, gabbros, pyroxenite, and mantle peridotites. In addition, the metamorphic rocks found in this ophiolite, are marble, schist, quartzite, banded metachert, skarn, amphibolitic rocks, spilite, metagabbro, serpentinite, rodingite, and listvenite. These metamorphic rocks are seen in a matrix of serpentinite. The most important metamorphic rocks, which considered in this research, are amphibolites and skarns. They have formed during the metamorphism of the oceanic crust and its overlying sediments. Amphibolitic rocks formed by the regional metamorphism of M1 (at about the middle of the amphibolite to the first of granulite facies), from basic rocks (basalts, pillow lavas, diabasic dikes) generated during the first rifting in Jurassic. Limestone covering these amphibolitic rocks, turned into skarn during a contact metamorphism of M2 (at albite-epidote hornfels to pyroxene hornfels facies), which caused by intrusion of tonalitic dikes in some parts. Then a retrograde metamorphism (M3) affected the skarns and amphibolites. So new foliation and new minerals (like prehnite, epidote and chlorite) formed in skarns and amphibolites, respectively. It was about greenschist facies. Presence of amphibolitic enclaves in skarn bodies indicates the formation of amphibolites before the skarns. Therefore, the occurrence of contact metamorphism (M2) was after the first regional metamorphism (M1). In addition, the second regional metamorphism (M3) has occurred after the contact metamorphism (M2).

1. Introduction

The Jurassic ophiolitic mélange of Nain consists of a wide variety of different rock. Some workers suggested that tectonic events caused some of the metamorphic rocks from metamorphic massif of Anarak-Khur (in northeast of the study area) to be transported to this ophiolite(Davoudzadeh, 1972, Lensch & Davoudzade, 1982, and Technoexport, 1984). Rahgoshay & Shafaii (2004) referred the occurrence of amphibolitic rocks to a paleo-transform fault within the mantle section of the Nain ophiolitic mélange. They also alluded to both marbles and fossiliferous Upper Cretaceous limestones, but did not explain whether these rocks were originally correlated. In addition, Rahgoshay & Shafaii (2004), Torabi et al. (2006, 2007) and Shirdashtzadeh (2007) did not find evidences for inverted metamorphic field gradients that would suggest a sole metamorphic process. According to petrography and geochemistry of the basic sheeted dykes of this ophiolite, (Rahmani et al. 2007), these rocks were only partially altered to the grade of green-schist facies.

This research will consider the metamorphism and evolution of the Nain ophiolite by studying different in situ metamorphic rocks.

1.1. Geological outlines: Ophiolitic mélange of Nain is located in the north of Nain town and west of the Central East Iran Microplate (CEIM). It is the residual part of the Neotethys Sea and originally of Mesozoic age (Davoudzadeh et al. 1981). The best outcrops of metamorphic rocks in this ophiolite zone can be found in the area between Nain town and Separab (Abyaneh-Nain, south of Kuh-e-Zard, near Soucheh Farm, Amirabad and Kazemabad). Many workers (e. g. Coleman 1977, Nicolas 1989, and Dilek & Newcomb 2003) have discussed the presence of metamorphic rocks in the ophiolites. This ophiolite contains a wide variety of metamorphic rocks reported by Davoudzadeh (1972), Davoudzadeh et al. (1981), Lensch & Davoudzadeh (1982), Technoexport (1984), and recently by Torabi (2003), Rahgoshay & Shafaii (2004), and Torabi et al. (2006, 2007). They are mostly amphibolites, skarns, metacherts, schists and marbles. The serpentinites and serpentinized ultramafics of mantle origin are the matrix for the other mentioned units.
Overall, metamorphism processes were in charge of the formation of marble and skarn from limestone, schist and phyllite from shale, quartzite from chert, banded metachert from banded chert, amphibolite from pillow lava and basalt, amphibolitic dyke from diabasic dyke, listwaenite and serpentinite from peridotite, spilite from basic pillow lava, and hornblende gabbro and rodingite from gabbro (Torabi et al. 2007). However, in this area, some other rock units do not show high-grade metamorphism indicating that they have just gone through some low-grade sub-sea metamorphism and spilitization. All of the rock units mentioned above intermixed forming a colored ophiolitic mélange.

2. Analytical Methods:

Mineralogical analyses were conducted by wavelength-dispersive EPMA (JEOL JXA-8800R) at the Cooperative Centre of Kanazawa University. The analyses were performed under an accelerating voltage of 15 kV and a beam current of 15 nA. ZAF corrections employed for data correction. Natural and synthetic minerals of known composition were used as standards. The Fe^{3+} content of minerals was estimated by assuming mineral stoichiometry (Droop 1987). Other geochemical data were adopted as referenced.

3. Petrography and mineral chemistry

3.1. Amphibolites: Microscopic and analytical studies indicated that amphibolitic rocks are mostly composed of hornblende (tschermakitic hornblende and magnesio-hornblende), plagioclase (andesine-oligoclase), pyroxene (diopside) and garnet (almandine-grossular) (Table 1). Other minerals include sphene, chlorite, calcite, quartz, prehnite, epidote, magnetite and ilmenite. Amphiboles were formed in exchange for igneous pyroxenes in rims and cracks. Most of the basic plagioclases were albitized during the sub-sea floor metamorphism. Based on Al-in-amphibole geobarometry (Schmidt, 1992) and hornblende-plagioclase geothermometry (Holland & Blundy, 1994), the P-T condition of the Nain amphibolites indicates that the regional metamorphism M1 that affected the Nain ophiolite have had developed in the amphibolite to granulite facies.

3.2. Skarns: Skarns are frequently found in, near or over the amphibolites. These skarn bodies are so small and widely scattered that they cannot be considered as economic ore deposits. Geochemical data show that pyroxenes are $Wo_{47.66-49.60}En_{26.09-30.83}Fs_{20.04-23.75}Ac_{0.51-0.96}$. The garnets are grossular-andradite with a composition of $Grs_{63.20-74.73}Adr_{18.73-34.42}Alm_{0.66-5.20}Sps_{0.32-0.72}$ (Table 1). Some garnets have transformed into clinopyroxenes in rims. Clinopyroxene and wollastonite are preserved as relict textures in garnet crystals indicating that here the formation of pyroxenes happened prior to that of garnets. Sometimes, garnets are broken down to prehnite, epidote and calcite in their fissures. In some areas, non-metamorphosed limestones on top of the upper parts of this ophiolitic sequence contain *Globotruncana*, characteristic for the Upper Cretaceous (Davoudzadeh 1972). In addition, some differently shaped amphibolitic fragments were found within the skarn bodies (at N32^o 54.837 and E53^o 07.433). These amphibolitic fragments are same with the studied amphibolitic bodies in the area and have produced by the regional metamorphism of M1. Moreover, general effects of a low-grade metamorphism (M3) were observed in amphibolites and skarns. In fact, skarns should be older than Upper Cretaceous since they show foliation S2 that is not found in the Upper Cretaceous non-metamorphosed limestones, pillow lavas and sheeted dykes (Torabi et al. 2006, 2007). Skarns bodies in the study area generally exposed above the amphibolitic rocks and were formed by a contact metamorphism (M2) in which the primary carbonates and limestone layers overlying the amphibolitic bodies were affected by some tonalitic intrusions. Geothermal energy flow from mantle played an effective role in this metamorphism stage. Mineralogy and thermometry of skarns and tonalites (Shirdashtzaeh et al., 2009) revealed temperatures of approximately 440 ^oC to 660^oC and pressures less than 3 kb for this contact metamorphism (M2).

3.3. Rodingites: Rodingites commonly consist of certain minerals like pectolite, actinolite, garnet, xonotlite, and chlorite. Sabzehei (2002) noted that genesis of rodingites in ophiolites of Iran is related to the intrusion of diabasic dykes in serpentinitized peridotites. As skarns and rodingites may show similar features they need to be studied carefully. Helpful in distinguishing these two rock types in this area may be the following: (1) Rodingites always find in serpentinites while the investigated skarns just found near or over the amphibolitic bodies with a similar foliation and they show no relation with serpentinites; (2) Characteristically, rodingites do not show a sharp contact with basic or serpentinitic rocks, however, shows sharp contact between amphibolite and tonalite; (3) Metacherts are formed by metamorphism of banded cherts and primary radiolarites and they are in gradual contact with nearby skarns. Thus, protoliths of skarns and metacherts developed in a marine setting in which pelagic limestones and radiolarites were formed; (4) As observed in their mineral parageneses, skarns formed under higher thermodynamic conditions than rodingites.

3.4. Metacherts: Besides skarns, metacherts are the other rocks produced during the contact metamorphism M2. They formed from the alternating chert and limestone layers. Thus, their calcitic parts contain calcite, clinopyroxene, garnet, wollastonite, sphene and epidote, while quartz, feldspars, clay minerals and chlorites concentrated in their siliceous parts.

4. Discussion

Several types of metamorphic events occurred in the Nain ophiolite that can be defined as serpentinization, sub-sea floor metamorphism and spilitization, rodingitization, regional metamorphism (M1), contact metamorphism (M2), low-grade metamorphism (M3) and listwaenitization. They caused mainly the formation of serpentinites, spilites, rodingites, amphibolitic rocks and schists, skarns and metacherts, schists and marbles, and finally listwaenites. In fact, diabasic dykes and basalts in the studied area formed when oceanic crust started spreading in Late Paleozoic (Technoexport 1984) or Early Mesozoic (Mohajjel et al. 2003). This oceanic crust were covered by pelagic sediments (banded cherts, overlain by limestones and shale successions) and Later, metamorphism M1 caused diabasic dykes, basalts and pillow lavas to change lithologically into amphibolites, banded cherts into banded meta-cherts, and limestone-shale successions into marble-schist (mostly muscovite schists and chlorite schists) successions. According to the presence of quartzites that have formed simultaneously with amphibolites, the first mid oceanic rifting (R1) occurred in a relatively deep-sea system. Therefore, these rocks cannot be some exotic blocks as claimed by Davoudzadeh (1972), Lensch & Davoudzadeh (1982), and Technoexport (1984), but are most probably rocks of the Nain ophiolite units metamorphosed in situ. Whole rock geochemistry of the amphibolitic rocks stated an inter-oceanic tholeiitic correspondence that is closely similar to N-type MORB (Shirdashtzadeh et al., 2009). During the contact metamorphism (M2), tonalitic dykes together with the upward flow of geothermal energy from the mantle caused that skarns were formed from pelagic limestones over the amphibolitic bodies. Banded metacherts were produced from alternating chert and limestone layers during the contact metamorphism (M2). Presence of amphibolitic fragments in these skarns indicates that amphibolites are older than the skarns and that they formed after M1. Second regional metamorphism (M3) affected marbles, quartzites, micaschists, skarns, amphibolites and tonalitic dykes and led to foliation S2. This low-grade metamorphism caused also Mn-garnetization and prehnitization in tonalites. Chloritization, epidotization, prehnitization and conversion of clinopyroxenes into amphiboles in amphibolitic rocks were also related to M3. M3 is characterized by a metamorphic grade up to greenschist facies.

5. Conclusions

All metamorphic rocks in the Nain ophiolitic mélange formed in situ and by several metamorphism types of the Nain ophiolite oceanic crust and its overlying sediments. In Early Jurassic, diabasic dykes, basalts and pillow lavas were produced, that were covered later by carbonates. After the oceanic crust had closed, they were metamorphosed in three major phases (M1, M2 and M3) in Middle Jurassic to Late Cretaceous. Amphibolitic rocks formed by the regional metamorphism of M1 from basic rocks (basalts, pillow lavas, diabasic dikes) generated during the first rifting in Jurassic. Limestone covering these amphibolitic rocks, turned into skarn during a contact metamorphism of M2. Then a retrograde metamorphism (M3) affected all the area rocks.

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Table 1. Representative mineral compositions (wt %), and end members of minerals in amphibolites, amphibolitic dykes, skarns and tonalites from the Nain ophiolitic mélange.

Rock Type	Amphibolites					Skarns				
Sample	4Amp	3 Pl	1 Grt	4 Cpx	2 Prh	11Cpx	5 Wo	9 Grt	6 Cal	2Sphene
SiO_2	42.62	66.00	37.88	51.10	43.51	51.90	51.78	38.85	0.01	30.93
Al_2O_3	12.41	16.87	21.48	2.42	24.16	0.77	0.00	15.33	0.00	2.69
TiO_2	1.17	0.00	0.19	0.25	0.09	0.02	0.01	0.98	0.02	37.11
Cr_2O_3	0.03	0.02	0.03	0.01	0.00	0.03	0.00	0.03	0.00	0.07
FeO*	17.08	0.15	24.32	10.11	0.22	12.83	0.18	8.94	0.06	0.41
MgO	10.21	0.10	2.95	11.73	0.01	10.15	0.07	0.27	0.02	0.00
MnO	0.43	0.02	3.28	0.41	0.03	0.57	0.16	0.25	0.05	0.04
CaO	11.57	5.18	10.40	22.82	26.28	23.51	46.72	35.24	56.88	27.99
Na_2O	1.61	11.25	0.03	0.59	0.08	0.19	0.03	0.01	0.00	0.03
K_2O	0.86	0.09	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.01
NiO	0.03	0.01	0.00	0.04	0.02	0.01	0.00	0.00	0.01	0.00
Total	97.97	99.12	100.56	99.48	94.35	99.98	98.96	100.08	57.04	99.28
Oxy*	23	8	12	6	22	6	6	12	3	5
Si	6.30	2.95	2.97	1.93	6.06	1.98	2.03	3.00	0.00	1.00
Al	2.16	0.88	9.03	0.11	3.97	0.03	0.00	1.39	0.00	0.10
Ti	0.13	0.00	0.01	0.01	0.01	0.00	0.00	0.06	0.00	0.91
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	1.41	0.00	1.54	0.25	0.03	0.38	0.05	0.10	0.00	0.00
Fe^{3+}	0.70	0.00	0.06	0.07	0.00	0.03	0.00	0.48	0.00	0.01
Mg	2.25	0.01	0.35	0.66	0.00	0.58	0.00	0.03	0.00	0.00
Mn	0.05	0.00	0.22	0.01	0.01	0.02	0.01	0.02	0.00	0.00
Ca	1.83	0.26	0.87	0.92	3.92	0.96	1.96	2.92	1.00	0.97
Na	0.46	0.97	0.01	0.05	0.02	0.01	0.00	0.00	0.00	0.00
K	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	15.46	5.08	15.05	4.00	14.01	4.00	4.00	8.00	1.00	3.00
Albite		83.70								
Anorthite		15.87								
Orthoclase		0.40								
Wollastonite				48.14		0.49	0.99			
Enstatite				34.42		0.29	0.00			
Ferrosilite				17.32		0.22	0.01			
Almandine			51.65					0.03		
Andradite			2.70					0.25		
Grossular			26.52					0.70		
Pyrope			11.57					0.01		
Spessartine			7.31					0.01		
Uvarovite			0.08					0.00		

*** Oxygen per formula unit**