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Ultramafic Hornfelses in Central Iran Ophiolites

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Abstract: There are leucocratic gabbro intrusions in serpentinized mantle peridotites of Central Iran ophiolites (Jandaq, Anarak, Naein and Ashin-Zavar). In contacts of gabbro intrusions and serpentinized mantle peridotites, ultramafic hornfelses are formed by contact metamorphism. These ultramafic hornfelses are different with host mantle peridotite in petrography, texture and mineral chemistry. Two-pyroxene thermometry of hornfelses and intact mantle peridotites that are far from contact metamorphism, present 987 and 1200°C, respectively. To occurring the reaction between the gabbro intrusions and mantle peridotites, the host rock should be serpentinized previously.

Key words: Serpentinized mantle peridotite, Gabbro intrusion, contact metamorphism, ultramafic hornfelse, Central Iran ophiolites

INTRODUCTION

Geological background: Ophiolites have played a major role in our understanding of earth's processes ranging from seafloor spreading, melt evolution and magma transport in oceanic spreading centers and hydrothermal alteration and mineralization of oceanic crust to collision tectonics, mountain building processes and orogeny. They provide the essential structural, petrological, geochemical and geochronological evidence to document the evolutionary history of ancient continental margins and ocean basin. Ophiolites include a peridotitic mantle sequence, generally characterized by high-temperature plastic deformation and residual chemistry and a comagmatic crustal sequence (gabbros, diabase dikes and submarine basalts), weakly or not deformed. According to this interpretation, ophiolites were allochthonous with respect to their country rocks. They were assembled during a primary accretion stage at an oceanic spreading center and later tectonically emplaced on a continental margin or island arc (Dilek and Newcomb, 2003).

The indigenous dikes of pyroxenites and gabbros that were injected into a melting peridotite, or intrusive dikes of pyroxenite and gabbro that injected when the peridotite was fresh and well below its solidus, are discussed in different ophiolite papers. Pyroxenite formation and contact of gabbro and mantle peridotite are discussed in different articles (Dilek and Newcomb, 2003; Santos *et al*., 2002). When a gabbro intrud to a fresh mantle peridotite could not significantly react with it, but if intrusion occur during the serpentinization, the gabbro will change to rodingite (Palandri and Reed, 2004; Hatzipanagiotou *et al*., 2003). Petrological data about of aureoles up to 2 km that have been generated by intrusive rocks in serpentinized mantle peridotite country rock, are discussed in Evans (1977). Regional and contact metamorphism of peridotites are presented in Arai *et al*. (2004), Faryad and Hoinkes (2003), Faryad *et al*. (2002), Hoinkes *et al*. (1999), Hong *et al*. (2007), Konishi *et al*. (2002), Melcher and Meisel (2004) and Nozaka (2005).

Depends on the composition of intrusive body, mineralogical assemblage of contact metamorphosed host rock will be different. Olivine + enstatite + tremolite + chlorite assemblage, is usually attained close to contacts with granodioritic and tonalitic intrusives, olivine + enstatite + hornblende + spinel assemblage, close to quartz diorite and gabbro and olivine + enstatite + diopside or anorthite + hornblende + spinel assemblage, in association with gabbro (Enavs, 1977). Typical rock in gabbro and serpentinized mantle peridotite contact is plagioclase peridotite, especially plagioclase lherzolite. Mineralogical assemblage of pyroxene hornfels (low pressure), will be forsterite, orthopyroxene, clinopyroxene and plagioclase as aluminum-phase. During the metamorphism of mantle peridotites, the olivine and orthopyroxene will form in lower temperatures than that in igneous environments (Evans, 1977).

Field study of the four Central Iran ophiolites (Fig. 1) conclude that different gabbro intrusions cross cut the mantle peridotites. Gabbro intrusions that are in fresh mantle peridotites, has an almost sharp contact zone. Some of gabbro intrusions that are in the serpentinized mantle peridotites are rodingitized. In special cases that gabbro entrance occurred after the serpentinization of mantle peridotites, new rocks that are ultramafic hornfelse are formed in contact zone (Fig. 2). In the cases that a gabbroic dike intrud the serpentinized mantle peridotite, the contact zone is composed of symmetrical screen of

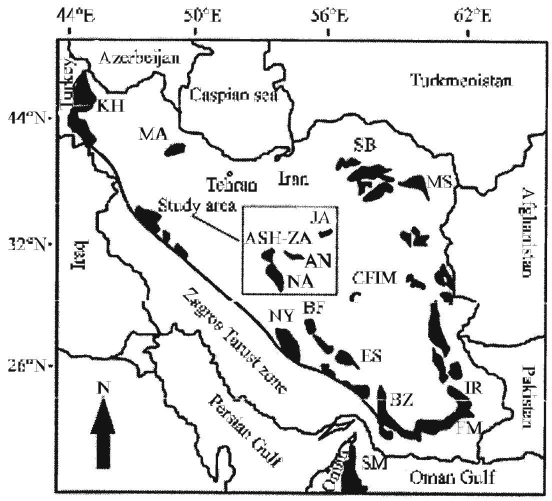

Fig. 1: Ophiolites of Iran and study area (Pessagno *et al*., 2004, with changes in Central Iran ophiolites). KH = Khoy; KR = Kermanshah; NY = Neyriz; BZ = Band Ziarat; BF = Baft; ES = Esphandagheh; FM = Fanuj-Maskutan; IR = Iranshahr; TK = Tchehel Kureh; MS= Mashhad; SB = Sabzevar; MA = Masooleh; SM=Samail; ASHZA= Ashin-Zavar; AN = Anarak; JA = Jandaq; NA = Naein

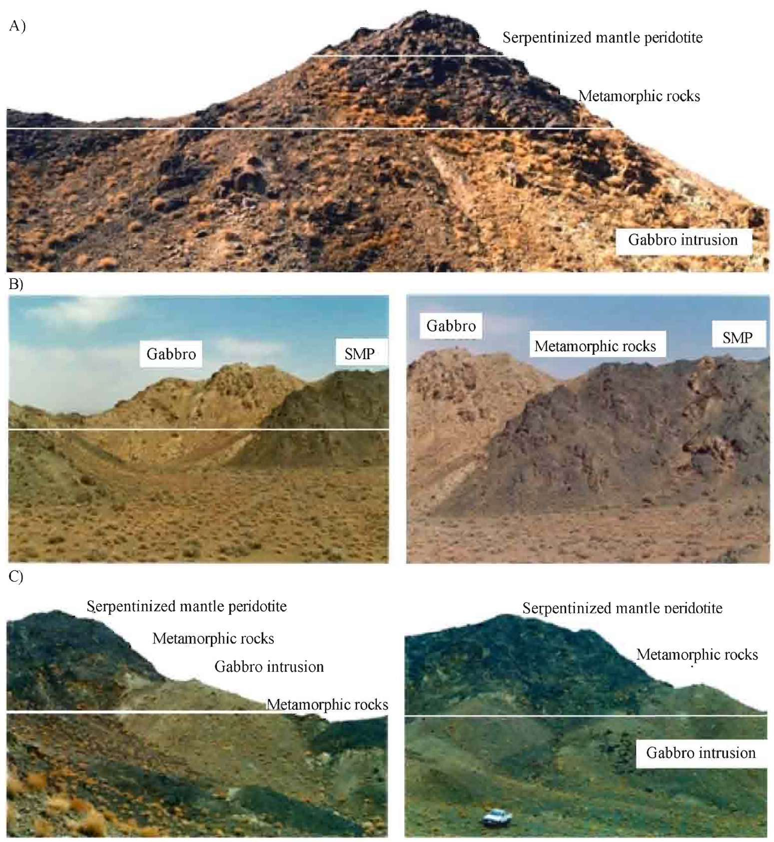

Fig. 2: Field relationships and formation of new rocks in contact of gabbro and serpentinized mantle peridotite (SMP). Field photos are from Jandaq (A), Anarak (B), Naein (C) and Ashin-Zavar (D) area

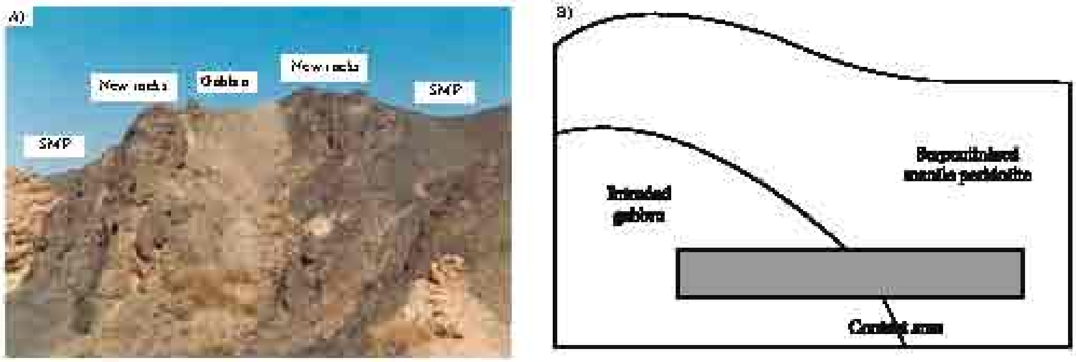

Fig. 3A: A gabbroic dike with two symmetrical side of new metamorphic rocks. The host rock is serpentinized manle peridotite (SMP)

B: The studied areas limit and contact zone of gabbro and peridotite

new contact metamorphic rocks on each side of the dike (Fig. 3A).

The order of appearance of ultramafic hornfelses from gabbro to mantle peridotite side is troctolite, plagioclase lherzolite, wehrlite and clinopyroxenite (Fig. 3B). These rocks are production of special type of contact metamorphism between the gabbro intrusions and serpentinized mantle peridotites. The intruded gabbros are different from the layared gabbros.

In this research the petrology and mineralogy of these contact metamorphic rocks in contact zone of gabbro intrusions and serpentinized mantle peridotites will be discussed.

Geological setting: There are four types of ophiolites in Iran: 1- Zagros ophiolites with Mesozoic age, that are exposed near the Zagros thrust zone. 2- Ophiolites around the Central-East Iran Microcontinent (CEIM) with age of Mesozoic. First and second types are remnants of Neo-Tethys. 3- Ophiolites that are remnants of Paleo-Thetys, with Paleozoic (Permian) age. These ophiolites are exposed in north and north-east of Iran. 4- Anarak and Jandaq ophiolites in Central Iran with age of Upper Proterozoic or Lower Paleozoic (Torabi, 2003) (Fig. 1).

The study area is located on the west of Central Iran and the southern margin of Great Kavir with highly deserted geographical conditions. Two types of ophiolitic rocks are found in studied area:

- Jandaq and Anarak ophiolites with age of Upper Proterozoic or Paleozoic are composed (Almasian, 1997; Torabi, 2003) of rock units of mantle peridotites and serpentinized mantle peridotites, cumulates, gabbros, basic and ultrabasic dikes, pyroxenites, glaucophane bearing meta-pillow lava, amphibolite, rodingite and Litsvenite. There are masses of plagiogranite which are cutting all members of this old ophiolitic sequence and metamorphites. The age of these plagiogranites is not clear. The Jandaq and Anarak ophiolite has been covered by Upper Proterozoic-lower Paleozoic metamorphic rocks (schist and marble). All of the rock units of these ophiolites have been metamorphosed in green schist and amphibolite facies, respectively (Almasian, 1997). There are no chromitite in these ophiolites. These old ophiolites have passed high degree of serpentinization.
- Naein and Ashin-Zavar ophiolitic melange with the age of Mesozoic. The age of pillow lavas and diabasic dikes is Upper Cretaceous (Rahmani *et al*., 2007). The Naein and Ashin-Zavar ophiolitic melanges comprise the following rock units: mantle peridotites (harzburgite, lherzolite, dunite, with associated chromitite), gabbro, pyroxenite, sheeted and swarm dikes, massive basalts, pillow lava, plagiogranite, Radiolarian chert, Glaubotruncana limestone, rodingite, litsvenite and metamorphic rocks (foliated amphibolitic dike, amphibolite, skarn, banded meta-chert, succession of schist and marble and meta-plagiogranite). The Naein and Ashin-Zavar ophiolitic melanges occurring as a wedge, which separates the Anarak-Khur metamorphic massif to the west and Kuh-e-Dom volcanic zone to the east. These ophiolites are relicts of Neo-Tethys.

The above mentioned two types of ophiolites have very different geological histories.

Field studies show that these ophiolitic bodies have been squeezed out on to the surface along deep fault zones. Geophysical data emphasized the existence of large

Table 1: Representative chemical analyses of minerals (wt %) from gabbro to host serpentinized mantle peridotites.

Rock	Minerals	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	NiO	Total
Gabbro	Plagioclase	46.74	0.00	33.93	0.04	0.20	0.00	0.01	17.25	1.72	0.02	0.00	99.91
[Far]	Clinopyroxene	55.76	0.04	0.29	0.04	6.17	0.23	15.64	21.67	0.20	0.03	0.00	100.09
Gabbro	Plagioclase	45.09	0.02	34.61	0.02	0.38	0.02	0.04	18.72	1.02	0.00	0.00	99.91
[Near]	Clinopyroxene	52.93	0.43	2.90	0.33	4.12	0.08	16.47	22.83	0.30	0.02	0.00	100.41
Troctolite	Plagioclase	43.50	0.00	35.36	0.00	0.39	0.02	0.09	19.70	0.55	0.04	0.01	99.66
[Contact Zone]	Olivine	40.11	0.02	0.00	0.01	12.57	0.21	46.96	0.02	0.03	0.01	0.24	100.17
	Plagioclase	44.52	0.00	35.29	0.00	0.31	0.02	0.03	19.32	0.73	0.03	0.01	100.24
Plagioclase	Clinopyroxene	52.93	0.20	2.32	0.71	4.11	0.11	17.78	21.97	0.14	0.01	0.04	100.32
Peridotite	Orthopyroxene	55.89	0.12	1.54	0.26	8.72	0.17	32.48	1.21	0.02	0.00	0.08	100.49
	Olivine	39.30	0.00	0.00	0.00	14.18	0.18	45.64	0.06	0.01	0.01	0.33	99.71
	Clinopyroxene	52.09	0.15	3.02	0.92	4.23	0.16	16.88	22.46	0.20	0.01	0.03	100.14
Wehrlite	Orthopyroxene	55.49	0.17	1.33	0.25	9.39	0.28	31.23	1.35	0.01	0.00	0.03	99.53
	Olivine	39.36	0.01	0.01	0.03	16.81	0.23	43.54	0.09	0.00	0.00	0.28	100.36
Clinopyroxenite	Clinopyroxene	51.70	0.18	3.62	0.41	4.56	0.17	16.85	22.80	0.18	0.02	0.01	100.50
Mantle Peridotite	Clinopyroxene	52.48	0.05	3.74	1.03	2.45	0.07	17.40	23.01	0.07	0.01	0.07	100.38
[Far]	Orthopyroxene	55.94	0.00	2.88	0.56	5.85	0.17	33.73	0.57	0.00	0.00	0.07	99.78
	Olivine	39.89	0.00	0.00	0.01	9.09	0.16	50.18	0.01	0.00	0.01	0.40	99.75

Table 2: Calculated structural formula of minerals of Table 1

Rock	Minerals	Oxyg.	Si	Ti	Al	Cr	Fe^{2+}	Fe^{+3}	Mn	Mg	Ca	Na	K	Ni	Total
Gabbro	Plagioclase (Bytownite)	8	2.15	0.00	1.84	0.00	0.01	0.00	0.00	0.00	0.85	0.15	0.00	0.00	5.00
[Far]	CPX (Augite)	6	2.06	0.00	0.01	0.00	0.19	0.00	0.01	0.86	0.86	0.01	0.00	0.00	4.00
Gabbro	Plagioclase (Anorthite)	8	2.08	0.00	1.88	0.00	0.02	0.00	0.00	0.00	0.93	0.09	0.00	0.00	5.00
[Near]	CPX (Diopside)	6	1.92	0.01	0.12	0.01	0.11	0.02	0.00	0.89	0.89	0.02	0.00	0.00	4.00
Troctolite	Plagioclase (Anorthite)	8	2.02	0.00	1.93	0.00	0.02	0.00	0.00	0.01	0.98	0.05	0.00	0.00	5.00
[Contact Zone]	Olivine (Chrysolite)	4	1.00	0.00	0.00	0.00	0.26	0.00	0.00	1.74	0.00	0.00	0.00	0.01	3.00
	Plagioclase (Anorthite)	8	2.05	0.00	1.92	0.00	0.01	0.00	0.00	0.00	0.95	0.06	0.00	0.00	5.00
Plagioclase	CPX (Augite)	6	1.92	0.01	0.10	0.02	0.08	0.04	0.00	0.96	0.85	0.01	0.00	0.00	4.00
Peridotite	OPX (Enstatite)	6	1.94	0.00	0.06	0.01	0.21	0.05	0.01	1.68	0.04	0.00	0.00	0.00	4.00
	Olivine (Chrysolite)	4	0.99	0.00	0.00	0.00	0.30	0.00	0.00	1.71	0.00	0.00	0.00	0.01	3.00
	CPX (Diopside)	6	1.90	0.00	0.13	0.03	0.07	0.06	0.01	0.92	0.88	0.01	0.00	0.00	4.00
Wehrlite	OPX (Enstatite)	6	1.96	0.01	0.06	0.01	0.26	0.02	0.01	1.64	0.05	0.00	0.00	0.00	4.00
	Olivine (Chrysolite)	4	1.00	0.00	0.00	0.00	0.36	0.00	0.01	1.64	0.00	0.00	0.00	0.01	3.00
Clinopyroxenite	CPX (Diopside)	6	1.88	0.01	0.15	0.01	0.05	0.09	0.01	0.91	0.89	0.01	0.00	0.00	4.00
Mantle Peridotite	CPX (Diopside)	6	1.90	0.00	0.16	0.03	0.06	0.02	0.00	0.94	0.89	0.01	0.00	0.00	4.00
[Far]	OPX (Enstatite)	6	1.93	0.00	0.12	0.02	0.17	0.00	0.01	1.74	0.02	0.00	0.00	0.00	4.00
	Olivine (Forsterite)	4	0.98	0.00	0.00	0.00	0.19	0.00	0.00	1.84	0.00	0.00	0.00	0.01	3.00

ophiolitic masses at depth. The Great Kavir fault separates the Anarak-Khur massif and the Ashin-Zavar ophiolitic structure.

The studied ophiolites have passed different phases of static and dynamic serpentinization during the formation and emplacement. Naein and Ashin-Zavar mantle peridotites suffered lower degree of serpentinization, but more gabbro intrusions and Ashin-Zavar ophiolite presents the best exposures of gabbro and serpentinized mantle peridotite contacts. The fresh olivine and orthopyroxene are rare in above mentioned old ophiolites (Anarak and Jandaq), so in this article we paid more attention to Ashin-Zavar ophiolite, because of more and complete exposures of contact zone.

MATERIALS AND METHODS

Mineralogical analyses were conducted by wavelength-dispersive EPMA (JEOL JXA-8800R) at the Cooperative Centre of Kanazawa University (Japan) and Leibniz University (Germany). The analyses were performed under an accelerating voltage of 15 kV and a beam current of 15 nA. JEOL software using ZAF corrections was employed for data reduction. Natural and synthetic minerals of known composition are used as standards. Representative analyses of the minerals and results of structural formula calculations are shown in Table 1 and 2. The Fe^{3+} content in minerals was estimated by assuming mineral stoichiometry.

RESULTS

Petrography

Petrography of mantle peridotites that are far from gabbro intrusions

Lherzolite: Lherzolite in hand specimen is dark and fresh. This rock consists of olivine, orthopyroxene, clinopyroxene and chromian spinel with granoblastic and porphyroblastic texture (Fig. 4A, B). The orthopyroxene porphyroclasts are surrounded by serpentine minerals. Orthopyroxenes show corrosion or absorption gulfs in margin and often contain exsolution lamellae of clinopyroxene. Spinel is anhedral with light brown colour.

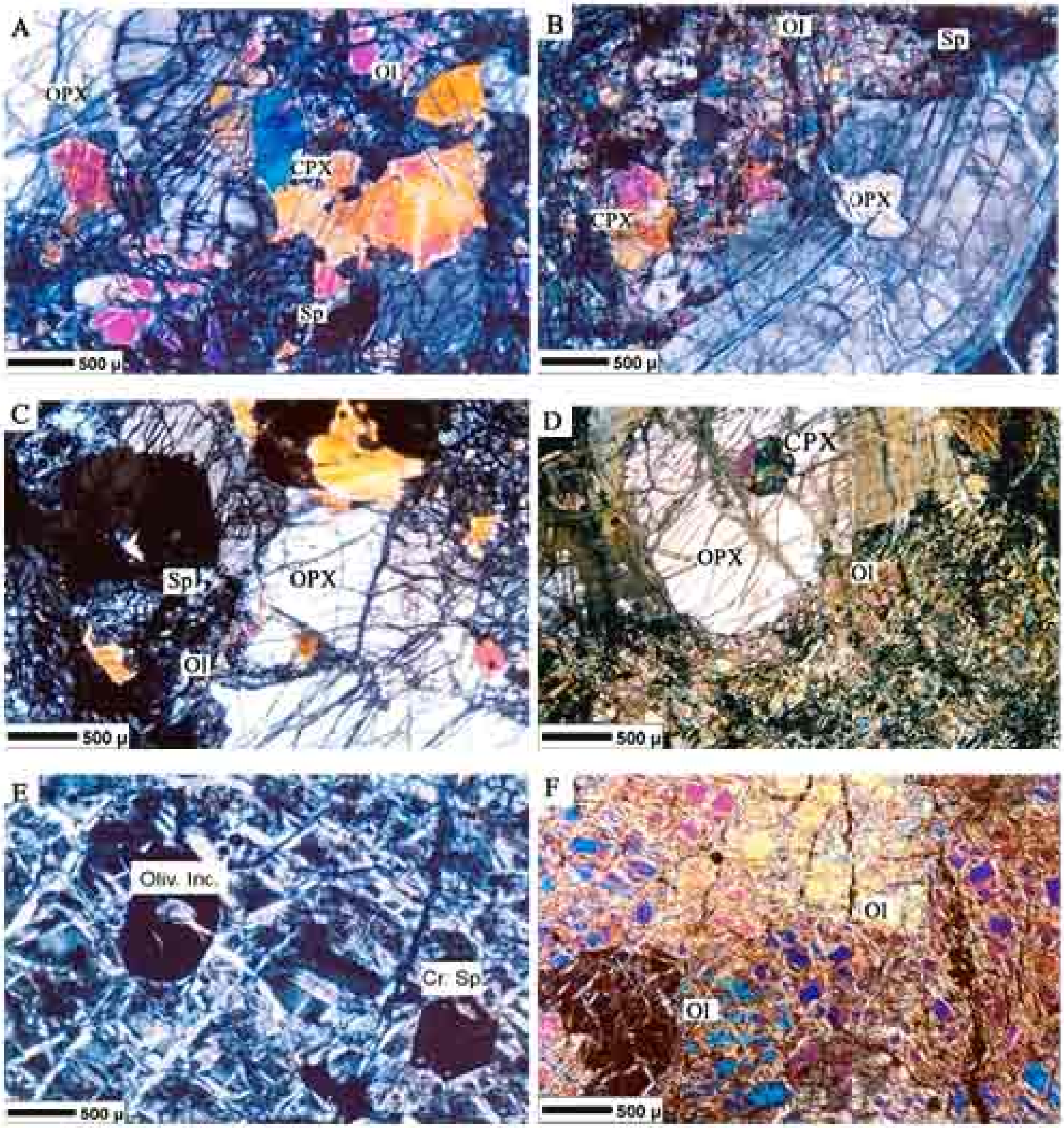

Fig. 4: Photomicrographs of serpentinized mantle peridotites that are far from gabbro intrusions. lherzolite (A, B), harzburgite (C, D) and dunite (E, F)

Harzburgite: Harzburgite consists of olivine, orthopyroxene with low amount of clinopyroxene and chromian spinel (Fig. 4C, D). Most of harzburgites show porphyroclastic texture. Olivines are anhedral, fine grain and most of them, are serpentinized. These minerals do not show any optical zoning and are free from deformation. Orthopyroxene crystals have deformed shape (kink band) and show corrosion or absorption gulfs on their rims. These gulfs have been filled with fine grain replacive olivines which have been derived from incongruent melting of orthopyroxenes. Orthopyroxenes present the evidence of plastic deformation at high temperatures. This deformation occurs when the temperature of these rocks were very close to the solidus temperature. These minerals have exsolution lamellae of clinopyroxene and partly altered to bastite. Chromian spinel is generally subhedral, larger and darker than that in lherzolite.

Dunite: Dunite is common as envelope around the podiform chromite deposits regardless of their shape and size. Dunites in hand specimen have yellow-green colour and present higher degree of serpentinization than that in the harzburgite. The main texture of these rocks is granoblastic but serpentinization process makes the mesh texture. In addition, main minerals of these rocks are olivine and serpentine and the minor minerals are orthopyroxene, clinopyroxene and chromian spinel. Olivine is euhedral and larger than that in harzburgite. Chromian spinel is fresh and subhedral to euhedral. Dunite contains more abundantly chromian spinel with euhedral shapes than that in harzburgite (Fig. 4E, F).

Petrography of contact metamorphism zone: There are coarse grain leucocratic gabbro intrusions that cutting the serpentinized mantle peridotites in west of Central Iran ophoiolites. In contact zone of these rock units, the new metamorphic rocks are formed. The thickness of these metamorphic rocks depends on degree of serpentinization of mantle peridotites (host rock) and volume of gabbro intrusion. High degree of serpentinization of mantle peridotites and big masses of gabbros will produce thick layer of ultramafic hornfelse around the gabbro intrusions and vice versa.

To find a comprehensive view about of this special type of metamorphism, the samples gathered in direct line from inner part of gabbro intrusion toward the margin, contact zone and then inner part of mantle peridotite (Fig. 3B).

Microscopic photos of gabbro intrusion, host serpentinized mantle peridotite and new rocks that are formed in contact zone, are presented in Fig. 5.

Petrographic studies conclude the *Troctolite*, *Plagioclase lherzolite*, *Wehrlite* and *Clinopyroxenite* formation in contact zone from gabbro side to mantle peridotite side. Changes of rock units are transitionaly.

All minerals of gabbro intrusions and rocks that formed in contact zone are coarse grain and do not show the deformation textures (e.g., Kink band) and are free from stress, but deformation textures are obvious in serpentinized mantle peridotite side.

Gabbro intrusions are as stock and dike in field studies. They are coarse grain leucogabbros that essentially formed by plagioclase and clinopyroxene with granular texture. The accessory minerals are amphibole, chlorite, prehnite, sphene, magnetite and calcite. Margin part of gabbro intrusions are fresh and secondary minerals are absent. There are no chilled margin in border of gabbro intrusion and serpentinized mantle peridotite.

There are *Troctolite* exactly in contact zone. This rock is absent in low-volume gabbro intrusion contacts and exist as thin layer in stock intrusions. Troctolite consists of plagioclase and olivine. Accessory minerals are clinopyroxene and orthopyroxene. Pyroxenes and plagioclases are fresh, but olivines present cracks and are partly serpentinized. After troctolite, the *Plagioclase lherzolite* is near to contact zone. Minerals are plagioclase, olivine, orthopyroxene and clinopyroxene. In some parts, the olivine and orthopyroxenes are as islands in clinopyroxenes. By going toward the *Wehrlite* and then *Olivine clinopyroxenite*, the plagioclse is absent and the amount of orthopyroxenes decrease. In some parts of plagioclase lherzolites, all olivines and orthopyroxenes, are as islands in clinopyroxenes. Finally, the *Clinopyroxenite* is observable. From clinopyroxenite toward the inner parts of host *Serpentinized mantle peridotite* the degree of serpentinization increases.

Mineral chemistry: *Plagioclase* is present from gabbro side to troctolite in contact zone and then in plagioclase lherzolite. Study of plagioclases show the anorthite content increasing from inner part of gabbro intrusions (Far) to margin (Near) part and troctolite in contact zone. But anorthite content decrease from troctolite to plagioclase peridotite. The maximum of anorthite content in plagioclases (95%) present in troctolites of exact contact zone. Plagioclase type of gabbros in inner parts is bytownite, but in margin are anorthite. All plagioclases that formed by gabbro intrusion entrance in ultramafic hornfeldes are anothite in composition.

Summary of calculations for percent of each end-member and Mg# values of minerals is presented in Fig. 6.

Clinopyroxene is present as essential mineral in all rocks, but as accessory mineral in troctolite of contact zone. The Mg#, wollastonite and enstatite content of clinopyroxenes increase from inner part of gabbros to margin part, but the ferrosilite content decrease. The clinopyroxene type of gabbro changes from augite in inner part, to diopside in margin. The Mg# value and enstatite content of new formed clinopyroxenes increase from clinopyroxenite to wehrlite and plagioclase peridotite, but the wollastonite and ferrosilite content decrease. The clinopyroxene composition in clinopyroxenite and wehrlite, changes from diopside to augite in plagioclase peridotite.

Orthopyroxene is present in wehrlite and plagioclase peridotite. All orthopyroxenes are enstatite in composition and the maximum of Mg# is in plagioclase peridotite.

Olivine is present in all ultramafic hornfelses. All olivines, that produced by gabbro intrusion and contact metamorphism, are chrysolite in composition but olivines of host serpentinized mantle pridotite are forsterite. The maximum forsterite content of metamorphic olivines (87%) is in troctolites of exact contact zone.

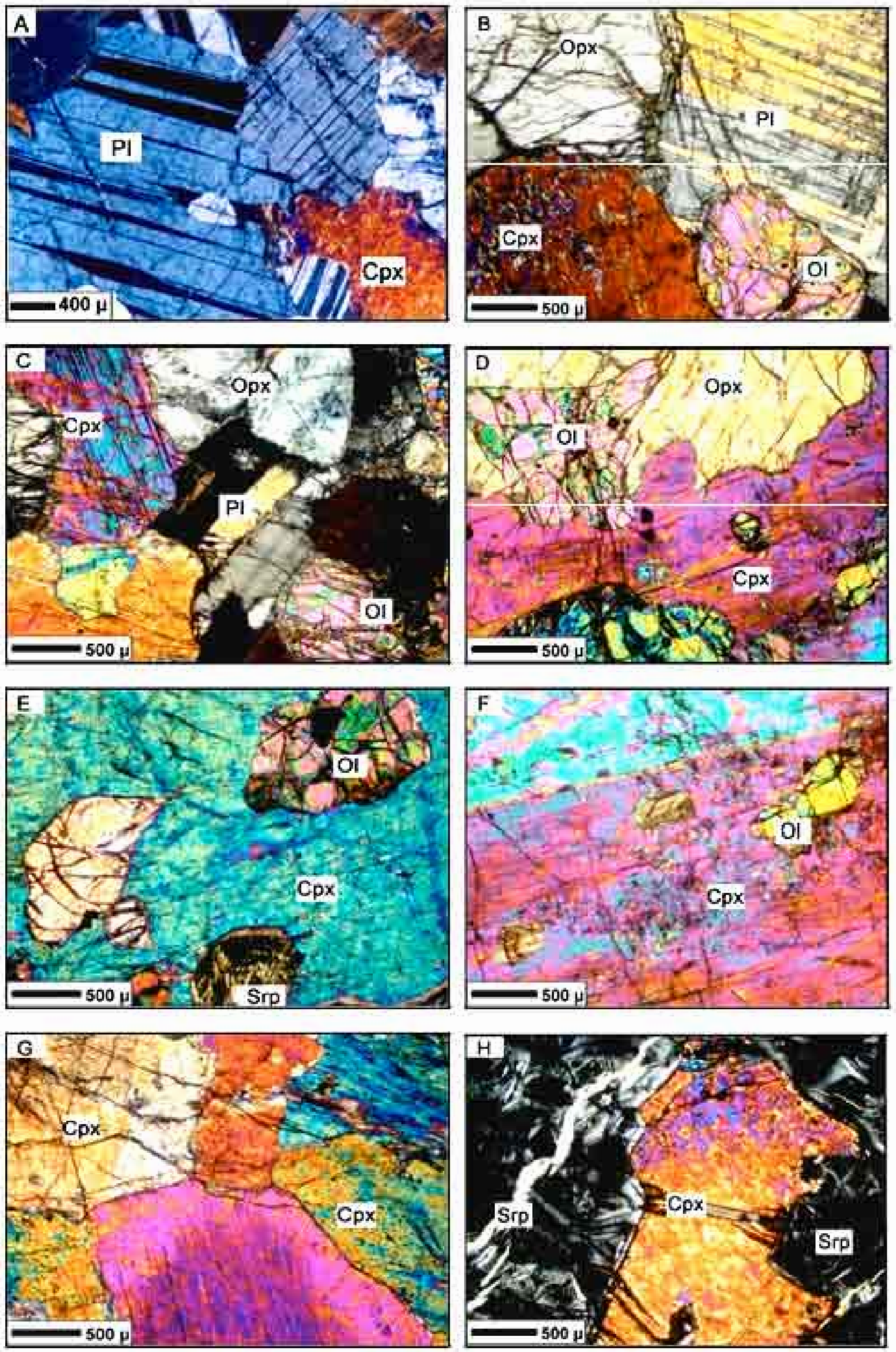

Fig. 5: Microscopic photos of studied rocks in contact zone of gabbro intrusion and serpentinized mantle peridotite.
A) Gabbro intrusion, B, C and D) Plagioclase lherzolite, E) Photo from a part of wehrlite, F and G) clinopyroxenite and H) Host serpentinized mantle peridotite

Gabbro (Far)	Gabbro (Near)	Troctotile (Contact zone)	Plagioclase peridotite	Wehrlite	Clinopyroxenite	Serpentinized mantle peridotite
Plagioclase	Plagioclase	Plagioclase	Plagioclase			
An 84.62	An 91.02	An 94.97	An 93.44			
Ab 15.72	Ab 8.98	Ab 4.80	Ab 6.39			
Or 0.12	Or 0.00	Or 0.23	Or 0.17			
Clinopyroxene	Clinopyroxene		Clinopyroxene	Clinopyroxene	Clinopyroxene	Clinopyroxene
Wo 44.75	Wo 46.57		Wo 43.47	Wo 45.49	Wo 45.66	Wo 46.78
En 44.93	En 46.74		En 49.47	En 47.57	En 46.95	En 49.22
Fs 10.32	Fs 6.69		Fs 6.59	Fs 6.94	Fs 7.40	Fs 4.00
Mg # 0.82	Mg # 0.88		Mg # 0.89	Mg # 0.88	Mg # 0.87	Mg # 0.93
			Orthopyroxene	Orthopyroxene		Orthopyroxene
			Wo 2.27	Wo 2.58		Wo 1.09
			En 84.72	En 83.00		En 89.90
			Fs 13.01	Fs 14.42		Fs 9.00
			Mg # 0.87	Mg # 0.86		Mg # 0.91
		Olivine	Olivine	Olivine		Olivine
		Fo 86.75	Fo 86.75	Fo 82.00		Fo 90.63
		Fa 13.02	Fa 13.02	Fa 17.76		Fa 9.21
		Tp 0.22	Tp 0.22	Tp 0.25		Tp 0.16

Fig. 6: Petrologic and mineralogic changes in contact zone of gabbro intrusion and serpentinized mantle peridotite

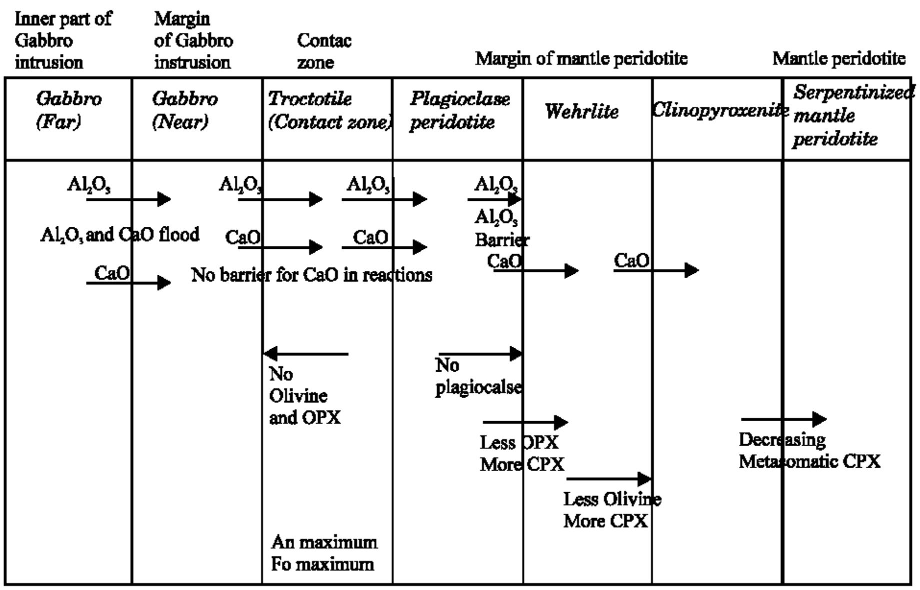

Fig. 7: CaO and Al_2O_3 flood toward the contact zone conclude the changes

DISCUSSION

Peridotitic part of contact zone and intact host mantle peridotites, essentially are formed by olivine, orthopyroxene and clinopyroxene. Textures of mantle peridotites and metamorphic rocks are different. In mantle peridotites, main texture is porphyroblastic, olivines are forsterite, fine grain and free from deformation, orthopyroxenes are porphyroclasts with mantle deformation features (kink band). Orthopyroxenes have absorption gulf in margins that are filled by fine grain olivines and clinopyroxene exsolution lamelae. Clinopyroxenes are crushed and fine to medium grain. Serpentinization is obvious and there are no olivine inclusion in pyroxenes. Morphology of chromian spinel changes from anhedral in lherzolite, to subhedral in harzburgite and euhedral in dunite and chromitite. Size of chromian spinel increases in this trend. But metamorphic rocks are granoblastic and poikiloblastic in texture with low serpentinization. All minerals are coarse grain, without absorption gulf in margin and kink band in pyroxenes. Olivines are forsterite to chrylolite in composition. Spinels are rare in metamorphic rocks.

Mineralogical study conclude the different composition of olivine, orthopyroxene and clinopyroxene of troctolite, plagioclase lherzolite, wehrlite and clinopyroxenite with minerals of host serpentinized mantle peridotite. Olivine, orthopyroxene and clinopyroxene present a systematic changes in composition from troctolite to clinopyroxenite. This matter conclude the formation of new metamorphic rocks between the serpentinized mantle peridotites and gabbro intrusions. Troctolite, plagioclase peridotite, wehrlite and clinopyroxenite are products of special type of contact metamorphism between the gabbro and serpentinized mantle peridotites.

Petrography of contact zone present the olivine and then orthopyroxene content decreasing from contact zone to mantle peridotite side. The plagioclase, orthopyroxene and olivine barrier is between the plagioclase peridotite-wehrlite, plagioclase peridotite-troctolite and gabbro-troctolite contact, respectively (Fig. 7).

Field, petrography and mineral chemistry studies conclude the chemical potential gradient formation immediately after gabbro entree. By this gradient, CaO and Al_2O_3 come from gabbro part and MgO from mantle peridotite part toward the contact zone (Fig. 7). The activity of CaO was higher than Al_2O_3 and MgO.

Whole rock geochemistry of gabbro intrusions in Ashin-Zavar ophiolite conclude that the margin part of gabbros are depleted in REE and present the negative Eu anomaly (Torabi, 2003) (Fig. 8).

Using the two-pyroxenes geothermometry for rocks of contact zone present 987°C, but 1200°C for host serpentinized mantle peridotites. For geothermometry of pyroxenes the reference of Nimis and Taylor (2000) is used. The lower temperature in thermometry of these new formed rocks conclude the special type of contact metamorphism origin for rocks of contact zone. Two-pyroxenes geothermometry reveals the pyroxene hornfels facies conditions for this type of contact metamorphism.

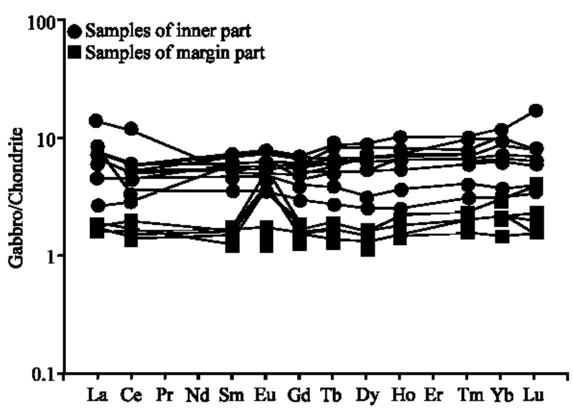

Fig. 8: Chondrite normalized diagram for REE content in gabbros of Ashin-Zavar ophiolite (Torabi, 2003). Lower content of REE and positive anomaly of Eu in margin samples are obvious

For occurring the above mentioned metamorphism and formation of new metamorphic rocks in contact zone of gabbro intrusions and mantle peridotite, the host rock should be previously serpentinized.

CONCLUSIONS

Intrusion of gabbros in serpentinized mantle peridotites of Central Iran ophiolites, a chemical potential gradient established and ultramafic hornfelses are formed in contact zone. Metamorphic rocks that produced by this contact metamorphism, are troctolite, plagioclase peridotite, wehrlite and clinopyroxenite, from gabbro side toward the serpentinized mantle peridotite side. These rocks are formed in expense of peridotitic part of contact zone. Texture, mineralogy and mineral chemistry of contact metamorphic rocks are different with host mantle peridotites.

Calcium flow from inner parts of gabbro intrusion towards the margin, caused the chemical composition difference of plagioclase and clinopyroxene. Plagioclases of margin part are more anorthitic and chemical composition of clinopyroxenes changed from augite in inner part to diopside in margin. Petrological and geotectonic interpretations of gabbro intrusions by chemical composition of minerals should be revised by occurring above mentioned reactions. Geothermometry of plagioclase peridotites of contact zone conclude the 213°C lower than mantle peridotites.

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REFERENCES

Almasian, M., 1997. Tectonics of the Anarak area (Central Iran). Ph.D Thesis, Islamic Azad University, Science and Research Unit.

Arai, S., S. Takada, K. Michibayashi and M. Kida, 2004. Petrology of peridotite xenoliths from Iraya volcano, Philippines and its implication for dynamic mantle-wedge processes. J. Petrol., 45 (2): 369-389.

Dilek, Y. and S. Newcomb, 2003. Ophiolite concept and the evolution of geological thought. Geol. Soc. America, Special Paper 373.

Evans, B.W., 1977. Metamorphism of Alpine peridotite and serpentinite. Ann. Rev. Earth Planet. Sci., 5 (5): 397-447.

Faryad, S.W., F. Melcher, G. Hoinkes, J. Puhl, T. Meisel and W. Frank, 2002. Relics of eclogite-facies metamorphism in the Austroalpine basement, Hochgrössen (Speik Complex), Austria. Mineral Petrol., 74(1): 49-73.

Faryad, S.W. and G. Hoinkes, 2003. P-T gradient of Eo-Alpine metamorphism within the Austroalpine basement units east of the Tauern Window (Austria). Mineral Petrol., 77 (1-2): 129-159.

Hatzipanagiotou, K., B. Tsikouras, G. Migiros, E. Gartzos and K. Serelis, 2003. Origin of rodingites in Ultramafic rocks from Lesvos Island (NE Aegean, Greece). Ofioliti, 28 (1): 13-23.

Hoinkes, G., F. Koller, G. Rantitsch, E. Dachs, U. Klötzli and M. Thöni, 1999. Alpine metamorphism of the Eastern Alps. Schweiz. Mineral Petrog., 79 (1): 155-181.

Hong, Zh., Wei-Guang Zhu, Zhu-Yin Chu, De-Feng He and Xie-Yan Song, 2007. Shrimp U-Pb zircon geochronology, geochemistry and Nd-Sr isotopic study of contrasting granites in the Emeishan large igneous province, SW China. Chem. Geol., 236 (1-2): 112-133.

Konishi, H., I., Dódony and P.R., Buseck, 2002. Protoanthophyllite from three metamorphosed serpentinites. Am. Mineral, 87 (8-9): 1096-1103.

Melcher, F. and T. Meisel, 2004. A metamorphosed early cambrian crust-mantle transition in the Eastern Alps. Aust. J. Petrol., 45(8): 1689-1723.

Nimis, P. and W.R. Taylor, 2000. Single clinopyroxene thermobarometry for garnet peridotites. Part I. Calibration and testing of a Cr-in-Cpx barometer and an enstiti-in-Cpx thermometer. Contrib. Mineral Petrol., 139 (5): 541-554.

Nozaka, T., 2005. Metamorphic history of serpentinite mylonites from the Happo ultramafic complex, Central Japan. J. Metamorph. Geol., 23 (8): 711-723.

Palandri, J.L. and M.H. Reed, 2004. Geochemical models of metasomatism in ultramafic systems: Serpentinization, rodingitization and sea floor carbonate chimney precipitation. Geochim. Cosmochim. Acta, 68 (5): 1115-1133.

Rahmani, F., M. Noghreyan and M. Khalili, 2007. Geochemistry of sheeted dikes in the Nain ophiolite (Central Iran). Ofioliti, 32 (2): 119-129.

Santos, J.F., U. Scharer, J.I. Gil Ibarguchi and J. Girardeau, 2002. Genesis of pyroxenite-rich peridotite at cabo ortegal (NW Spain): Geochemical and Pb-Sr-Nd isotope data. J. Petrol., 43 (1): 17-43.

Torabi, G.H., 2003. Petrology of Anarak area ophiolites (Central Iran, NE of Isfahan Province). Ph.D Thesis, in Petrology (Unpublished), Tarbiat Modarres University, Iran.