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RODINGITES FROM THE SOUTHEASTERN PARTS OF THE NEYRIZ OPHIOLITE COMPLEX IN THE ZAGROS RANGE, IRAN

BY

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ABSTRACT

Mineral paragenesis of the Neyriz rodingites comprises garnets ("paragarnet", grossular, andradite and hydrogrossular) and diopsidic clinopyroxene, wollastonite, prehnite, calcite, pectolite, chlorite, clinozoisite, epidote and vuagnatite. The rodingites formed close to the ancient accretion margin from primary gabbros under PT conditions of greenschist facies. During the final stages of emplacement of serpentinized peridotites, the rodingites underwent cataclastic deformation and retrograde chlorite, tremolite, epidote and vuagnatite were formed.

INTRODUCTION

Rodingites are very common rocks within serpentinites of the ophiolite belts throughout the world (Coleman, 1977). In Iran they have been found and studied in only two localities. Davoudzadeh (1972) described the rodingites from the Nain area in Central Iran whereas Alberti *et al.*, (1976) studied the rodingites within the Turbat-i Haidari "Coloured Melange" situated close to Mashad in the northeastern parts of the country. Gansser (1972), in his paper of large-scale regional character, mentioned the occurrence of rodingites in the area of Neyriz within the Zagros Range but without any data on their mineralogy and petrology.

During 1976 and 1977 the authors mapped the southeastest parts of the Neyriz ophiolite complex and studied rodingites from many localities. The aim of the paper is to present rodingites from the Neyriz area and in this way to give the first description of these rocks from one ophiolitic complex of the Zagros Range.

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GEOLOGIC SETTING

The Neyriz ophiolite complex is a part of an intermitent belt of ophiolitic rocks which can be traced for about 1,000 km within the Imbricated zone of the Zagros Range situated between the Sanandaj-Sirjan zone and the Zagros Folded belt (Fig. 1). The ophiolitic belt extends to the northwest in southern Turkey and to the southeast to Oman. The ophiolite complex of the Zagros Range is thought to be the remnant of the Tethyan ocean floor consumed by the subduction either along the present Main Zagros Thrust (Haynes and McQuillan, 1974 and others) or along the

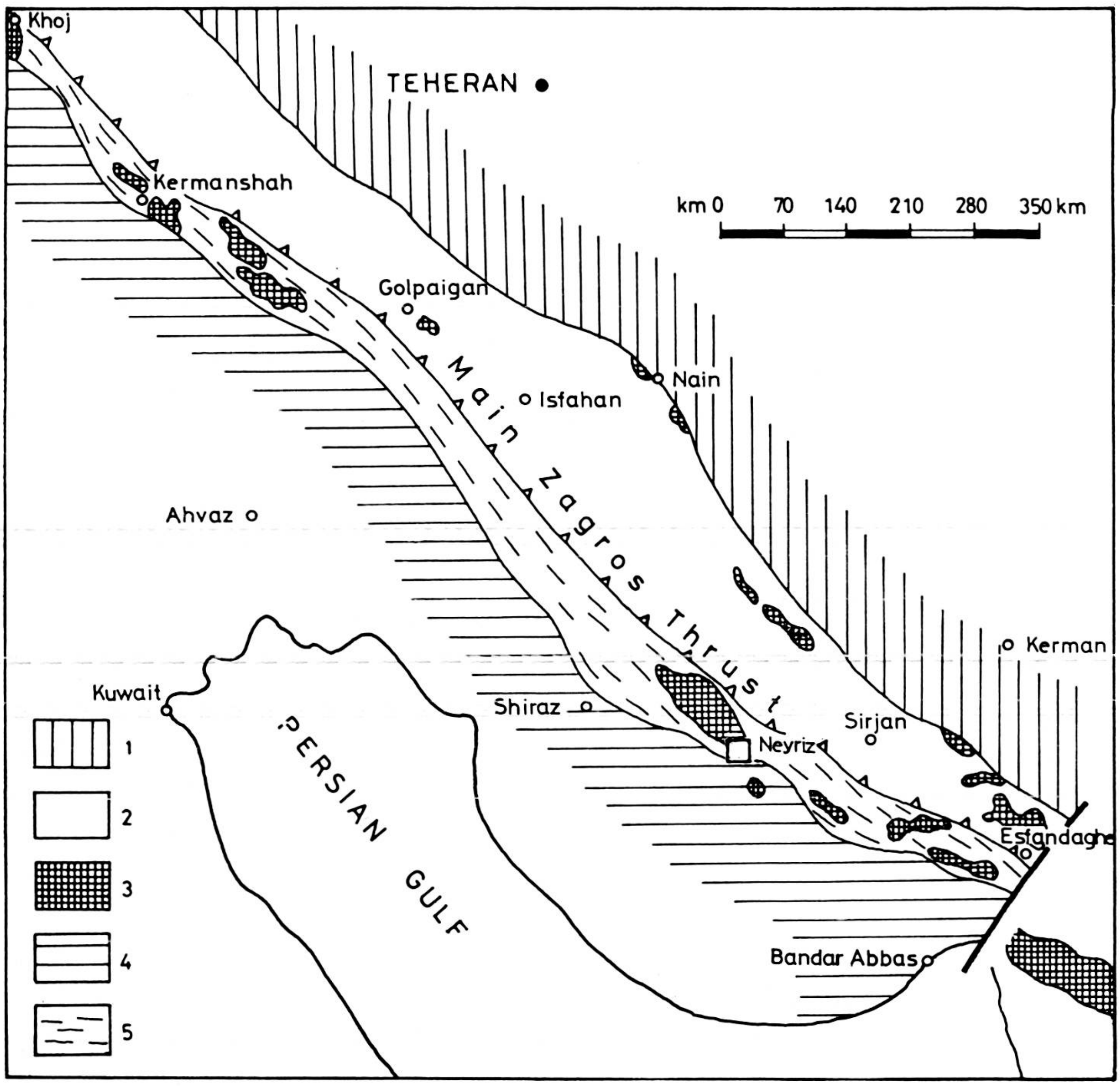

FIG. 1. — Map showing the position of ophiolites within the Zagros Range.
1. Volcanic belt; 2. Sanandaj-Sirjan zone; 3. Ophiolite occurrences; 4. Zagros Folded belt; 5. Imbricated zone.

southeastern margin of the Volcanic belt, i.e. ancient magmatic arc (Pamić *et al.*, 1979), as a result of northward drift of the Afro-Arabian continent (Dewey and Bird, 1971; Takin, 1972).

The Neyriz ophiolitic complex was described by Ricou (1971 and 1976), Houshmand-zadeh (1977) and Adib and Pamić (1979). Ricou separated several geological units, and one of them is the ophiolite nappe subdivided into two parts. He found skarns which were formed, according to his opinion, by a contact metamorphism along the contact between peridotites and Tang-e Hana marble nappes. We sampled these rocks occurring along the eastern contact between peridotite and marbles, which have been determined by Ricou (1971) as skarns. We have found that these "skarns" represent in fact rodingites and our field and laboratory data will be presented elsewhere. Adib and Pamić (1979) have presented in detail mineralogy and petrology of the Tang-e Hana ultramafic and mafic cumulate complex.

The ophiolitic rocks of the area under investigation occur in a flat area of the large Neyriz valley eastern of the Lake Bakhtegan (Fig. 2). Radiolarites with pelagic limestones and shales, in a few places interlayered with spilite-diabase, occur in central parts of the investigated area. Basic volcanics with radiolarites and limestones, in many places strongly tectonized, occur in the eastern parts close to the Main Zagros Thrust. A peridotite body stretches between the tectonized volcanics with radiolarites and limestones, and Lake Bakhtegan. It consists mostly of harzburgite tectonites with subordinate dunite, lherzolite and pyroxenite. The peridotite body is invaded by smaller gabbro masses, and swarms of unparallel gabbro dikes can be frequently found in the host peridotite. Smaller exposures of "melange" occur south of the peridotite body. The "melange" is a chaotic mixture of different rocks: harzburgite, serpentinite, chert, limestone, amphibolite, micaschist and some other rocks without any matrix.

Rodingites occur in the peridotite commonly not far from the gabbro masses, but also without any relation to the gabbro. They occur as single veins about 30-40 cm thick which can be traced along the strike commonly for about 5-10 m, in some places for more than 20-30 m. The latter can be folded with fold amplitudes of several meters. The rodingites occur also as a system of veins consisting of 5 to 10 single veins each 10-30 cm thick and commonly intersecting each other. The rodingites of both occurrences are commonly strongly boudinaged and dismembered within the peridotite and form a kind of "melange".

PETROGRAPHY

Rodingites are genetically related to gabbro, and nearly all transitional stages from comparatively fresh gabbro to milky white or pale gray rodingite can be observed. Some of the rodingite veins contain coarse sphene and/or ilmenite grains.

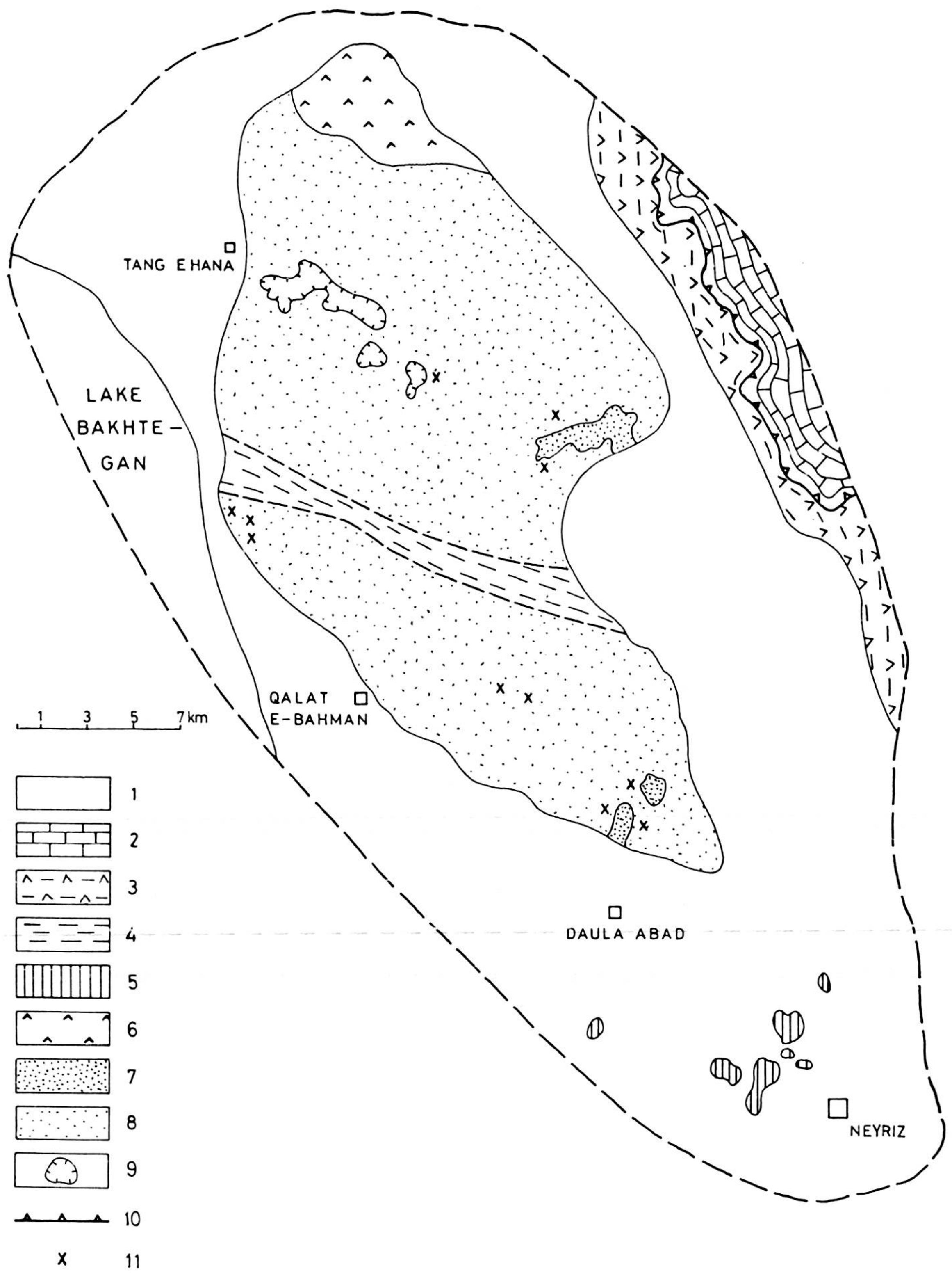

FIG. 2. — Geologic sketch map of the southeastest parts of the Neyriz ophiolitic complex. 1. Quaternary; 2. Cretaceous-Tertiary limestones; 3. Volcanic rocks with chert, limestone and shale; 4. Chert and limestone; 5. "Melange"; 6. Diabase; 7. Gabbro; 8. Harzburgite; 9. Marble nappes; 10. Main Zagros thrust; 11. Frequent rodingite occurrences.

A systematic sampling across the rodingite veins was carried out in all localities marked in the map (Fig. 2). Thin sections of rodingites and gabbros were at first studied with petrographic microscope. The bulk chemistry was determined by XRF, emission spectrochemical and classical chemical analyses (Table 2).

Chemical composition of minerals were analyzed with ARL-EMX-SM electron microprobe at the Stanford University. Both samples and mineral standards were carbon-coated simultaneously to a uniform thickness. In some cases a semiquantitative spectral scan was done to determine the elements involved.

Gabbro

Larger masses of gabbro emplaced into peridotites consist for the most part of olivine gabbro with subordinate troctolite and clinopyroxene gabbro, and ultramafic cumulates as exemplified by the largest Tang-e Hana gabbro body (Adib and Pamić, 1979). Gabbro veins occurring in the neighbourhood of the larger gabbro masses are made up mainly of clinopyroxene gabbro in which olivine and orthopyroxene are scarce.

Plagioclase of the vein gabbro has fairly uniform chemical composition shown by An_{86-90} which is nearly the same as the plagioclase from the larger gabbro masses. In partly rodingitized gabbro the An-content of plagioclase decreases to as low as An_{44-52}, and it becomes partly replaced by garnet and clinozoisite.

Clinopyroxene shows changes in composition $En_{42}Fs_{8-9}Wo_{43-48}$ (Table 1). The clinopyroxene is commonly quite fresh or slightly transformed into chlorite irrespective of the degree of rodingitization of the gabbro.

The accessory olivine is of fairly uniform chemical composition Fo_{78-80} whereas the average chemical composition of the accessory orthopyroxene is $En_{80}Fs_{20}$

Rodingites

The great variation both in texture and mineral composition in the rodingites is due to the different degrees of metasomatic transformation of the primary gabbro, its primary modal composition, grain size and subsequent deformation. As the degree of metasomatic transformation increases the rock becomes finer-grained and dense followed by strong tectonization and brecciation. Therefore some Neyriz rodingites can be classified as cataclastic rodingites (Capedri *et al.*, 1977) consisting of rodingite fragments cemented by late calc-silicates and carbonates.

Garnet and clinopyroxene are the essential minerals of the rodingites. Garnet is the most characteristic mineral of the rodingites. Its quantity varies from 5 percent in slightly rodingitized melanocratic and mesocratic gabbro up to 90 percent in fine-grained and dense rodingites. Several garnet varieties can be distinguished. The plagioclase grains are replaced in the slightly rodingitized gabbro by a dirty

TABLE 1. — *Microprobe analyses of minerals from rodingites and gabbros.*

GABBRO RODINGITE								
	Ol	Cpx	Pl	Cpx	And	Gr	HGr	PGr
SiO_2	40,0- 41,0	50,6-53,1	45,7-46,0	50,5-52,9	35,6- 36,1	39,1- 39,3	27,3-33,1	38,2
TiO_2	— —	0,2- 0,3	— —	0,1- 0,1	2,6- 1,7	0,9- 0,1	n.d.-n.d.	0,9
Al_2O_3	— —	2,8- 2,7	34,6-34,0	4,4- 1,8	6,3- 6,3	17,7- 19,7	24,1-26,0	11,0
FeO	16,7- 13,9	5,1- 4,6	— —	4,5- 5,2	24,4- 24,6	6,3- 5,9	0,2- 0,3	17,6
MgO	42,5- 45,5	18,3-16,4	— —	14,3-14,7	0,1- 0,1	0,1- 0,2	0,3- 0,3	n.d.
CaO	— —	19,9-22,1	17,9-18,1	25,4-24,6	31,8- 31,8	35,8- 35,4	40,2-32,6	32,4
Na_2O	— —	0,3- 0,2	1,7- 1,1	0,1- 0,1	n.d.-n.d.	n.d.-n.d.	n.d.-n.d.	n.d.
K_2O	— —	0,0- 0,1	— —	0,1- 0,0	0,1- 0,1	0,1- 0,1	0,1- 0,1	0,1
Anhydrous Total	99,2-100,4	97,2-99,5	99,9-99,2	99,4-99,4	100,4-100,7	100,0-100,7	92,2-92,4	100,2

RODINGITE									
	Ch	Ch	Pr	Wo	Cz	Ep	S	V	X
SiO_2	24,8-25,8	23,6-24,3	42,9	51,7-51,4	38,8	38,5-39,3	30,5	35,2	41,4
TiO_2	n.d.-n.d.	0,1- 0,1	n.d.	n.d.-n.d.	n.d.	0,1- 0,1	37,1	n.d.	n.d.
Al_2O_3	25,2-23,5	26,2-24,4	24,8	n.d.-n.d.	32,3	24,4-24,6	2,6	26,3	29,5
Fe_2O_3	21,0-23,4	28,2-32,2	0,9	0,7- 0,4	2,7	11,7-11,2	0,1	0,1	n.d.
MgO	17,3-16,5	13,6-12,7	0,1	0,1- 0,1	n.d.	n.d.-n.d.	n.d.	n.d.	0,3
CaO	0,2- 0,2	0,8- 1,0	27,1	46,9-47,7	23,3	22,5-24,1	29,1	31,3	25,1
Na_2O	n.d.-n.d.	n.d.-n.d.	0,2	n.d.-n.d.	n.d.	n.d.- 0,1	n.d.	n.d.	n.d.
K_2O	n.d.-n.d.	0,1- 0,1	n.d.	0,1- 0,1	n.d.	n.d.-n.d.	0,1	n.d.	n.d.
Anhydrous Total	88,5-89,4	92,6-94,8	96,0	99,5-99,8	97,1	97,2-99,4	99,5	92,9	96,3

Ol: olivine; Cpx: clinopyroxene; Pl: plagioclase; And: andraditic garnet; Grs: grossular garnet; HGr: hydrogarnet; PGr: paragarnet; Ch: chlorite; Pr: prehnite; Wo: wollastonite;

brownish aggregate of "paragarnet" (Honnorez and Kirst, 1975) with strongly varying chemical composition. It shows no distinct grain boundaries, and the isotropism is modified by milky to milky-white-brownish internal reflections to abundant quantity of opaque impurities (Table 1).

Anhedral garnets predominate, and have variable compositions ranging from andradite to grossular (Table 1). Andradite was found only in the rodingitized gabbro together with "paragarnet", and disappears completely with increased degree of the metasomatic transformation. Grossular and hydrogrossular are present in the proper rodingites, and they show comparatively small variation in chemical composition. The habit of grossular differs from massive microcrystalline to isometric crystals of 0.1 to 0.3 mm in diameter.

Clinopyroxene shows only slight difference in chemical composition when compared to those from the primary gabbro. This is shown by a slight increase in Fs and Wo molecules. The clinopyroxene can be altered to the same extent and replaced mainly by chlorite with some clinozoisite and/or epidote, and rarely by tremolite-actinolite.

A "secondary" more diopsidic pyroxene is found in some rodingitized gabbros and it is associated with "paragarnet", some grossular and relics of calcic plagioclase. The diopsidic pyroxene shows slight changes in chemical composition: $En_{32-33}Fs_{10-11}Wo_{58-56}$.

Minor constituents commonly make up the cement between the rodingite fragments and/or fill the veinlets cutting the cemented rock itself.

Prehnite seems to be the most frequent minor constituent; it is common in veinlets together with calcite. Prehnite is also present in the matrix either intimately intergrown with pectolite or in form of patches replacing clinozoisite.

Wollastonite was not found in the rodingites from all localities. It occurs in form of radiating laths and polygonal mosaic together with grossular, diopsidic clinopyroxene and epidote.

Vuagnatite, a rare hydrous Ca-Al silicate described most recently by Sarp *et al.*, (1976), is found in numerous veinlets. Under the microscope it is euhedral, usually less than 0.3 mm, rectangular or rhomb-shaped with yellowish to orange interference colours. With an optical axial angle of about 50° and very strong dispersion $r > v$, negative sign of elongation and no cleavage it can be really easily distinguished from other rock-forming minerals of the rodingite. The definite identification of this mineral was possible after obtaining the X-ray powder pattern and actual chemical composition (Table 1).

Chemical analyses obtained by microprobe on 4 thin sections from various localities show that the vuagnatite has a fairly uniform chemical composition. Its chemical composition, when compared with the published data (Sarp *et al.*, 1976; Matsubara *et al.*, 1977) shows that it is more siliceous and aluminous than previously studied samples.

TABLE 2. — *Chemical analyses of the Neyriz rodingites.*

	1	2	3	4
SiO_2	43,2	37,3	34,0	33,9
TiO_2	0,4	2,4	0,7	0,1
Al_2O_3	12,2	20,7	28,6	30,1
Fe_2O_3	8,3	5,6	2,6	0,6
MnO	0,4	0,2	0,2	0,1
MgO	21,6	4,2	4,4	1,5
CaO	10,3	23,4	23,2	29,7
Na_2O	0,5	1,0	1,2	0,1
K_2O	0,1	0,5	0,2	0,1
Anhydrous Total	97,0	95,3	95,1	96,2

1: Slightly garnitized gabbro; 2: Titaniferous andradite-grossular rodingite; 3: Grossular-hydrogrossular rodingite; 4: Hydrogrossular rodingite.

Accessory minerals of rodingites are apatite, magnetite, ilmenite and sphene. The increased content of TiO_2 in some rodingites (Table 2) is caused by the increased quantity of ilmenite and/or sphene.

Bulk chemistry of rodingites is represented by 4 chemical analyses given in Table 2.

DISCUSSION

The Neyriz rodingites can be quite well correlated with the rodingites from other ophiolitic terrains within the Alpine-Himalaya belt, as for example from the eastern Alps (Dal Piaz, 1969), Dinarides (Grčev *et al.*, 1962), Hellenides (Caperdi *et al.*, 1977) as well as with the rodingites dredged from the Mid-Atlantic ridge (Aumento and Loubat, 1971; Honnorez and Kirst, 1975).

The mineral composition of the Neyriz rodingites shows a great variation that fits quite well with general characteristics of rodingites (Vuagnat, 1967; Coleman, 1977). They must have originated from the primary gabbro veins through complex metasomatic processes comprising the depletion of SiO_2, MgO and total iron, and the introduction of larger amounts of CaO and Al_2O_3. The metasomatic processes gave rise to the origin of new major minerals – garnet, and diospidic clinopyroxene accompanied by wollastonite and abundant prehnite. Because the rodingites occur within the serpentinized ultramafics it is very probable that both serpentinization and rodingitization operated simultaneously (Coleman, 1977).

The PT conditions of metasomatic formation of the rodingites can be estimated on the basis of data of experimental petrology. Buchner *et al.*, (1960) showed that wollastonite will form under hydrothermal conditions by dehydration of xonotlite or from a gel of appropriate composition at 400° C and atmospheric pressure, and at 430° C under increased pressure, respectively. This can be quite well correlated with the stability of serpentine minerals of the host serpentinite (Kitahara and Kennedy, 1967). Consequently, the metasomatic processes occurred under PT conditions of greenschist facies (Coleman, 1977).

The present geotectonic setting of the Neyriz ultrafamics invaded by gabbros and veined by rodingites favours the idea that they represent tectonic slabs of the Mesozoic upper mantle and oceanic crust. The rodingite veins are included within the ophiolitic rocks which are found along the Main Zagros Thrust which might have represented either an ancient trench zone, i.e. subduction zone (Haynes and McQuillan, 1974) or frontal parts of the large thrusts in which dismembered slices of the ophiolitic rocks, primarily emplaced along the margin of the Iranian microplate (Pamić *et al.*, 1979), are included. The processes of serpentinization and rodingitization predate the diapric intrusion of the cold ultramafic body. They must have occurred close to the Mesozoic accretion plate margin when the ultramafic diapir moving upwards reached at higher levels the PT conditions of greenschist facies.

The final stages of the emplacement of the ultramafic diapir were characterized by strong tectonization and rodingites underwent to cataclastic deformation. This was accompanied by the formation of large quantity of prehnite associated with pectolite, calcite and vuagnatite as a result of a partial retrogradation.

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