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Discovery and geological implication of rodingites derived from eclogites of ophiolites at Changawuzi, western Tianshan, China*

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Abstract We here report the first case of rodingites that were formed at the expense of eclogite enclosed in the ultramafic rocks of Changawuzi ophiolites. The rodingites contain a mineral assemblage of grossular, diopside, prehnite, chlorite, and relict omphacite and Fe-Mg-Al garnets. The presented data indicate that the formation of the rodingites resulted from a phase of secondary serpentinization during exhumation of the subducted oceanic plate. The rodingitization started at 370~410 ℃/6.5~8.5kbar, while pervasive rodingitization took place under the condition of 200~350 ℃/4~6kbar. The established PT path shows a retrograde track from eclogites to rodingites. We conclude that the process of rodingitization could also take place under subduction conditions in addition to its more common occurrence under ocean-floor metamorphic conditions.

Keywords: rodingite, eclogite, serpentinite, subduction, western Tianshan.

Rodingites are calcium-rich, silica-undersaturated lithologies, which are formed by metasomatism from mostly basaltic precursors during serpentinization. Rodingites are therefore genetically related to serpentinites, and occur as a by-product of serpentinization. The breakdown of clinopyroxene in a peridotite liberates Ca, which cannot be accommodated in the serpentine crystal structure. Thus, Ca is accumulated in the fluid associated with the process of serpentinization until supersaturation results in the reaction with less mafic rocks. Most documented rodingites in the world were formed during ocean floor metamorphism, and are principally composed of Ca- and mostly water-bearing silicates such as hydrogrossular, diopside, clinozoisite, epidote, vesuvianite, and, less commonly, phlogopite, prehnite and pumpellyite. When these metasomatized rocks experience high pressure and high temperature metamorphism, they evolve into metarodingites. Lawsonite pseudomorphs from rodingites in Southern Urals indicated that the rodingite of Maksyutovo Complex experienced PT conditions of 520~540 ℃/18~21 kbar[1].

In this paper we report for the first time the occurrence of rodingites formed at the expense of eclogites from the Changawuzi ophiolites in Xinjiang. Detailed studies on the petrological and mineralogical transformation from eclogite facies rocks to rodingites are presented. PT conditions based on the recognized mineral assemblages, measured chemical characteristics and observed microtextures are used in this paper to determine PT conditions for the process of rodingitization.

1 Geological setting

The Southwestern Tianshan ophiolitic mélange extends along the NE-SW axis of the tectonic ridges and faults of the Tianshan Mountain Range. It starts at Changawuzi town on the north side of Harkeshan, extends via Gutuoguo, Wuwamen to Kumishen's Liuhuangshan, Tonghuashan and Yushugou. Together with blueschists, the ophiolitic mélange constitutes an accretionary complex on the south margin of the Yili-Central Tianshan plate[2]. The Changawuzi ophiolitic mélange is located in the south of the Changawuzi fault near North-Muzaerte River (Fig. 1). The ophiolitic rocks and sequence is poorly preserved. Serpentinized ultramafic rocks occur together with interlayered south-dipping blueschists or greenschists. The entire sequence of ultramafic, mafic rocks and accompanied schists has experienced greenschist and blueschist facies metamorphism.

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It has been suggested that the Changawuzi ophiolitic sequence represents relics of a Silurian oceanic crust from a back-arc basin in the southern margin of the Yili Central plate[3~5]. However, the true nature of the ocean basin is under dispute. Li[6] considered it to be an open oceanic environment, while Tang[5] believed that the subduction produced mélange consisted of Early Paleozoic ophiolites, continental marginal sediments and subducted continental basement units. The mélange experienced blueschist and greenschist facies metamorphism during late Devonian to late Carboniferous time[5]. Subsequent collision and thrust resulted in rapid exhumation of the mélange and expose it to the surface[6].

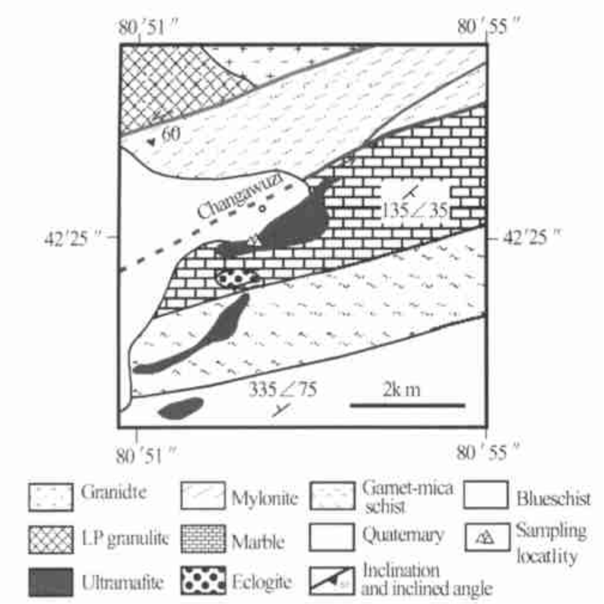

Fig. 1. Geological sketch map of Changawuzi ophiolite mélange in western Tianshan.

2 Field occurrence and petrological characters

2.1 Eclogites

Field observations reveal that eclogites are enclosed in the serpentinite bodies in the form of lenses or tectonic inclusions. Serpentinized peridotites are located in the southern margin of Changawuzi fault (Fig. 1). The mineral assemblage of the eclogites is: garnet (5% ~ 15%), omphacite (10% ~ 20%), albite (5% ~ 10%), clinozoisite (10% ~ 30%), sodic amphibole (5% ~ 10%), mica (5% ~ 10%) with minor titanite and rutile (Fig. 2(a)). Garnet phenocrysts are associated with omphacite, albite, chlorite and biotite respectively (Fig. 2). The grains of these minerals are commonly smaller than 0.2 to 2.0 mm. No symplectitic textures were observed in the eclogites, which commonly form during retrograde metamorphism. The garnets show no zonation and corona textures.

2.2 Rodingites

Rodingites were enclosed in the ultramafic rocks as lenses. Partial metasomatism leads to incomplete rodingitization, as is obvious from the common preservation of relict eclogitic minerals. Rodingitic rocks with complete rodingitization, usually with fine crystal grains of 0.2 ~ 1.0 mm in diameter, show the following mineral contents: garnet (5% ~ 10%), clinopyroxene (10% ~ 25%), prehnite (15% ~ 35%), chlorite (20% ~ 40%) and minor clinozoisite, titanite and carbonates. These rodingites have a porphyroblastic texture: garnets are mainly found in a matrix of chlorite, or as relics within pseudomorphic (true? This is assumed from Fig. 2 (d)) prehnites. Clinopyroxenes are mostly diopsides except for a few omphacite relics. Apart from pseudomorphic prehnite after garnet, this phase also occurs as fine grains within veins.

2.3 Serpentinites

Serpentinites of the working area have experienced complete serpentinization. No ultramafic minerals such as olivine and pyroxene were observed under both a microscope and SEM. According to texture observations, the ultramafic rocks have undergone at least two phases of serpentinization, and, accordingly, have gone through at least three metamorphic events, i.e. ocean-floor metamorphism, high-pressure metamorphism and late rodingitic metasomatism. The late elongated serpentines and relict early mylonitic serpentines can clearly be recognized and distinguished (Fig. 2(e)). The mylonitic texture of the serpentinite is considered to originate from early, i.e. ocean-floor serpentinization and later subduction-related high-pressure metamorphism. The late serpentinization occurred during the process of exhumation to the surface after subduction. Because the late serpentines are associated with brucites (Fig. 2(f)), their serpentine minerals should be mainly antigorites.

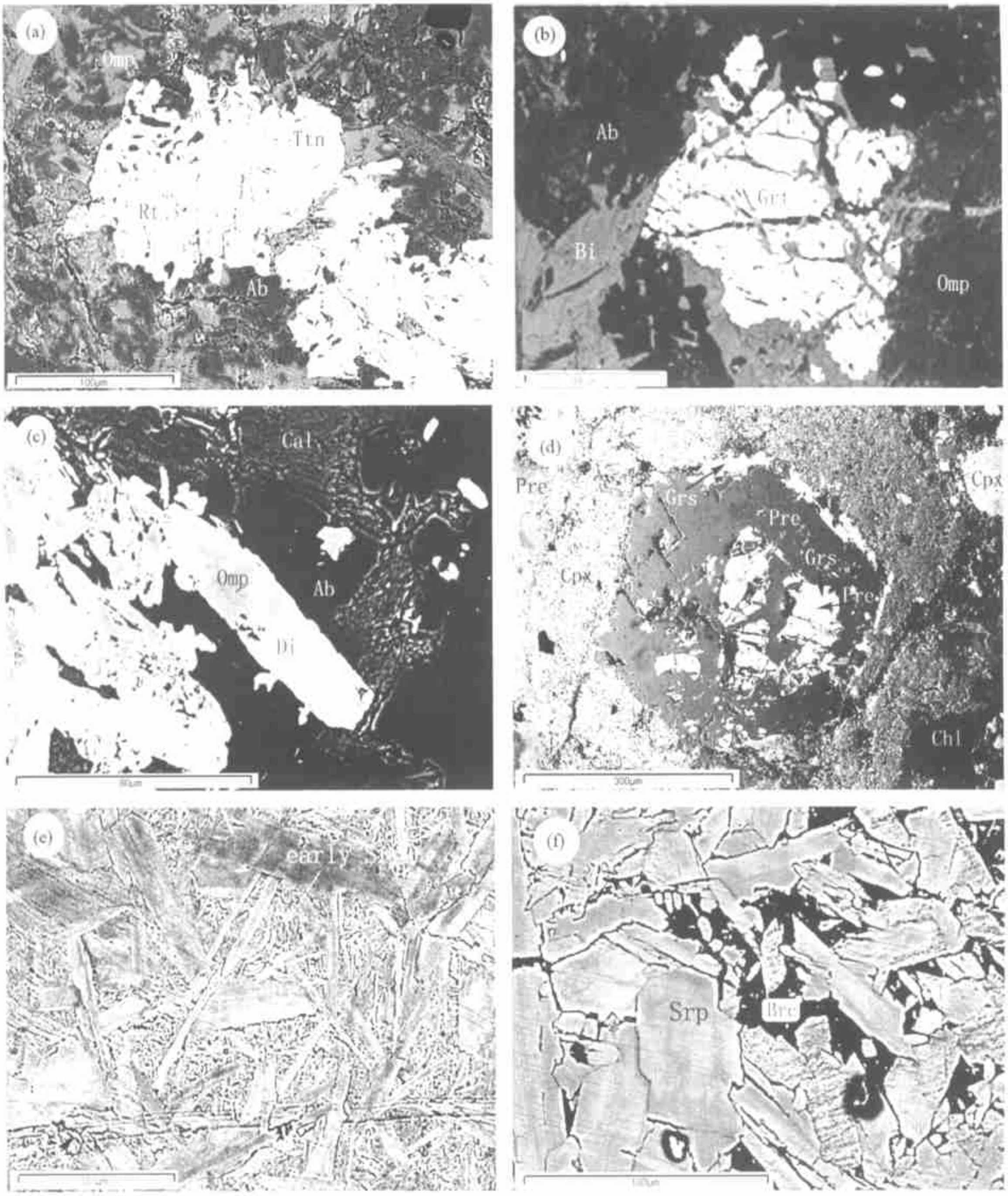

Fig. 2. Microtextural relationship between rodingite and eclogite at Changawuzi, Western Tianshan. (a) Rutile (Rt) relics in titanite (Ttn) within former eclogite; (b) relict garnet (Grt) in former eclogite; (c) diopside (Di) overgrowth on omphacite (Omp) in a rodingite; (d) pseudomorphic prehnite after garnet in a rodingitized eclogite; (e) late elongated serpentine (Srp) crystals and relict early serpentine with a mylonitic texture in serpentinite; (f) late serpentine and brucite (Bru) in serpentinite.

3 Mineralogy

Major minerals in the eclogites and rodingites are garnet, clinopyroxene, albite, K-feldspar, prehnite, clinozoisite, chlorite, amphibole and biotite. Microprobe analyses were carried out systematically on all the minerals presented in investigated samples, and were performed on a microprobe instrument JXA-8800R at Peking University, operated at an acceleration voltage of 15 kV and a beam current of 20 nA.

3.1 Clinopyroxenes

Two types of clinopyroxenes can be distinguished: omphacite and diopside. The chemical variation of clinopyroxenes from eclogite to rodingite is displayed in Fig. 3 (a). The jadeite contents in clinopyroxene vary from 53% to almost zero (Table 1). The composition of the omphacites in the eclogite of Changawuzi is comparable to those found in other HP and UHP eclogites of the western Tianshan[7~9]. Diopsides grew at the expense of omphacites during rodingitization (Fig. 2(c)), and the diopsides have taken up some Na_2O. The variation in composition, however, is rather abrupt than a smooth gradation by transformation from omphacite to diopside. Nowhere pure endmember diopside could be found in these samples in contrast to those typically found in rodingites1). Diopsides from the Changawuzi rodingites show Na_2O contents of from 0.2% to 2.4% (Table 1).

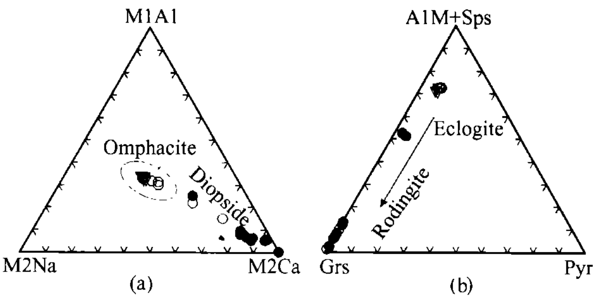

Fig. 3. Chemical variation of clinopyroxenes (a) and garnets (b). Triangles represent pyroxenes and garnets from the eclogite facies paragenesis; solid circles show pyroxenes and garnets from the rodingites; open circles mark transitional mineral compositions between typical eclogite and rodingite assemblages.

Table 1. Chemical composition of representative garnets and clinopyroxenes from rodingites and eclogites at Changawuzi, western Tianshan

Sample	12971	12972	129821	129822	129932	129911	129912	12991	129932	12971	12974	12982	12984	12991	12992	12993	12997
	Garnets in eclogite				Garnets in rodingite					Clinopyroxenes in eclogite				Clinopyroxenes in rodingite			
SiO_2	37.13	37.65	37.78	37.63	38.50	38.35	39.27	39.16	39.21	56.52	56.76	56.29	56.97	54.23	54.60	51.64	51.90
TiO_2	0.00	0.06	0.16	0.16	0.25	0.39	1.01	0.65	1.31	0.32	0.05	0.11	0.05	0.33	0.07	0.62	0.63
Al_2O_3	21.67	21.17	21.15	21.23	21.10	21.45	20.01	20.70	19.09	12.00	12.14	11.51	11.95	4.73	2.43	3.65	3.02
Cr_2O_3	0.00	0.02	0.21	0.44	0.13	0.05	0.32	0.31	0.01	0.04	0.07	0.56	0.34	0.00	0.15	0.71	0.34
FeO^*	28.31	28.22	25.58	25.70	20.94	21.03	3.77	5.17	4.15	4.25	4.08	4.62	4.22	6.64	6.03	6.69	8.04
MnO	3.89	3.92	6.66	6.96	2.75	3.01	0.91	2.09	0.28	0.02	0.11	0.34	0.00	0.29	0.13	0.17	0.25
MgO	2.05	1.83	1.68	1.61	0.59	0.82	0.04	0.08	0.04	7.57	7.09	7.29	7.12	11.00	12.90	16.36	16.44
CaO	6.59	7.00	7.51	7.30	16.43	15.78	35.25	32.59	36.65	12.02	12.01	12.01	11.65	21.36	22.40	20.06	19.01
Na_2O	0.00	0.03	0.02	0.04	0.07	0.01	0.02	0.04	0.00	7.77	7.86	7.69	7.96	2.41	1.60	0.35	0.22
K_2O										0.00	0.00	0.02	0.01	0.00	0.00	0.02	0.02
Total	99.64	99.93	100.75	101.07	100.76	100.89	100.61	100.78	100.73	100.54	100.18	100.44	100.32	100.00	100.38	100.29	99.87
Si	2.98	3.02	3.00	2.99	3.01	3.00	2.97	2.97	2.97	1.99	2.00	1.99	2.01	1.98	2.00	1.89	1.91
AlVI	2.03	2.00	1.98	1.97	1.95	1.98	1.76	1.82	1.67	0.48	0.50	0.47	0.50	0.18	0.11	0.05	0.05
Ti	0.00	0.00	0.01	0.01	0.02	0.02	0.06	0.04	0.08	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.02
Cr	0.00	0.00	0.01	0.03	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.02	0.01
Fe^{3+}	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.12	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	1.90	1.89	1.70	1.71	1.37	1.38	0.11	0.21	0.05	0.13	0.12	0.14	0.12	0.20	0.19	0.20	0.25
Mn	0.26	0.28	0.45	0.47	0.18	0.20	0.06	0.13	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01
Ca	0.57	0.60	0.64	0.62	1.38	1.32	2.86	2.65	2.97	0.45	0.45	0.46	0.44	0.83	0.88	0.79	0.75
Na	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.53	0.54	0.53	0.54	0.17	0.11	0.03	0.02
K										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alm	63.84	63.43	56.83	57.15	45.69	45.93	3.56	6.98	1.72								
Adr	0.00	0.00	0.00	0.00	0.00	0.00	6.65	5.93	10.77								
Grs	19.04	20.09	20.74	19.41	45.51	43.99	86.63	81.21	86.73								
Pyr	8.24	7.33	6.67	6.38	2.30	3.21	0.15	0.31	0.15								
Sps	8.88	8.92	15.00	15.68	6.09	6.67	1.93	4.46	0.60								
Uvr	0.00	0.06	0.66	1.39	0.40	0.16	0.99	0.92	0.03								
WEF										47.93	46.92	48.31	46.31	82.83	88.63	97.44	98.38
JD										52.08	53.08	51.69	53.69	17.17	11.37	2.56	1.62
AE										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* Total iron, NiO< 0.05, calculation on the basis of Grt = 12 and Cpx = 6 oxygen.

Table 2. Chemical composition of representative other minerals from the rodingites and eclogites at Changawuzi, western Tianshan

Samples	129741	12983	12973	12974	12981	12971	129821	12982	12987	129872	129911	129921	129931	129743	12983	12991
	Retrogressive minerals in eclogite										Rodingite					
	Feldspar		Edenites and Pargasites			Mica		Clinozoisite			Prehnite			Chlorite		
SiO_2	68.38	68.85	48.31	47.2	42.3	38.76	37.21	39.26	39.29	31.14	44.03	44.09	43.85	28.27	28.56	28.75
TiO_2	0.01	0.01	0.079	0.086	0.251	0.45	0.11	0.09	0.06	0.04	0.09	0.04	0.13	0.02	0.45	0.03
Al_2O_3	19.57	19.66	9.9	10.82	18.01	15.81	18.40	28.56	28.88	28.82	25.04	24.90	24.63	20.74	19.28	20.13

To be continued

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1) Li, X. P. et al. The texture and poly-metamorphic evolution of the Zermatt-Saas serpentinites. Journal of Metamorphic Geology (accepted).

Continued

Samples	129741	12983	12973	12974	12981	12971	129821	12982	12987	129872	129911	129921	129931	129743	12983	12991
	Retrogressive minerals in eclogite										Rodingite					
	Feldspar		Edenites and Pargasites			Mica		Clinozoisite			Prehnite			Chlorite		
Cr_2O_3	0.00	0.01	0.028	0.055	0.24	0.11	0.16	0.24	0.10	0.08	0.00	0.14	0.00	0.21	0.40	0.11
FeO	0.23	0.07	12.50	12.93	14.22	14.50	14.46	6.21	5.26	5.79	0.28	0.16	0.18	18.55	17.58	18.29
MnO	0.05	0.02	0.26	0.31	0.19	0.17	0.30	0.05	0.02	0.06	0.00	0.04	0.03	0.33	0.29	0.28
MgO	0.03	0.08	12.89	12.61	8.72	15.56	14.25	0.01	0.01	0.00	0.02	0.00	0.00	20.30	19.50	18.92
CaO	0.01	0.29	10.43	10.36	8.63	0.06	0.05	23.87	24.20	23.96	27.20	27.09	27.01	0.22	0.31	0.18
Na_2O	0.11	11.59	3.27	2.66	5.19	0.14	0.15	0.03	0.00	0.02	0.00	0.02	0.04	0.17	0.07	0.08
K_2O	11.76	0.02	0.43	0.49	0.69	9.39	9.88	0.07	0.02	0.03	0.00	0.02	0.00	0.02	0.84	0.56
NiO	0.00	0.00	0.08	0.06	0.00	0.00	0.00	0.01	0.00	0.02	0.03	0.01	0.00	0.00	0.06	0.08
ToTal	100.15	100.60	98.18	97.57	98.45	94.937	94.97	98.40	97.84	97.96	96.69	96.50	95.86	88.83	87.43	87.42
Si	12.21	11.96	7.07	6.92	6.21	5.76	5.55	3.02	3.03	3.01	5.98	6.00	6.01	5.66	5.82	5.85
Al	4.11	4.02	0.93	1.08	1.79	2.24	2.45	0.98	0.97	0.99	2.02	2.00	1.99	2.34	2.18	2.15
AlVI			0.78	0.78	1.33	0.54	0.79	1.60	1.65	1.63	1.99	2.00	1.99	2.54	2.44	2.67
Ti	0.00	0.00	0.01	0.01	0.03	0.05	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.07	0.01
Cr	0.00	0.00	0.00	0.01	0.03	0.01	0.02	0.01	0.01	0.00	0.00	0.02	0.00	0.03	0.06	0.02
Fe^{3+}			0.05	0.22	0.00	0.00	0.00	0.37	0.31	0.35	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.03	0.01	1.48	1.36	1.75	1.80	1.80	0.03	0.03	0.02	0.03	0.02	0.02	3.10	2.99	3.11
Mg	0.01	0.02	2.81	2.75	1.91	3.45	3.17	0.00	0.00	0.00	0.00	0.00	0.00	6.05	5.95	5.74
Mn	0.01	0.00	0.03	0.04	0.02	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.05
Ca	0.00	0.05	1.64	1.63	1.36	0.01	0.01	1.96	2.00	1.98	3.96	3.95	3.97	0.05	0.07	0.04
Na	0.04	3.90	0.93	0.76	1.48	0.04	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.07	0.03	0.03
K	2.68	0.00	0.08	0.09	0.13	1.78	1.88	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.22	0.15
Ni	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Ab	1.40	98.50														
An	0.10	1.40														
Or	98.50	0.10														
Ps								0.13	0.11	0.12						
Fe–FeMg														0.34	0.33	0.35
Mg–FeMg														0.66	0.67	0.65

Total iron, calculation on the basis of Fsp= 32, Amph= 23, Bio=22, Pre= 22, Czo= 12.5 and Chl= 28 oxygen.

3.2 Garnet

Garnets show a homogeneous chemical composition and grain size of 0.1 ~ 0.5 mm. In the eclogites, garnets consist of 55% almandine, 20% grossular, 15% spessartine and less than 10% pyrope (Table 1). Such compositions are similar to garnet compositions found in other HP-UHP eclogites of the western Tianshan[7~9]. The garnets show no zoning, but sometimes are surrounded by or dissected by veins of biotite (Fig. 2(b)). Occasionally, garnets exist as isolated grains in a matrix of albite.

Garnets in the rodingites contain 80% ~ 87% grossular, 1%~7% almandine, less than 5% pyrope and less than 1% spessartine. Occasionally, the garnets in the rodingites contain high amounts of Fe-Mg component, which would be characteristic for the garnets of the eclogites with more than 50% of pyralspite component. Such analyses document the transition from pyralspite-rich into ugrandite-rich compositions when rodingitic garnets replace the eclogitic garnets (Fig. 3(b)). Again, the change in composition of these two types of garnets is not continuous, but abrupt as observed for the clinopyroxenes.

3.3 Prehnite

Prehnites either occur as pseudomorphs after altered garnets (Fig. 2(d)) or form monomineralic veins of xenomorphic fine-grained aggregates. The distribution and size of prehnite veins in the rodingites looks very similar to the albite veins in the eclogites.

3.4 Other Minerals

Feldspars are albites and occasionally K-feldspars. Albites are distributed in the matrix of the rodingitized eclogites with a grain size of 0.1 ~ 1.0 mm.

Hornblendes in the eclogites are fine-grained edenites and pargasites, and they occur along with biotite and chlorite in the matrix. No hornblende has been found in the rodingites.

Biotite is found only in rocks of incomplete rodingitization. According to microscopic observations, biotite is suggested to pseudomorphically replace hornblende.

Idioblastic clinozoisites with $Ps_{11\text{-}13}$ appear to be in texture equilibrium with omphacite garnet and biotite. Fine-grained metasomatic clinozoisites show overgrowth of albites.

Chlorites show a homogeneous composition in all investigated samples. According to their composition, they are Mg-Fe chlorites.

4 Metamorphic PT conditions

A P-T path from eclogite facies to rodingitization conditions was constructed and is illustrated in Fig. 4. The P-T value at point A in Fig. 4 was calculated on the basis of the observed mineral assemblages in eclogite facies rocks by using the Holland and Powell thermodynamic database[10], and an input into the program containing the measured mineral compositions of all major phases (garnet, omphacite, albite, clinozoisite, chlorite). According to these calculations, the eclogite facies paragenesis was stable at condition of 540 ℃ and 17 kbar.

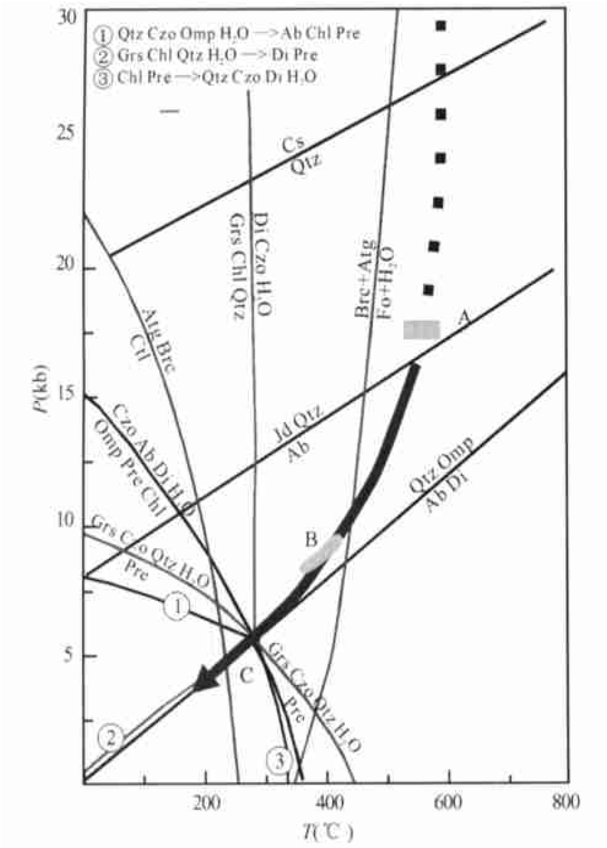

Fig. 4. The P-T path of the rodingites and their associated eclogites at Changawuzi, western Tianshan.

With regard to the relict ecolgite facies minerals, rodingitization was assumed to start at point B (Fig. 4). Temperature conditions of this stage were calculated from the Cpx-Grt[11] geothermometer of Krogh-Ravna by using the composition of relict garnet (Prp+Alm=50—56) in grossular and the composition of relict omphacite in diopside (a_{Jd}=0.17). The calculated $K_D = (X_{Fe^{2+}}/X_{Mg})^{Grt}/(X_{Fe^{2+}}/X_{Mg})^{Cpx}$ varies between 55 and 60 and intersects with the equilibrium reaction of Ab = Jd_{15-20} + Qtz[12] at P-T conditions of 370~410 ℃ and 6.5~8.5 kb.

Pervasive rodingitization occurred at stage C, which is constrained by the formation of prehnite after grossular, clinozoisite and clinopyroxene (Fig. 4). P-T conditions of stage C corresponding to the process of pervasive rodingitization were 250~300 ℃ and 5~6 kb. In detail, the P-T stable area for stage C in Fig. 4 is constrained by the reactions Grs+Czo+Qtz+H_2O→Pre, Czo+Ab+Di+H_2O→Omp+Pre+Chl and Atg+Brc→Ctl.

5 Discussion and conclusions

According to numerous previous studies rodingitization usually represents a typical product of ocean-floor metamorphism. Although further progressive metamorphisms could be superimposed on the rocks after their rodingitization (see e. g. rodingites from Alps[13,14]), there is no report on the formation of rodingite in connection with a subduction zone.

Based on our investigations, the Changawuzi rodingites of western Tianshan underwent rodingitization in the subduction zone during exhumation by alteration of the eclogitic parageneses, triggered by a process of nearby secondary serpentinization. Accordingly, a new type of origin for rodingites is proposed. Relict pyroxenes in serpentinites show at least part of Ca released from secondary serpentinization. The mineral assemblages and the inferred P-T conditions for the different stages of metamorphism and metasomatism are consistent with other P-T estimates obtained from ultrahigh-pressure eclogite facies in western Tianshan[7,8]. The mafic rocks on the subducted ocean floor are expected to transform into eclogites during HP-UHP metamorphism. During the subduction process, the protoliths of the later eclogites or the already transformed eclogites were enclosed into the serpentinized ultramafic bodies as tectonic inclusions. In the case of the rodingites found at Changawuzi the rodingitization process started at about 30 km on the way of exhumation, and ended at depths of around 15 km to the surface. The formation of the rodingites indicates that a large amount of fluid existed inside the subduction zone during exhumation, which leads to the secondary serpentinization.

During the secondary serpentinization process, the Ca released from the breakdown of clinopyroxene could not be accommodated by the structure of serpentine minerals, and was accumulated within the driving fluid. The Ca-bearing fluids altered the eclogitic rocks enclosed in the serpentinites, which resulted in the formation of the rodingites. Eclogitic protoliths lost Na and K as well as SiO_2 during rodingitization. The Na and K are commonly precipitated along with available Al_2O_3 as albite, biotite, or orthoclase ahead of the front of rodingitization[15]. Albite-as well as Fe-Mg-rich eclogites, therefore, give rise to the later formation of prehnites and clinozoisites during the process of rodingitization. The distribution of pervasive prehnite veins in rodingites looks similar to that of albite veins in eclogites. It is, therefore, reasonable to assume that adding Ca and losing Na and Si during rodingitization could result in prehnites replacing albites in the veins where fluid flow is concentrated. The chemical reaction for this replacement is as follows:

$$2NaAlSi_3O_8 + 2Ca^{2+} + 2OH^- \longrightarrow$$
$$Ca_2Al_2Si_3O_{10}(OH)_2 + 2Na^{1+} + 3SiO_2(aq)$$

Because the mineral compositions of the investigated eclogites are comparable to other eclogites of the western Tianshan, which have experienced HP-UHP metamorphism, the Changawuzi eclogites are expected to have experienced deep subduction along with oceanic slices, and they were tectonically wrapped into the larger ultramafic bodies during subduction or obduction/exhumation. Both eclogites and rodingites, therefore, are the products of the same subduction-exhumation cycle. Future radiometric age dating has yet to be determined for the temporal context in detail.

Since the rodingitization process observed in the rodingites of the Changawuzi region was related to an event of secondary serpentinization, the volume of the fluid involved must have been limited if compared to a large-scale seawater interaction commonly associated with rodingite formation on the seafloor, so that high-Si prehnite has become the dominated minerals, while more Si-poor phases such as grossular and clinozoisite which are usually abundant within the rodingites are less common than prehnite.

In conclusion, the Changawuzi rodingites reveal an origin and mineral assemblage different from common rodingites. Further studies on this type of rodingite may provide a new approach to exploring the role and quantity of fluids during subduction. The determination of the fluid source and the age of rodingitization will have important implications for the understanding on the formation and closure of the pristine oceanic crust in the western Tianshan.

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References

1 Schulte, B. et al. K-rich fluid metasomatism at high-pressure metamorphic conditions: Lawsonite decomposition in rodingitized ultramafite of the Maksyutovo Complex, Southern Urals (Russia). Journal of Metamorphic Geology, 2002, 20: 529.

2 Zhang, Q. et al. Ophiolites in China (in Chinese). 1st ed. Beijing: Science Press, 2001, 40.

3 Xiao, X. C. et al. Tectonics of North Xinjiang and Its Adjacent Areas (in Chinese). 1st ed. Beijing: Geological Publishing Company, 1992.

4 Li, M. S. et al. Ophiolitic terrane in western Tianshan. In: Ophiolites and Dynamic Studies (in Chinese). Beijing: Geology Publishing House, 1996, 99~103.

5 Tang, Y. J. et al. Ophiolites and Blueschists in Western Tianshan (in Chinese), Beijing: Geology Publishing Company, 1995, 92~96.

6 Li, J. L. Tectonics of collision orogenic belt. In: Modern Geology Corpus (I) (in Chinese), Nanjing: Nanjing University Publishing House, 1992.

7 Zhang, L. F. et al. Ultrahigh pressure metamorphism in western Tianshan, China. Part I: evidences from the inclusion of coesite pseudomorphs in garnet and quartz exsolution lamellae in omphacite in eclogites. American Mineralogist, 2002, 87: 853.

8 Zhang, L. F. et al. Ultrahigh pressure metamorphism in western Tianshan, China. Part II: evidence from magnesite in eclogite. American Mineralogist, 2002, 87: 861.

9 Gao, J. et al. P-T path of high-pressure/low-temperature rocks and tectonic implications in the western Tianshan Mountains, NW China. Journal of Metamorphic Geology, 1999, 17: 621.

10 Holland, T. J. B. et al. An internally consistent thermodynamic data set for phases of petrological interest. J. Metamorphic Geol., 1998, 16: 309.

11 Ravna, K. The garnet-clinopyroxene Fe^{2+}-Mg geothermometer: an updated calibration. J. Metamorphic Geol., 2000, 18: 211.

12 Holland, T. J. B. The experimental determination of activities in disordered and short-range ordered jadeitic pyroxenes. Contributions to Mineralogy and Petrology, 1983, 82: 214.

13 Li, X. P. et al. Rodingites in the Zermatt-Saas Ophiolite, Central Alps - A key to understand metamorphic processes in ultramafic rocks. In: Proceedings of EUG11, Strasbourg, Germany, 2001, 569.

14 Schandl, E. S. et al. Rodingites in serpentinized ultramafic rocks of the Abitibi greenstone belt, Ontario. Canadian Mineralogist, 1989, 27: 579.

15 O'Hanley, D. S. Serpentinites Records of Tectonic and Petrological History. New York: Oxford University Press, 1996, 277.