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LETTERS

Significance of magnesite paragenesis in ultrahigh-pressure metamorphic rocks

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Abstract

Magnesite was identified in garnet websterite and eclogite from two localities where coesite and microdiamond have been reported in the Dabie ultrahigh-pressure metamorphic terrane of central China. This finding, together with other reported occurrences of magnesite in similar ultrahigh- and high-pressure rocks and in kimberlite, supports experimental data showing that magnesite is stable at mantle depths. Magnesite coexists in the garnet websterite with garnet, diopside, enstatite, and titanium clinohumite. It has a nearly end-member composition with 0.13 wt% CaO and a Mg/(Mg + Fe) ratio of 0.94 and may have formed at about 56 kbar and 800–900 °C. Magnesite in coesite-bearing eclogite contains a considerable amount of FeO, with a formula of $Mg_{0.75}Fe_{0.25}CO_3$, and formed at $P > 26$ kbar within the coesite stability field.

Introduction

Magnesite typically occurs as an alteration product in Mg-rich igneous and metamorphic rocks. Recent experimental studies on magnesite stability indicate that magnesite is a major stable carbonate at mantle conditions, has the ability to store C in the Earth's upper and lower mantle, and may also be a carrier of C in subducting plates (Kushiro et al., 1975; Brey et al., 1983; Katsura et al., 1991; Biellmann et al., 1993; Redfern et al., 1993; Gillet, 1993). Rare occurrences of magnesite in kimberlite of mantle origin have been described (McGetchin and Besancon, 1973). The diopside + magnesite assemblage occurs in magnesite + orthopyroxene eclogite from the ultrahigh-pressure (UHP) metamorphic terrane of the West Gneiss Region of Norway (Lappin and Smith, 1978). Here we describe the occurrence of this assemblage in garnet websterite and eclogite of the Dabie UHP in metamorphic terrane, central China. Similar magnesite-bearing garnet peridotite with different paragenesis has been recently reported by Yang et al. (1993) from the southern Su-Lu region, which is an east extension of the Dabie terrane. Magnesite occurrence in the UHP metamorphic complex provides additional evidence that magnesite is stable at mantle depths and allows us to deduce independently the possibility of the existence of diamond in the southeastern Dabie terrane.

Occurrence and composition

Magnesite was identified in two localities in the Dabie UHP metamorphic terrane, where trace amounts of coesite are widespread (Wang and Liou, 1991) and microdiamond has been reported (Xu et al., 1992). Petrographic and compositional characteristics of magnesite from these two localities are described below.

Magnesite was found in garnet websterite of the Bixiling body, an outcrop 1.5 km² in area, which is the largest coesite-bearing mafic-ultramafic complex in the Dabie Mountains, central China. The metamorphic complex consists of layered eclogites containing kyanite, zoisite, talc, and coesite and eclogites rich in rutile, with small layers of garnet lherzolite, wehrlite, and websterite. The occurrence of coesite in the eclogites indicates metamorphism at mantle pressures. Magnesite in the garnet websterite occurs as rounded to subhedral crystals (0.2–1 mm in size) in the matrix, and as minute inclusions (~0.02–0.15 mm) in garnet and diopside. The garnet websterite consists of about 40% garnet, 50% enstatite + diopside, 3–4% titanium clinohumite, and 4–5% magnesite. Coarse-grained magnesite appears to be in textural equilibrium with orthopyroxene, garnet, titanium clinohumite, and diopside (Fig. 1), but most magnesite is rimmed successively by very fine-grained dolomite and chlorite. Minor retrograded phases include fine-grained talc after enstatite, and olivine + ilmenite after titanium clinohumite.

In magnesite-bearing coesite eclogite at Shoughe, about 15 km southeast of the Bixiling complex, coarse-grained magnesite (0.2–1.2 mm in size) was identified as an eclogitic phase coexisting with garnet and omphacite. Abundant coesite and its pseudomorphs occur as inclusions in garnet and omphacite, which have well-developed radial fractures. Magnesite is rimmed by dolomite (Fig. 2); omphacite is replaced by a retrograde symplectite of amphibole + plagioclase.

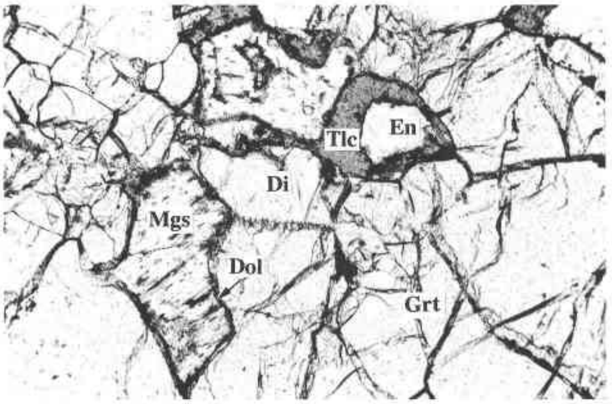

Fig. 1. Photomicrograph showing coarse-grained magnesite coexisting with diopside. Very thin rim of dolomite occurs around magnesite. Plane-polarized light, width of field: 1.44 mm.

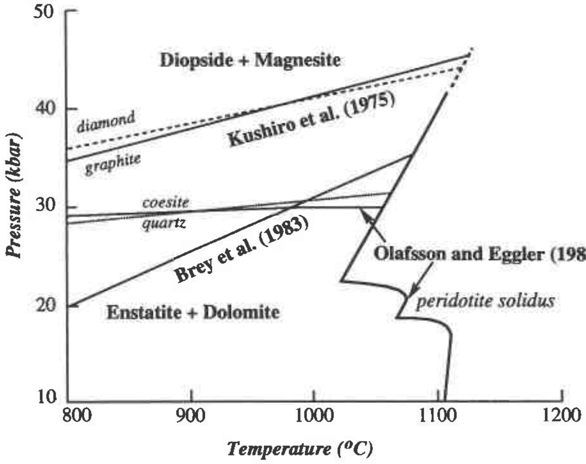

Fig. 3. P-T diagram comparing experimentally determined positions of the univariant reaction diopside + magnesite = dolomite + enstatite by Kushiro et al. (1975), Olafsson and Eggler (1983), and Brey et al. (1983). Peridotite solidus is also shown.

Compositions of magnesite and coexisting phases (e.g., garnet, orthopyroxene, clinopyroxene) are listed in Table 1. The magnesite in garnet websterite is nearly Ca-free, with a Mg/(Mg + Fe) ratio of 0.94. This Mg-rich magnesite is distinctly different from magnesite in the Norwegian magnesite + orthopyroxene eclogite, which contains 0.01–0.06 Ca, 0.09–0.12 Fe, 0.82–0.90 Mg pfu. Orthopyroxene in garnet websterite from the Bixiling complex contains very low Al_2O_3 (0.11–0.13 wt%); diopside contains 3.5–3.8 wt% Na_2O and has a Ca:Fe:Mg ratio of 44:09:46; garnet is Mg-rich, at about 63 mol% pyrope. Metamorphic temperatures were estimated using the clinopyroxene-garnet (Krogh, 1988), orthopyroxene-garnet (Lee and Ganguly, 1988), and orthopyroxene-clinopyroxene (Wood and Banno, 1973) geothermometers; the average temperatures were 888, 783, and 820 °C, respectively. The very low Al_2O_3 content of enstatite yielded a high pressure of 56 kbar at 800 °C with the orthopyroxene-garnet geobarometer of Brey and Köhler (1990).

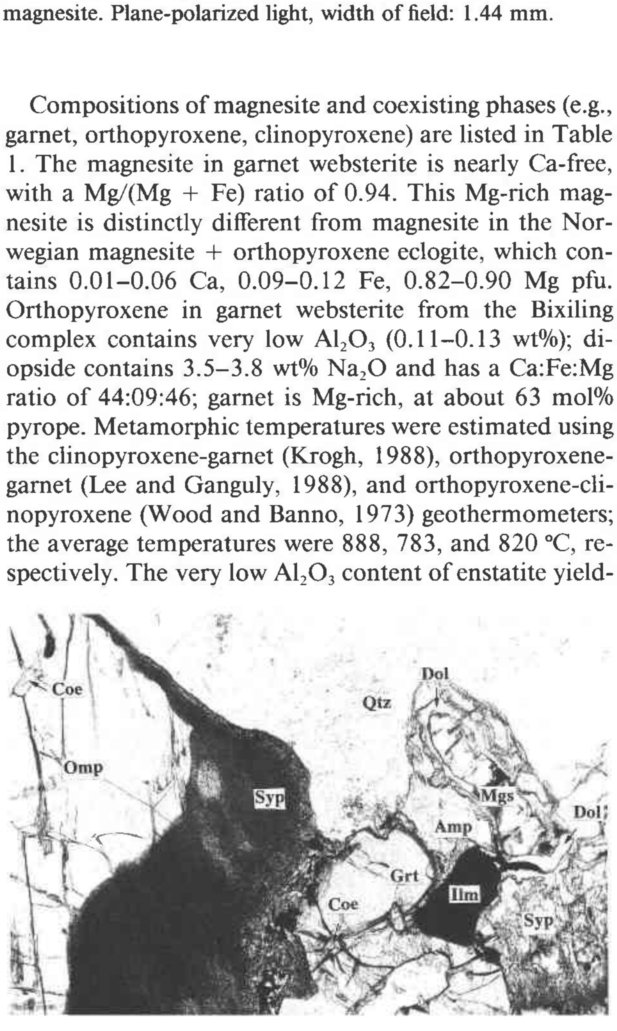

Fig. 2. Magnesite rimmed by dolomite in contact with a symplectite (Syp) after omphacite; secondary amphibole occurs at the contact between magnesite and garnet, both suggesting the former coexistence of magnesite, garnet, and omphacite. Both omphacite and garnet contain inclusions of coesite and pseudomorph after coesite. Plane-polarized light, width of field: 1.44 mm.

Magnesite from the coesite-bearing eclogite at Shoughe lies essentially on the Fe-Mg join, with $Mg_{75}Fe_{25}$. Garnet is rich in almandine ($Alm_{55}Prp_{18}Grs_{26}Spe_1$), and the omphacite contains 43 mol% jadeite ($Jd_{43}Acm_{11}Aug_{46}$). The coesite-bearing eclogite was formed at about 590 °C, on the basis of the clinopyroxene-garnet geothermometer of Powell (1985) and a minimum P of 26 kbar within the coesite stability field.

P-T STABILITY OF MAGNESITE

Figure 3 shows experimental determinations of the diopside + magnesite = dolomite + enstatite equilibrium by Kushiro et al. (1975), Brey et al. (1983), and Olafsson and Eggler (1983). Preliminary experiments of Kushiro et al. (1975) located the reaction between 40–45 kbar at 1000 °C and 45–50 kbar at 1200 °C, close to the graphite-diamond transition. Recent experiments of Brey et al. (1983) located this reaction at 30 kbar at 1000 °C and 39 kbar at 1200 °C. Magnesite is a CO_2-bearing solidus phase at mantle depths of 100–120 km, whereas dolomite occurs as a solidus phase only at depths of 80–110 km. The univariant line of Kushiro et al. lies 10–14 kbar higher than that of Brey et al., whereas the equilibrium line by Olafsson and Eggler (1983) lies very close to the coesite = quartz transition and has a much gentler P-T slope. Brey et al. (1983) attributed the discrepancy to a large uncertainty in P measurement and possible metastable growth of enstatite and dolomite in the experiments of Kushiro et al. The differences in the P-T position and the slope of this simple reaction point to the necessity for experimental recalibration. Nevertheless, available experimental data indicate that the assemblage diopside + magnesite is stable at mantle depths and that magnesite

TABLE 1. Mineral compositions of magnesite-bearing rocks

Sample	Garnet websterite 122A				Eclogite 74G			
Min.	Mgs*	Cpx	Grt	Opx	Mgs*	Dol*	Omp	Grt
SiO_2	0.00	54.68	41.58	57.33	0.07	0.00	55.90	39.67
TiO_2	0.02	0.03	0.02	0.00	0.00	0.00	0.07	0.05
Cr_2O_3	0.00	0.41	0.28	0.05	0.00	0.02	0.00	0.00
Al_2O_3	0.00	3.07	23.01	0.11	0.00	0.02	10.02	22.25
FeO	5.54	4.83	14.55	7.40	21.02	6.11	6.20	20.13
MnO	0.06	0.02	0.36	0.08	0.09	0.07	0.06	0.46
MgO	45.46	13.81	17.60	34.51	35.20	18.99	7.49	4.77
CaO	0.13	17.97	2.80	0.08	0.56	30.02	12.19	14.53
Na_2O	0.01	3.75	0.00	0.02	0.01	0.02	7.87	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	51.22	98.57	100.20	99.58	56.95	55.24	99.80	101.86
O no.		6	12	6			6	12
Si	0.00	2.01	3.01	1.99	0.00	0.00	2.01	3.00
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.13	1.96	0.00	0.00	0.00	0.43	1.98
Fe	0.06	0.15	0.88	0.22	0.25	0.08	0.19	1.27
Mn	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.03
Mg	0.94	0.76	1.90	1.79	0.75	0.43	0.40	0.54
Ca	0.00	0.71	0.22	0.00	0.00	0.49	0.47	1.18
Na	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.00	4.05	8.00	4.01	1.00	1.00	4.05	8.01

* The formulae of magnesite and dolomite were calculated on the basis of 1 cation.

could be a major C-host mineral in the deep upper mantle.

DISCUSSION

Minute inclusions of siderite-magnesite (McGetchin and Besancon, 1973) and decarbonation products of dolomite such as brucite + calcite intergrowths (Berg, 1986) occur in mantle-derived xenoliths within kimberlite. Although the *P-T* positions of the univariant reaction of magnesite + diopside = enstatite + dolomite differ among investigators (Fig. 3), the magnesite + diopside assemblage is undoubtedly a high-*P* assemblage formed at upper mantle depths.

Rare diopside + magnesite assemblages have been recognized in garnet websterites from the West Gneiss Region of Norway and the Dabie UHP terrane of central China. Norwegian magnesite contains minor Ca and considerable Fe and formed at 20–45 kbar and 700–900 °C (Smith, 1988), whereas magnesite from central China is nearly Ca-free, with very minor Fe, and may have formed at 56 kbar and similar temperatures. The experimental studies of Brey et al. (1983) indicated that the Ca content of magnesite decreases with increasing pressure or decreasing temperature. The analyzed compositions are consistent with the experimental data and estimated pressures.

Magnesite-bearing garnet peridotite from the Su-Lu region consists of garnet + forsterite + enstatite + minor diopside + trace magnesite. Magnesite occurs as an interstitial grain among olivine crystals and is in equilibrium with olivine. Fine-grained magnesite relics are enclosed by dolomite, which is later replaced by a periclase ± calcite symplectite. Such paragenesis differs from that of the Dabie magnesite-bearing websterite described above. Geothermobarometry yields an extremely high *P* of equilibration at 45–65 kbar within the diamond stability field (Yang et al., 1993).

Magnesite has been reported in kyanite eclogite from the Tauern Window, Austria (Holland, 1978), and occurs as a primary phase in coesite-bearing eclogite at Shoughe in the Dabie terrane. Because of the mafic compositions of these rocks, magnesite from both areas contains substantial $FeCO_3$ and minor $CaCO_3$ [9 wt% FeO in Tauern magnesite ($Fe_{11}Mg_{88}Ca_{01}$) and 21 wt% FeO in Dabie magnesite ($Fe_{25}Mg_{75}$)]. The associated omphacite contains only 47 ± 3 mol% diopside. With these compositions, the minimum *P* for the coexistence of magnesite + omphacite will shift from the end-member reaction toward lower pressures. Tauern eclogite crystallized at 19.5 ± 2.5 kbar and 620 ± 30 °C (Holland, 1978); coesite has not been recorded. However, the magnesite in the coesite-bearing eclogite from Shoughe must have formed at depths >80 km.

Experimental data shown in Figure 3 suggest that the minimum *P* for the observed magnesite + diopside (or omphacite) assemblage from garnet websterite (or eclogite) of the Dabie UHP terrane is greater than the quartz = coesite transition, inasmuch as coesite relics are abundant in the associated eclogites. Independent *P* estimates for the garnet websterite yield a *P* of about 56 kbar, where diamond is stable. At such mantle depths, diamond is stable at reduced f_{O_2} conditions defined by the enstatite + magnesite = forsterite + diamond + O_2 (EMOD) equilibrium (e.g., LaTourrette and Holloway, 1993). In fact, microdiamond has been reported from the associated UHP eclogites of this area. The rarity of microdiamond could be due to relatively higher f_{O_2} conditions, evidenced by the abundance of carbonates, including calcite, dolomite, and magnesite, in the associated eclogitic rocks from the Dabie terrane (e.g., Wang and Liou, 1993).

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