Petrology of the nyböite-bearing eclogite in the Donghai area, Jiangsu Province, eastern China

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Abstract

Nyböite occurs as porphyroblasts in the Jianchang eclogite in the Donghai area, northeastern Jiangsu Province, eastern China. The Jianchang eclogite contains some inclusions of quartz after coesite in clinopyroxene, garnet and epidote. It has colourless to pale-violet pleochroism. A thin rim with violet pleochroism often develops around nyböite and is taramitic. It is further retrogressed by the symplectite which is mainly composed of hornblende, aegirine-augite and albite. Nyböite is associated with jadeitic pyroxene in the Jianchang eclogite, although other porphyroblastic amphiboles in other Donghai eclogites are barroisitic to katophoritic and are associated with omphacite.

Fe–Mg partitioning between garnet and clinopyroxene and the presence of coesite pseudomorphs indicate *P–T* conditions in the Jianchang eclogite of about 740 ± 60 °C and more than 28 kbar. Similar *P–T* conditions were estimated for other porphyroblastic amphibole-bearing eclogites in the Donghai area. Nyböite can occur in the Na–Al–Fe-rich local bulk composition under the medium to high temperature and very high-pressure conditions. Retrograde rim amphibole is poorer in Na_B, variable in Si content, and richer in Na_A variable than the porphyroblastic amphibole in the Donghai area. This roughly implies a *P–T* path where *P* decreases without a large decrease of *T*.

KEYWORDS: nyböite, coesite, eclogite, China.

Introduction

HIGHLY sodium-rich amphibole near the ideal composition $Na_ANa_{B2}Mg_3Al_2Si_7AlO_{22}(OH)_2$ was given the name 'miyashiroite', as one of the hypothetical amphibole end-members, of Phillips and Layton (1964). Such amphiboles were found to occur naturally in an eclogite pod at Nybö in the Western Gneiss Region of Norway by Ungaretti *et al.* (1981), who proposed a new end-member name of 'nyböite'. It was subsequently approved by the CMNNM Commission of the IMA.

Yang and Smith (1989) reported a new locality of nyböite from eastern China at the third international eclogite conference in Wurzburg. We also found nyböite in the Jianchang eclogite, in the Donghai area, northeastern Jiangsu Province, eastern China, and two papers were given at the IMA meeting in Beijing; Smith *et al.* (1990) and Zhang *et al.* (1990). These two research groups found nyböite at the same locality. Recent petrographic work reveals that the eclogite in both the Nybö and Donghai areas contains metamorphic coesite or coesite pseudomorphs (Smith, 1984; Yang and Smith, 1989; Hirajima *et al.*, 1990). In this paper, the petrology of the nyböite-bearing eclogite is reported and its significance discussed.

Regional geology and occurrence of eclogite

The nyböite eclogite occurs at Jianchang in Donghai County, Jiangsu province, eastern China (Fig. 1). Donghai County is situated in the southern part of the Jiaodong block, east of the Tancheng-Lujiang (Tan-Lu) fracture zone. It is located in a zone developed between the Sino-Korean craton and the Yangzi craton (Tectonic Map Compiling Group, 1974: Ma and Zhang, 1988; Liu *et al.*, 1989). The basement rocks of this block are 'Proterozoic' metamorphic rocks, Proterozoic and Mesozoic granites and later supracrustal rocks. In the Jiaodong block, eclogite and ultramafic rocks occur in the 'Proterozoic' com-

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plex, which consists of a variety of gneiss, schist, amphibolite and a small amount of marble and quartzite. The whole sequence was subjected to amphibolite-facies metamorphism. In China, coesite and coesite pseudomorphs were recently found from many eclogites in the Jiaodong block (Yang and Smith, 1989; Enami and Zang, 1990; Hirajima *et al.*, 1990), and in the Dabie Mountains about 500 km southwest of the Donghai area (Okay *et al.*, 1989; Wang *et al.*, 1990). The Jiaodong block and the Dabie Mountains area are considered to have been offset about 600 km by lateral movement to the left of the Tan-Lu fracture zone (Zhang *et al.*, 1984).

An age of 2233 Ma by U–Pb concordia zircon dating and 1855 Ma by a whole rock Rb-Sr isochron of the diorite intrusion in the Jiaodong block (Wang, 1986) suggest a Proterozoic age of the original rocks of the Jiaodong block. However, recent radiometric studies of eclogites in the block show a wide variation of cooling and formation ages, from Precambrian to Mesozoic (Cong *et al.*, in prep.). Even in the Donghai area various ages were reported: K–Ar phengite ages of 664 Ma, 220 Ma and 159 Ma for the Jianchang eclogite, 656 Ma and 561 Ma for the Hushan eclogite and 722 Ma and 669 Ma for the Qinglongshan eclogite (Ishiwatari *et al.*, 1990); 875 Ma and 435 Ma phengite plateau ages by the $^{40}Ar/^{39}Ar$ method for the Qinglongshan and Menzhong eclogite (Cong *et al.*, in prep.); and 210 Ma Sm–Nd isochron ages for garnet, omphacite and whole-rocks of the Qinglongshan eclogite (Wang *et al.*, 1989). Hence the timing of the very high-pressure metamorphism is still under discussion.

The nyböite-bearing Jianchang eclogite is exposed as lenses, up to 5 × 10 m in size, in the middle of a wheat field. Although the contact with the country rock could not be observed, it seems

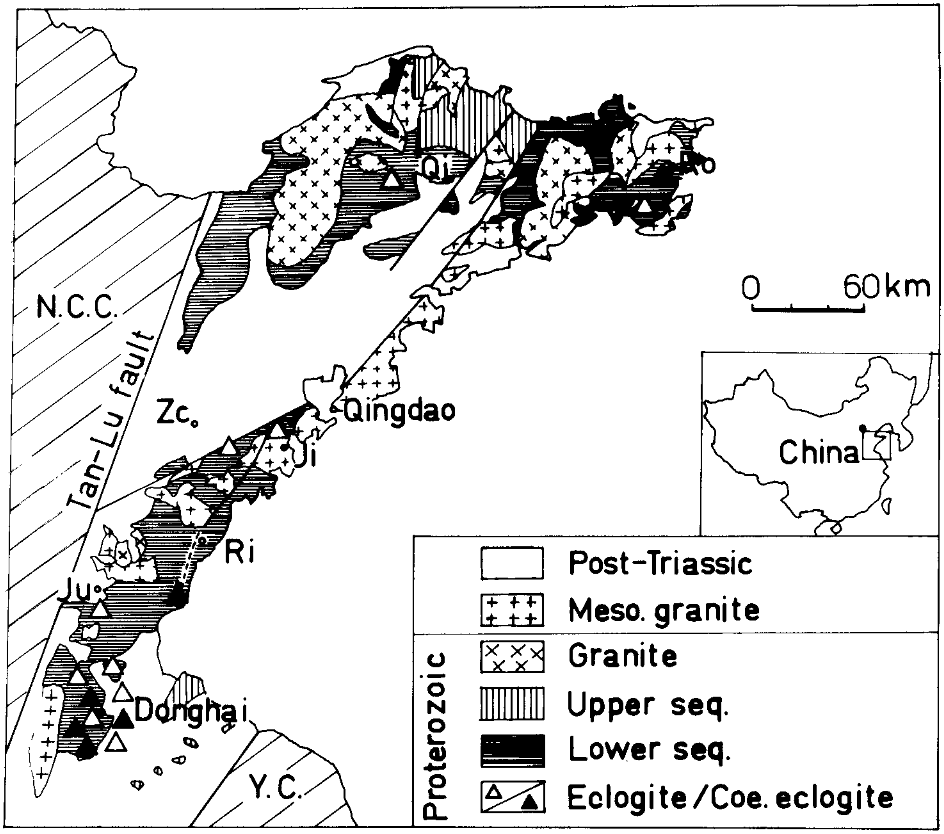

FIG. 1. Geological sketch map of the Jiaodong area. The eclogite occurs in the Proterozoic complex, associated with gneiss, marble or ultramafic rocks. Coesite and/or its pseudomorphs were found in eclogites throughout the area. Ro, Rongchen; Ri, Rizhao; Ji, Jiaonan; Zc, Zhucheng; Ju, Junan; Qi, Qixia; N.C.C., North China Craton; Y.C., Yangzi Craton; Meso, Mesozoic; seq, sequence; Coe, coesite.

to be included in the biotite gneiss, which crops out in a small quarry 100 m from the eclogite occurrence.

Petrography

The Jianchang eclogite (Fig. 2) shows a heterogeneous banded structure and contains garnet, clinopyroxene, porphyroblastic amphibole, kyanite, epidote, phengite, rutile, aluminous titanite, and apatite, as well as quartz after coesite. Many of the clinopyroxenes and porphyroblastic amphiboles were more or less replaced by secondary minerals or by symplectitic aggregate, and kyanite in the matrix was usually replaced by paragonite at the margin. The modal amount of the primary minerals varies from place to place even in a single block. Four representative parts of the Jianchang eclogite were selected and analysed by electron microprobe analyser; samples E88J4, E88J5 and E88J8 were collected from the same block and sample E88J12 was from another block.

E88J8: Clinopyroxene–garnet predominant part. The clinopyroxenes are up to 5 × 2 mm in size, and the garnet is finer grained—about 1 mm in diameter. Symplectite and acicular paragonite are developed along the grain boundary between them. Symplectite is mainly composed of hornblende, epidote and albite. Polycrystalline quartz inclusions are found in clinopyroxene and garnet with radial cracks developed around the inclusions.

E88J4: Amphibole porphyroblast-bearing part. This part is composed mainly of clinopyroxene, garnet, kyanite, epidote and quartz, apart from the amphibole porphyroblast. Porphyroblastic amphibole, up to 3 × 5 mm, shows pleochroism with Z′ = colourless and X′ = pale-violet, and is usually surrounded by a thin amphibole rim (<0.2 mm in width) with a slightly different

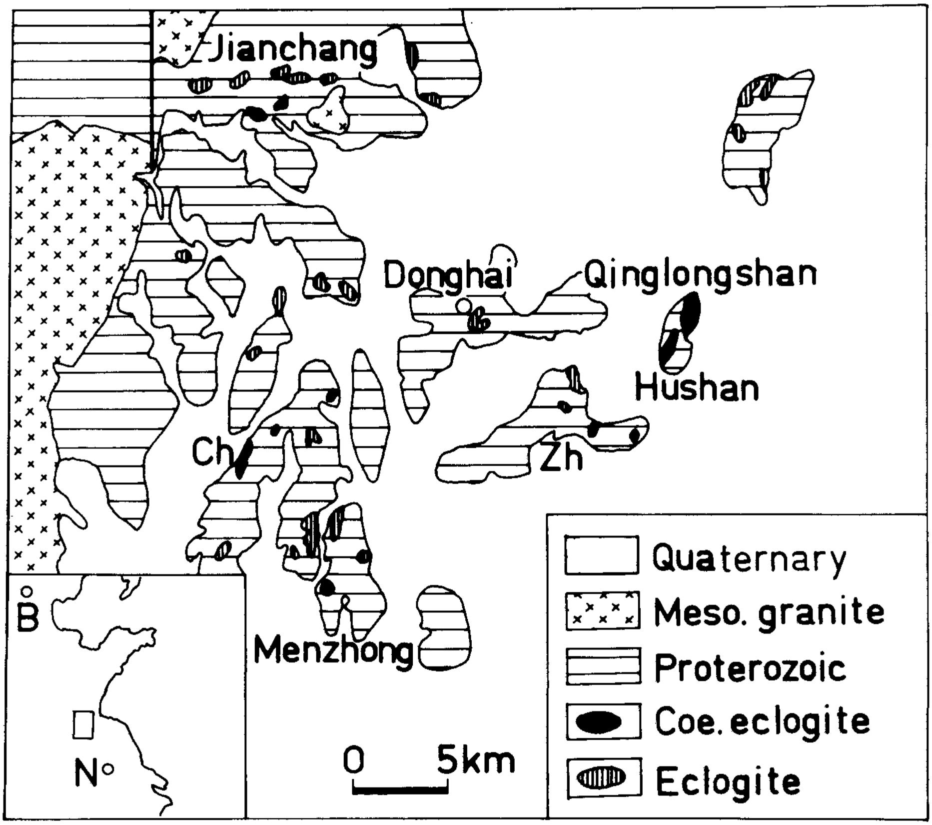

FIG. 2. Eclogite localities in the Donghai area. Nyböite porphyroblast were found in the Jianchang eclogite, and barroisite/katophorite in Qinglongshan and Hushan eclogite. Coesite occurs only in the eclogite at Menzhong village. The other coesite eclogites in the figure include coesite-pseudomorphs. Zh, Zhimafang; Ch, Chizhuang; B, Beijing; N, Nanjing.

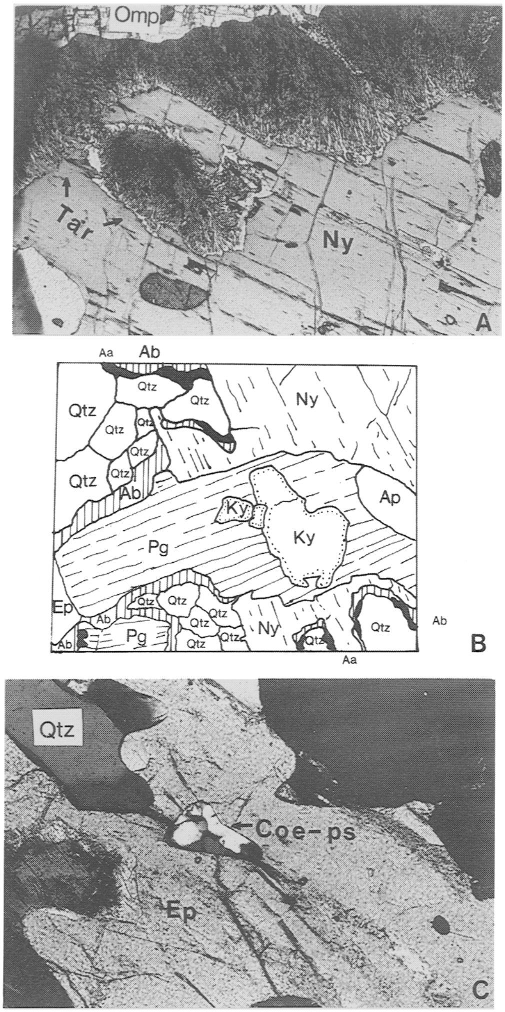

FIG. 3. (*a*) Photomicrograph of nyböite porphyroblast (Ny) in the Jianchang eclogite (Sample E88J4). Long dimension of photo is 2 mm. Plane polarized light. Tar, Taramite rim; Omp, Omphacite. (*b*) Sketch figure of kyanite (Ky) replaced by paragonite (Pg) in Sample E88J4. A thin film of albite (Ab: vertical ruler) develops between paragonite and quartz (Qiz). Secondary aegirine-augite (Aa: solid) and albite also develop between nyböite porphyroblast (Ny) and quartz. Ep, epidote; Ap, apatite. Long dimension of figure is 1 mm. (*c*) Photomicrograph of coesite pseudomorph (Coe-ps) in epidote (Ep) of the Jianchang eclogite (Sample No. E88J5). Long dimension of photo is 2 mm. Crossed polars. Qtz: Quartz.

extinction position and with greenish-violet pleochroism (Fig. 3*a*). It is further rimmed by a symplectite of green amphibole, epidote, albite and an opaque mineral. Amphibole porphyroblasts include garnet and clinopyroxene. Epidote often contains several wt.% of rare earth element in the core. Retrogressive reactions had developed. Almost all of the clinopyroxenes were rimmed by symplectite which is composed of green amphibole, epidote, aegirine-augite and albite. Garnet is usually surrounded by greenish-blue amphibole, and kyanite in the matrix by paragonite. A thin film of albite usually develops at the boundary between paragonite and large coarse-grained quartz (Fig. 3*b*). As far as we observed, albite is not found at the boundary between kyanite and paragonite. These paragonites are sometimes in contact with a symplectite which replaces clinopyroxene. It follows that kyanite coexisted with jadeitic clinopyroxene at the maximum eclogite stage. Some paragonite grains include taramitic amphibole, suggesting that the paragonite is later stage growth.

E88J5: Epidote porphyroblast-rich part. Epidote porphyroblasts up to 5 × 10 mm in size, include garnet, clinopyroxene, amphibole, quartz and rutile. Polycrystalline quartz after coesite occurs in some of the epidote porphyroblasts (Fig. 3*c*). Another characteristic mineral in this part is Al-rich titanite, occurring as amoeba-shaped crystals. There are two modes of occurrence of amphibole, but its modal amount is small: (*a*) irregular-shaped interstitital grains between the boundaries of clinopyroxene and garnet; and (*b*) inclusion in epidote, clinopyroxene, garnet or titanite. In both cases, amphibole shows pale-green to bluish-green pleochroism.

E88J12: Flaky phengite-bearing part. This part is foliated and is composed mainly of garnet, clinopyroxene, phengite and quartz. Symplectite surrounding clinopyroxene and garnet is weakly developed. Amphiboles with pale green to bluish-green pleochroism occur as small interstitial grains among eclogite minerals.

Mineralogy of the nyböite-bearing eclogite

Representative chemical analyses of the main constituent minerals of the nyböite-bearing eclogite are shown in Table 1. Chemical analyses were carried out by an electron-probe microanalyser (Hitachi S550) with an energy-dispersive X-ray analytical system (Kevex 8000 + Kevex Quantum detector) at Kyoto University, following the procedure of Mori and Kanehira (1984).

Amphibole. The composition of amphibole in the Jianchang eclogite is shown in the Na_B–Si and Na_B–Na_A diagrams (Figs. 4*a* and *b*, respectively). As they do not contain much Ca-poor amphibole, the Fe^{3+}/Fe^{2+} ratio of amphibole is estimated assuming that the total cations in the *T* and *M* sites = 13.0 from the microprobe analysis. The texture of porphyroblasts described before is very similar to that of the 'early amphibole' in certain Norwegian eclogites (Lappin and Smith, 1978; Smith, 1988). The porphyroblast was formed before its rim and that of the symplectitic amphibole, and it poikiloblastically includes clinopyroxene and garnet. Hence, the porphyroblastic amphibole probably grew slightly later than the main eclogitic minerals. However, there still remains the possibility that amphibole crystallization started at the same time as the main eclogite minerals. The rims of the porphyroblasts and the symplectitic amphibole clearly grew after the eclogite stage.

The cores of porphyroblastic amphiboles in eclogite E88J4 are clearly richer in the Na_B and Na_A variables of those in the Donghai area (Fig. 4). It is nyböite (Ungaretti *et al.*, 1981). The rim of porphyroblast is poorer in Na_B and Si than the core. Similar compositional change of retrograde amphibole was reported from those in the Norwegian eclogite by Krogh (1980, 1982) and Ungaretti *et al.* (1981). In the case of the Jianchang eclogite, the rims of nyböite porphyroblasts are of taramite (Fig. 4). Symplectite amphibole in this eclogite is much poorer in the Na_B variable than in the taramite rim. Interstitial amphibole composition in the Jianchang eclogite has an intermediate composition between barroisite and katophorite. It is not certain when the interstitial amphibole grew.

For comparison, core and rim compositions of the porphyroblastic amphibole in the Qinglongshan and Hushan eclogites in the Donghai area are also plotted in Fig. 4. Their cores have a similar pleochroism to nyböite, but their composition is from barroisite to winchite. Their rims are also richer in the Na_A varible and poorer in the Na_B variable and Si content than the core.

Clinopyroxene. The composition of clinopyroxene from the Jianchang eclogite is shown in a jd–acm–(di + hd + cat) triangular diagram (Fig. 5), with the compositional range of clinopyroxenes from other eclogites in the Donghai area. Eclogitic clinopyroxene in the Jianchang eclogite is relatively homogeneous in each thin section,

Table 1. Representative chemical compositions of the Jianchang eclogite

Sample No.	E88J4	E88J4	E88J4	E88J4	E88J4	E88J4	E88J4	E88J4	E88J4
PointNo.	2	35	4	34	26	36	42	23	21
Mineral	amp core	amp core	amp rim	amp rim	amp symp	px core	px core	px symp	ep rim
SiO2	50.89	48.87	39.85	39.90	43.12	56.97	57.24	53.51	39.15
TiO2	0.08	n.d.	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Al2O3	12.09	12.92	20.88	20.35	12.17	14.64	14.92	1.12	26.08
FeO	9.76	10.64	15.05	15.97	15.28	8.19	8.18	21.64	9.18
MnO	0.07	n.d.	0.37	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MgO	12.42	12.38	7.32	6.80	11.21	3.15	3.09	4.55	n.d.
CaO	2.93	3.71	6.86	7.04	9.55	4.95	5.14	7.65	22.98
Na2O	8.42	8.32	6.27	6.46	5.52	11.74	11.59	9.86	n.d.
K2O	0.27	0.29	0.07	0.00	0.00	n.d.	n.d.	n.d.	n.d.
Total	96.93	97.13	96.73	96.52	96.91	99.64	100.16	98.33	97.39
O=	23	23	23	23	23	6	6	6	25
Si	7.196	6.947	5.866	5.936	6.451	2.002	2.004	2.000	6.097
Ti	0.009	-	0.007	-	-	-	-	-	-
Al	2.015	2.165	3.622	3.568	2.143	0.606	0.616	0.049	4.787
Fe3+	0.332	0.466	0.666	0.451	0.299	0.190	0.163	0.665	1.195
Fe2+	0.822	0.799	1.186	1.536	1.610	0.051	0.076	0.011	-
Mn	0.008	-	0.046	-	-	-	-	-	-
Mg	2.618	2.624	1.606	1.508	2.497	0.165	0.161	0.254	-
Ca	0.444	0.565	1.082	1.122	1.529	0.186	0.193	0.306	3.834
Na	2.308	2.293	1.789	1.863	1.599	0.800	0.787	0.714	-
K	0.049	0.053	0.013	-	-	-	-	-	-
Total	15.801	15.911	15.885	15.986	16.128	4.000	4.000	4.000	15.913

Fe3+/Fe2+ ratio of clinopyroxene is calculated as total cations =4.0, and that of amphibole is total cations in M and T sites = 13.0.
Abbreviations:inter=interstitial grain of amphibole. symp=symplectite

but they have variable compositions from place to place. Those from samples E88J4 and E88J8 are impure jadeite, and the others are omphacite (E88J5 and E88J12). Later stage pyroxene in the

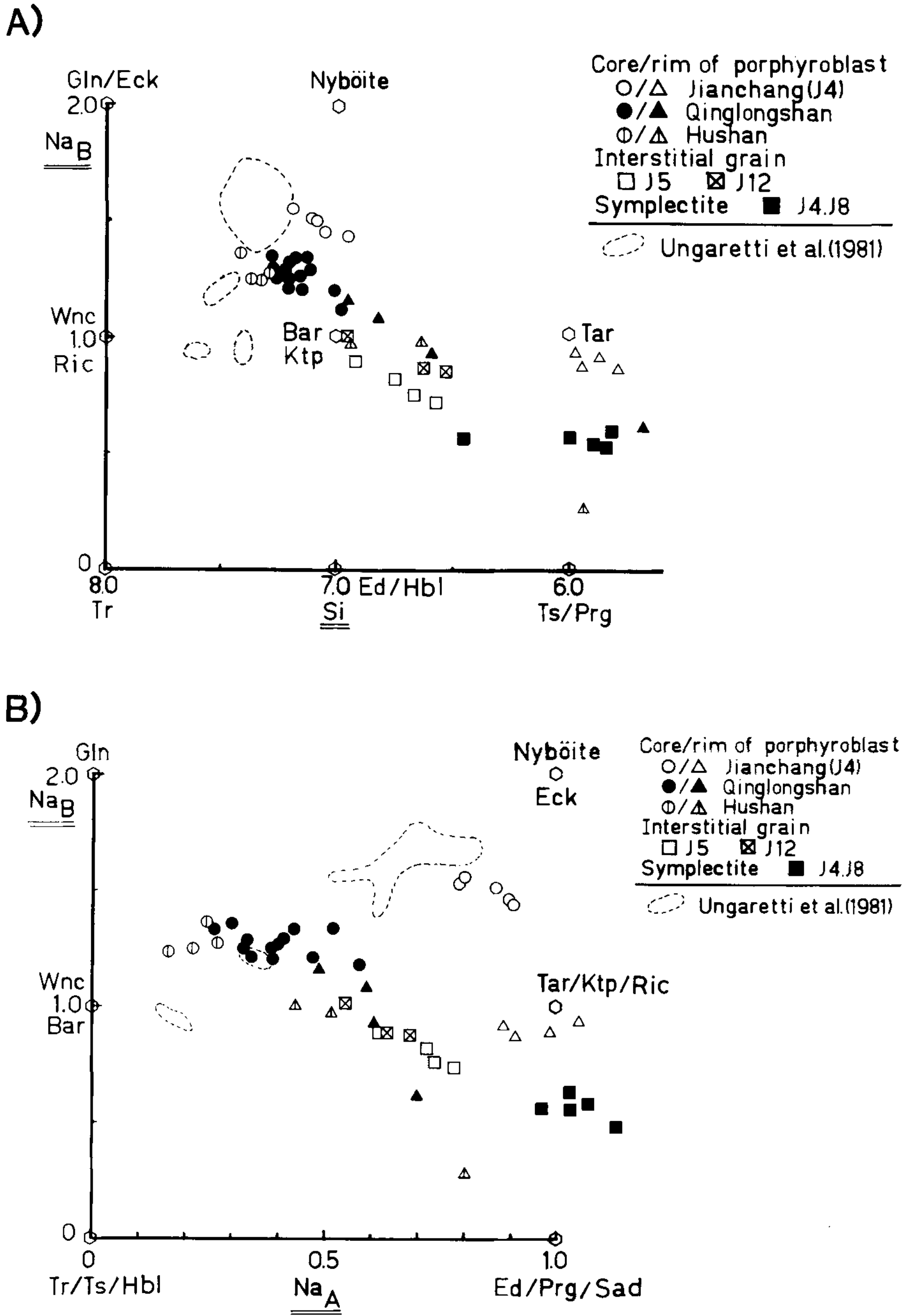

FIG. 4. (*a*) Si–Na_B diagram and (*b*) Na_B–Na_A diagram for amphiboles in the Donghai area. For comparison, 'early amphibole' in the Nybö eclogite pod (Ungaretti *et al.*, 1981) is also shown. End-member names of amphiboles follow Leake (1978) and Smith (1988). Sad, Sadanagaite; Ric, Richterite; other abbreviations follow Kretz (1983).

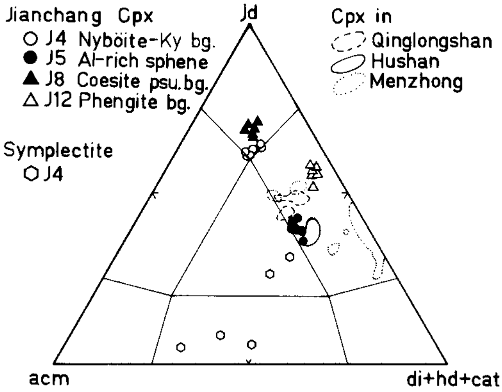

FIG. 5. Compositions of clinopyroxenes in the Jianchang eclogite. They are homogeneous in each thin section, but show chemical variations from place to place, mainly based on the local bulk chemistry. bg, bearing; psu, pseudomorph.

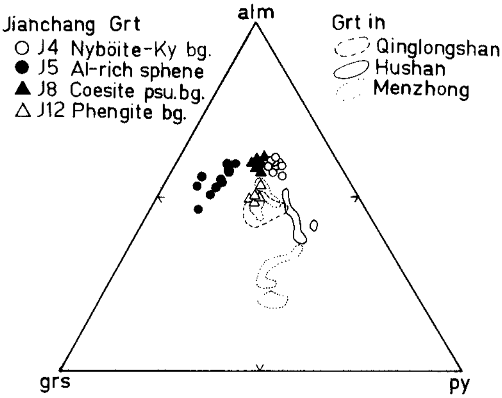

FIG. 6. Compositions of garnets in the Jianchang eclogite. They are homogeneous in each thin section, except garnet in sample J5 (Al-rich titanite-bearing garnet), but are slightly different from place to place. bg, bearing; psu, pseudomorph.

symplectite is chloromelanite to aegirine-augite (Fig. 5).

Garnet. The garnet compositions are shown in Fig. 6. They are generally homogeneous in each thin section, except for the sample E88J5. Among them, garnets from samples E88J4 and E88J8 are richer in Fe and poorer in Ca (alm = 0.55–0.62, grs = 0.14–0.22, py = 0.18–0.29) than the others (Fig. 6). Garnet in sample E88J5 shows irregular zoning but there is no typical growth zoning (Ghent, 1988). Their compositions are the most Ca-rich and Mg-poor in the Donghai area (alm = 0.46–0.60, grs = 0.26–0.42, py = 0.23–0.36). Nyböite is associated with the Fe-richest and Ca-poorest garnet in the Donghai area.

Other minerals. Al-rich titanite, in sample E88J5, contains Al_2O_3 up to 7.4 wt.% and minor amounts of Fe_2O_3 (about 1 wt.%) and MgO (<0.3 wt.%). They have a similar compositional range to those from the Liset eclogite pod (Smith, 1988).

Phengite in sample E88J12 has a similar grain size to the eclogitic clinopyroxene and garnet, and they define a foliation. Some of analysed phengites show chemical zoning, Si-rich cores (Si = 3.47–3.57) and Si poor-rims (Si = 3.32–3.30) with a small paragonite component (core: about 4 mol%, rim: 4–7 mol%). Hence, its core recorded the maximum eclogite stage.

Porphyroblastic epidote in sample E88J5 is generally homogeneous with a composition of Y_{Ps} ($=Fe^{3+}/(Fe^{3+} + Al)$) = 0.24 both in the matrix and in inclusions in garnet.

P–T condition of Jianchang eclogite

To estimate the formation temperature of the eclogite, Fe–Mg partitioning between garnet and clinopyroxene was examined. There is chemical zoning in some garnets and clinopyroxenes, so, only K_D values for pairs in contact with each other were calculated. K_D for the core–core pair was not calculated as it is difficult to find suitable core-pairs. Uncertainties in the estimate of the Fe^{3+}/Fe^{2+} ratio probably makes a major contribution to the wide range of scattering of estimated temperatures. As there is no explicit way to estimate that ratio from microprobe analysis, Fe^{3+} = Na-$Al^{(VI)}$ and Fe^{2+} = Fe(total)-Fe^{3+} were adopted, and the geothermometer of Powell (1985) was used. However, estimated temperatures show systematic differences in the Jianchang eclogites:

E88J4: average, 790 °C: range, 680–880 °C
E88J8: average, 840 °C: range, 820–890 °C
E88J5: average, 750 °C: range, 690–790 °C
E88J12: average, 730 °C: range, 680–790 °C

The estimated temperatures from the pair with a high X_{Jd} clinopyroxene ($X_{Jd} > 0.6$: E88J4 and E88J8, see Fig. 5) are higher than those from the pair for normal omphacite ($0.35 < X_{Jd} < 0.6$). A similar tendency has been reported in an Alpine eclogite by Koons (1984) and Heinrich (1986). They ascribed this fact to the preferential incorporation of Fe^{2+} into *M*2 sites in jadeitic pyroxene. Therefore, the estimated temperature from a normal omphacite pair will consequently show the temperature at the maximum eclogite stage.

Significance of the nyböite occurrence

The compositions of amphibole porphyroblasts in the Donghai area (Fig. 4) are clearly correlated with the Na/(Na + Ca) ratios of clinopyroxene (Fig. 5) and with the Fe/(Fe + Mg + Ca) ratios of garnet (Fig. 6). The positive correlation of Na/(Na + Ca) ratios between clinopyroxene and amphibole in the eclogite has been also reported in the Nybö eclogite by Ungaretti *et al.* (1981) and in the Adula nappe by Heinrich (1986). Carman and Gilbert (1983) synthesized miyashiroite between 800 and 950 °C at more than 20 kbar. The estimated temperature for the Jianchang and Nybö eclogites by the clinopyroxene–garnet geothermometer is between 680 and 850 °C (this study, and Lappin and Smith, 1978) and metamorphic coesite has been confirmed from both areas. Recent petrographic work on a kyanite eclogite in Norway, Adula nappe in the eastern Alps and Turkey (Lappin and Smith; 1981; Jamtveit, 1987; Heinrich, 1986; Okay, 1985) showed the common occurrence of amphibole porphyroblast as a primary of 'early-stage mineral' of the eclogite facies. In these areas, amphibole is mainly barroisitic, pargasitic and edenitic under the *P–T* conditions of 16–29 kbar and 630–800 °C. In the Adula nappe, most jadeitic clinopyroxene is associated with glaucophane under the *P–T* conditions of 450–550 °C and 12–22 kbar (Heinrich, 1986). These natural occurrences of amphiboles suggest that the nyböite is a stable phase under high-temperature and very high-pressure conditions, where coesite is stable, although there still remains the question of the exact timing of the amphibole growth.

Kienast *et al.* (1991) found a primary glaucophane from the pyrope-bearing mica schist in the southern part of the Dora Maira, western Alps. They estimated the maximum *P–T* conditions as 680–750 °C and more than 28 kbar, which is very similar to those in the coesite eclogite in the Norway and Jianchang eclogites. Bulk composition of glaucophane–pyrope mica schist is distinctly richer in Na_2O, MgO and Al_2O_3 than that of the common eclogite and is close to the synthetic system of Carman and Gilbert (1983). Because of the solid-solution effect on the amphibole, nyböite will be expected in the Na-rich natural eclogite under such *P–T* conditions.

Inferred *P–T* path of the Jianchang eclogite

The presence of coesite and Fe–Mg partitioning suggest that the pressure was higher than 28 kbar and the temperature was around 680–790 °C at the maximum metamorphic stage of the Jianchang eclogite (Fig. 7). Similar temperatures at the maximum stage were estimated for coesite pseudomorphs and amphibole prophyroblast-bearing eclogites at Qinglongshan (average, 760 °C; range, 700–830 °C) and Hushan (average, 710 °C; range, 620–850 °C) by the same method. Coesite and kyanite-bearing eclogite at Mengzhong village shows about 810 °C and over 28 kbar (Hirajima *et al.*, 1990). These eclogites occur as lens-shaped bodies within regional gneiss. However, some of the eclogites associated with ultramafic rocks at Menzhong quarry showed much lower temperatures (average, 580 °C; range 520–670 °C). Hence, the estimated *P–T* conditions and the mode of occurrence suggest that coesite or coesite pseudomorph-bearing eclogites within gneiss in the Donghai area share the same *P–T* history. Some of the Qinglongshan eclogites include Cl-bearing pargasitic hornblende in

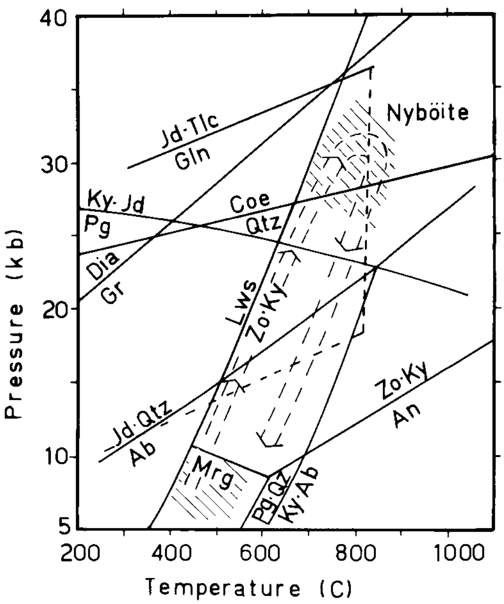

FIG. 7. Inferred *P–T* path of coesite and coesite pseudomorph-bearing eclogites in the Donghai area. The prograde path is inferred from prograde relics of paragonite (Pg), Cl-bearing hornblende and margarite (Mrg) included in eclogitic minerals. The retrograde path is from rim composition of clinopyroxene, amphibole and retrograde paragonite surrounding kyanite. Graphite (Gr) = diamond (Dia) (Kennedy and Kennedy, 1976), quartz (Qtz) = coesite (Coe) (Mirwald and Massone, 1980), glaucophane (Gln) = jadeite (Jd) + talc (Tlc) and stability field of nyböite (Carman and Gilbert, 1983). Pg = Jd + Ky, Pg + Qtz = Ky + Ab, Ab = Jd + Qtz and Lws = Zo + Ky (Holland, 1979). Margarite stability field (Perkins *et al.*, 1980). Abbreviations mainly follow Kretz (1983).

garnet and epidote, as well as paragonite, kyanite and margarite in amphibole and epidote porphyroblasts as primary phases. In the latter case, kyanite and paragonite occur as isolated grains in the porphyroblasts, and have no reaction rims around them. It is noteworthy that lawsonite and glaucophane have not been observed as primary inclusions in eclogites of the Donghai area. This is distinctly different from the Spitsbergen eclogite reported by Hirajima *et al.* (1988). This formed at about 600 °C and 18 kbar, and does not contain coesite, but includes lawsonite in garnet. Therefore, the prograde path of the very high-pressure eclogite in the Donghai area is shown as a very steep positive slope (Fig. 7).

Retrograde stage crystallization of the Jianchang eclogite is characterized by the decrease of $NaSiCa_{-1}Al_{-1}$ vectors both in amphibole and clinopyroxene, the increase of $Al_2Mg_{-1}Si_{-1}$ and $NaAlSi_{-1}$ vectors in the amphibole, and by the replacement of kyanite by paragonite. In the Jianchang eclogite, secondary paragonite is not in direct contact with quartz, nor kyanite with albite, as far as is known. Therefore, it is difficult to determine which side of the following reaction,

$$\text{paragonite} + \text{quartz} = \text{kyanite} + \text{albite} + H_2O \quad (1)$$

was stable during the retrograde stage. Kyanite is replaced by paragonite at the margin but albite never exists near kyanite or paragonite. A thin film of albite usually separates paragonite from large crystals of quartz (Fig. 3*b*). These textures suggest that paragonite coexisted with quartz at one stage. Na_2O and Al_2O_3 may have been supplied by a decomposition of primary clinopyroxene and amphibole. Retrograde metamorphism continued until a later stage, because X_{Jd} of secondary clinopyroxene varies from approximately 0.30 to 0.10. Therefore, the retrograde path of the eclogite in the Donghai area is also shown by a very steep positive slope (Fig. 7).

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