QUARTZ-ECOLGITE IN SHUANGHE AREA OF THE DABIE MOUNTAINS: HOT OR COLD?

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Abstract

Quartz-eclogite blocks were discovered in Shuanghe area of the Dabie Mountains, which belongs to the so-called hot eclogite terrain. The peak metamorphic assemblage of the eclogites is garnet + omphacite + phengite + kyanite + rutile + quartz. Their P-T conditions are estimated as P=2.0 GPa and T=700°C by using garnet-omphacite-phengite barometer and garnet-omphacite thermometer. Tectonically, the contrast in peak metamorphic temperatures is more significant. Therefore, the quartz-eclogite in Shuanghe could also be considered as "hot" eclogite, although it experienced no UHP metamorphism.

1. Introduction

A southward decrease in peak metamorphic temperature within the Dabie eclogite zone has long been recognized (Wang and Liou, 1991). Okay (1993) subdivided it into a northern "hot" and a southern "cold" eclogite terrain, with boundary running roughly along the south bank of the Hualiangting reservoir. The hot eclogite terrain is characterized by higher-temperature eclogites and marble-eclogite association, while the cold eclogite terrain by coesite-free eclogite and sodic amphibole-bearing eclogite. This subdivision was supported by Carswell et al. (1997), who preferred to term them the Central Dabie UHP eclogite-bearing terrain and the Southern Dabie HP eclogite-bearing terrain. However, during a systematic sampling study, we have found coesite-free quartz-eclogite in Shuanghe area (Fig. 1), which is located in the northern hot eclogite terrain of Okay, or the Central Dabie UHP eclogite-bearing terrain of Carswell et al. In the present paper, we will describe the petrography and estimate the peak metamorphic P-T condition of the unique eclogite member from Shuanghe.

2. Field Occurrence and Petrography

Shuanghe village is located at the southwest of Qianshan County, Anhui Province (Fig. 1). The studied area is only hundreds of meters to south of the UHP slab mapped by Cong et al. (1995). Eclogite blocks of meter-scale occur in the epidote-mica schist, which is surrounded by granitic gneiss. Foliation developed in the schist wraps the mechanically competent eclogite blocks, as showing a block-in-matrix structure. Two kinds of eclogite blocks have been recognized based on the petrological study, with one being UHP eclogite and the other HP eclogite (Liu, 1998).

The UHP eclogites, represented by sample LXD21, are similar to those in the northern UHP slab described by Cong et al. (1995). They are characterized by peak metamorphic assemblage of Grt + Phen + Omp + Rt + Qtz/Coe, as well as retrograde assemblage of Cpx + Hbl + Pl + Ap + Bi + Qtz + Ilm and Pl + Hbl+ Ep + Spn + Bi + Qtz.
The HP eclogites, represented by sample LXD23, are medium-grained, and contain garnet, omphacite, phengite, rutile, sphene, kyanite, amphibole, paragonite, and quartz. No coesite or its pseudomorph has been found. Garnet, occurring as large porphyroblast, is the most abundant phase in the eclogite. Most of the garnet grains range from 0.6 to 2.5 mm in diameter and show good zonation (Fig. 2) with pyrope component decreasing from core ($X_{\text{Mg}}=0.40$) to rim ($X_{\text{Mg}}=0.26$). Inclusions of omphacite, paragonite, and apatite in the core bring garnet an atoll shape. The garnet grains are always surrounded by corona composed of green amphibole + epidote + albite. Omphacite is the second abundant phase. It occur either as large grains in matrix, or as inclusions in garnet. Some omphacite grains have partially replaced by symplectite of diopside and albite.

Fig. 1 Geological map in Shuanghe area

Fig. 2 Compositional profile of garnet (LXD21)
TABLE 1 Representative microprobe analyses of minerals from eclogite LXD23

<table>
<thead>
<tr>
<th></th>
<th>Grt (core)</th>
<th>Grt (rim)</th>
<th>Omp (core)</th>
<th>Phen (core)</th>
<th>Phen (rim)</th>
<th>Hbl</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>38.714</td>
<td>37.391</td>
<td>56.215</td>
<td>51.794</td>
<td>48.625</td>
<td>39.421</td>
<td>63.311</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.084</td>
<td>0.081</td>
<td>0.026</td>
<td>0.431</td>
<td>0.446</td>
<td>0.494</td>
<td>0.050</td>
</tr>
<tr>
<td>Cr2O3</td>
<td>0.000</td>
<td>0.000</td>
<td>0.028</td>
<td>0.018</td>
<td>0.043</td>
<td>0.007</td>
<td>0.000</td>
</tr>
<tr>
<td>MgO</td>
<td>10.202</td>
<td>6.471</td>
<td>10.415</td>
<td>3.726</td>
<td>3.246</td>
<td>11.617</td>
<td>0.076</td>
</tr>
<tr>
<td>FeO</td>
<td>21.645</td>
<td>27.153</td>
<td>3.022</td>
<td>1.292</td>
<td>1.379</td>
<td>10.742</td>
<td>0.012</td>
</tr>
<tr>
<td>MnO</td>
<td>0.378</td>
<td>1.425</td>
<td>0.111</td>
<td>0.009</td>
<td>0.050</td>
<td>0.066</td>
<td>0.300</td>
</tr>
<tr>
<td>CaO</td>
<td>6.435</td>
<td>5.196</td>
<td>15.055</td>
<td>5.000</td>
<td>0.000</td>
<td>12.262</td>
<td>3.998</td>
</tr>
<tr>
<td>BaO</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.008</td>
<td>0.029</td>
<td>5.909</td>
<td>0.354</td>
<td>0.880</td>
<td>4.176</td>
<td>9.186</td>
</tr>
<tr>
<td>K2O</td>
<td>0.000</td>
<td>0.012</td>
<td>0.000</td>
<td>10.715</td>
<td>9.323</td>
<td>0.154</td>
<td>0.067</td>
</tr>
<tr>
<td>TOTAL</td>
<td>99.354</td>
<td>99.075</td>
<td>99.769</td>
<td>95.693</td>
<td>93.024</td>
<td>96.257</td>
<td>99.077</td>
</tr>
</tbody>
</table>

Phengite, usually showing a composition zone, is concentrated in matrix. Rutile occurs either in matrix or as inclusions in garnet and omphacite. The rutile close to garnet is always rimmed by sphenite. Kyanite co-exists with garnet, omphacite, phengite and rutile. Its retrograde products include margarite + quartz and paragonite. Paragonite occurs either as inclusion in garnet, or as large flake mounting omphacite and garnet, as well as retrograde corona surrounding kyanite.
At least three metamorphic stages could be recognized. Their peak metamorphic assemblage is Grt + Phen + Omp + Ky + Rt + Qtz, and retrograde assemblages are Cpx + Pg + Phen + Hbl + Pl + Qtz + Spn/IIm and Pl + Hbl + Ep + Bi + Mr-g + Qtz.

3. Mineral Chemistry and P-T Paths

Mineral compositions (Table 1) were analyzed at analytical conditions of 15 KV acceleration voltage and 20 nA current using microprobe (CAMECA SX51) in the Laboratory of Lithosphere Tectonic Evolution, Institute of Geology, Chinese Academy of Sciences.

![Diagram A: Alm+Sps](image1)
![Diagram B: Q(V,Er,Fs)](image2)

Fig. 3 Compositional variation of garnets (A) and omphacites (B)

The garnet in the LXD23 is characterized by zonation with pyrope end-member decrease from core to rim (Fig. 2) and low content of grossular ranging from 0.07 to 0.17 (Fig. 3). The Jadeite content of omphacite in the studied eclogite (LXD23) is lower than that in the nearby UHP eclogite (LXD21), with the former being 0.31-0.45 and the later being 0.43-0.60 (Fig. 4). The Si content in the phengite is about 3.3-3.5 p.f.u. (O=11). Other representative mineral composites are shown in Table 1.

The peak metamorphism P-T could be calculated by using garnet-omphacite-phengite barometer and garnet-omphacite thermometer. In the K$_2$O-CaO-MgO-FeO-Al$_2$O$_3$-SiO$_2$-H$_2$O system, absolute pressures for stability of the peak assemblage could be calculated through reaction equilibriums (Fig. 4):

$$\begin{align*}
3 \text{ Al-Cel} + 2 \text{ Grs} + \text{ Pyr} &= 3 \text{ Mus} + 6 \text{ Dio}, \\
\text{Alm} + 3 \text{ Al-Cel} + 2 \text{ Grs} &= 3 \text{ Mus} + 3 \text{ Hed} + 3 \text{ Dio}, \text{ and} \\
2 \text{ Alm} + 3 \text{ Al-Cel} + 2 \text{ Grs} &= \text{ Pyr} + 3 \text{ Mus} + 6 \text{ Hed}.
\end{align*}$$

The temperatures could be calculated through reaction equilibrium (Fig. 4):

$$3 \text{ Dio} + \text{ Alm} = 3 \text{ Hed} + \text{ Pyr}.$$ 

The peak metamorphic P-T conditions are calculated using the GeO-Calc software package of Brown et al. (1988). The thermodynamic data source for the calculations was given by Massonne (1992, 1997). The calculations yield $P = 2.0$ GPa and $T = 700^\circ$C from the quartz-eclogite (LXD23) and $P = 3.9$ GPa and $T = 750^\circ$C from one nearby eclogite block (LXD21) (Fig. 5). On the other hand, the peak metamorphic pressure of the epidote-mica
schist as matrix of the eclogitic blocks was estimated as $P > 2.2$ GPa at $T = 700^\circ$C, based on mineral assemblage of Rut + Grs + Coe/Qtz + Sph + Czo (Liu, 1998).

The retrograde $P$-$T$ conditions were estimated as $P = 0.8$ GPa and $T = 650^\circ$C, based on the following reactions in the Na$_2$O-CaO-MgO-Al$_2$O$_3$-SiO$_2$-H$_2$O system:

$11$ Grs + $10$ Pyr + $27$ Qtz + $6$ H$_2$O = $6$ Tr + $21$ An,
$7$ Grs + $3$ Pg + $5$ Pyr + $18$ Qtz = $3$ Tr + $15$ An + $2$ Ab,
$2$ Grs + $5$ Pyr + $7$ Ab + $3$ Qtz + $10$ H$_2$O = $3$ Tr + $7$ Pg, and
Grs + $5$ Pyr + $3$ An + $9$ Ab + $12$ H$_2$O = $3$ Tr + $9$ Pg.

![Fig. 4 P-T diagram showing peak metamorphic condition of the eclogites LXD23 (solid lines) and LXD21 (dash lines)](image)

1. $3$Al-Cel + $2$Gr + Py = $3$Ms + $6$Di
2. Alm + $3$Al-Cel + $2$Gr = $3$Ms + $3$Hed + $3$I
3. $3$Di + Alm = $3$Hed + Py
4. $2$Alm + $3$Al-Cel + $2$Gr = Py + $3$Ms + $6$Hk

On the other hand, the retrograde of kyanite to margarite + quartz and paragonite indicate the following reactions:

$5$ Ky + $2$ Zoi + $3$ H$_2$O = $4$ Mrg + $3$ Qtz,
$2$ Ky + $2$ Zoi + $3$ Pg = $4$ Mrg + $2$ Ab, and
Ab + Ky + H$_2$O = Pg + Qtz.

In the Na$_2$O-CaO-Al$_2$O$_3$-SiO$_2$-H$_2$O system the calculations of these retrograde $P$-$T$ conditions yield $P = 0.8$ GPa and $T = 670^\circ$C, which are quite close to the estimation in the Na$_2$O-CaO-MgO-Al$_2$O$_3$-SiO$_2$-H$_2$O system mentioned above.

The summary of the above $P$-$T$ estimations gives a clockwise and isothermal decompression path for the quartz-eclogite in Shuanghe (Fig. 5).

4. Discussion and Conclusion

The first temperature-based subdivision of eclogite facies was put forward by Banno (1970) and emphasized by Caswell (1990). Their three-fold classification put $550^\circ$C as boundary between low temperature (LT) and medium temperature (MT) eclogites, and $900^\circ$C between MT and high temperature (HT) eclogites. These subdivisions have an advantage that they broadly correlate with eclogite formation in three fundamentally different
geological environments. The LT eclogites are associated to blueschist developed in oceanic subduction zones. The MT eclogites are stable in tectonically thickened continental crust in continent-continent collision zones. The HT eclogites are characterized by xenolithic assemblages in the upper mantle. Obviously, the LT, MT, and HT eclogites have a meaning different from Okay's "hot" and "cold" eclogites mentioned above. The "cold" eclogites, as a descriptive term appeared first in study of the Dora Maira eclogite terrain (Chopin et al., 1991). It was invented to denote a coesite-free eclogite unit, which yielded peak metamorphic temperature as about 500°C, in contrast to 700°C in the nearby coesite-bearing eclogite unit. Okay (1993) followed the usage in study of the Dabie eclogite terrain, and added another term "hot" eclogites to describe the nearby coesite-bearing unit. In fact, the two units subdivided by Okay (1993) and Canwell et al. (1997) differ not only in their peak metamorphic temperature (800±50°C in the northern unit and 635±40°C in the southern one), but also in their peak metamorphic pressure (>3.8 GPa in the northern unit and 1.8±2.6 GPa in the southern one).

Fig. 5  P-T paths of the eclogites LXD23 and LXD21

The quartz-eclogite studied in the present paper, however, is characterized by high temperature (700 °C) and low pressure (2.0 GPa) peak metamorphic conditions. It differs either in peak temperature from the coesite-free eclogite to the south, or in peak pressure from the nearby coesite-bearing eclogite on the north. Should we call it as "hot" or "cold" eclogites? No pigeonhole fits it, if considering only the peak metamorphic temperature and pressure. However, we prefer to call it as the "hot" eclogite, when taking into account of the garnet zonation that indicates a homogenization at high peak temperature and modification in the later retrogradation. As shown in another paper in the same volume (Wang et al., 1998), when the deep-subducted "hot" coesite-bearing unit exhumed, the "cold" coesite-free unit could be heated. This indicates that the contrast in their peak metamorphic temperatures might be more tectonically significant.

The Shuanghe eclogites and other UHP rocks have been considered as the tectonic melange formed when supracrustal rocks subducted down to mantle depth (Cong et al., 1995; Wang et al., 1997, 1998). The special melange is characterized not only by composition variation either in their protolith (Cong et al., 1995) or in their oxygen isotope (Zheng et al., 1997), but also by block-in-matrix structure and peak pressure contrast between different eclogite blocks, as shown by the present study. Such a melange nature implies that not all of the rocks in the coesite-bearing unit were subducted down to the same depth. Some might stumble halfway and join into a upward flow, as a block turning its way in the corner flow (Cloos,
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1982). In such a case, the “in situ” contact between eclogites and their UHP or HP country rocks only denotes that they all subducted down to great depth. However, it does not mean that they were metamorphosed side by side. They might be separated far from each other in an extensive UHP environment, and mixed together as “foreign” blocks during exhumation.

Acknowledgments

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