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**Abstract** Recent studies have shown that apatites with needle-like exsolution lamellae are widely found in eclogites as well as in ultramafic rocks in the Dabie-Sulu UHP metamorphic belt. These studies demonstrated that most of these exsolution lamellae are sulfides e.g., pyrite and chalcopyrite with an intriguing mineral chemistry. In this contribution, we focus on the composition of solid exsolution lamellae in apatites from a fresh plengite eclogite and a highly retrograded eclogite from the Qinglongshan Jiangsu province. Scanning electron microscope (SEM) examinations, electron microprobe, and X-ray energy-dispersive (EDS) analyses show that exsolution lamellae in these apatites are dominantly copper-bearing sulfide, possibly CuS₂. Experimental studies have shown that CuS₂ crystal can only be synthesized under high temperature and high pressure conditions (T = 700 ~ 1000°C and P = 4.5 ~ 5.0 GPa). Such a condition is consistent with the UHP metamorphism experienced by the Qinglongshan eclogites. The preservation of UHP sulfide phases in apatites can be understood by considering the shielding effect of apatite which is extremely stable and chemically inert in the Sulu eclogites. Therefore, apatites may have behaved similarly to garnet or omphacite primary phases that host coesite and diamond to facilitate the preservation of UHP sulfide phases.

**Key words** Apatite; Exsolution lamellae; Eclogite; UHP metamorphic belt.

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1. LREE
2. Groen and Silver
3. Nd
4. S
5. Watson and Harrison
6. Ayres and Harris
7. Zeng et al., 2005a
在变质岩中，磷灰石也是一常见副矿物，而且稳定范围很宽，从低级变质岩到高级变质岩中都可以存在，是重要的低温热年代学工具（磷灰石裂变径迹），在揭示近地表地质过程中有重要的应用。在榴辉岩中，与锆石相比，尽管磷灰石也是较常见的副矿物之一，但研究较少，对磷灰石在高压超高压变质岩石中所富含的地球化学和变质反应动力学缺乏深入的认识。在超高压变质岩中的主要成岩矿物（如：石榴石、辉石和橄榄石等）中，经常发育有各种出溶结构，由于它们对于超高压岩石形成的温度、压力和地球化学条件等地质环境具有重要的指示意义，而受到了研究者的普遍关注（例如：许志琴等，陈晶等，Bark & Dyer，2003）。最近几年，一些学者发现，在超高压变质岩石的常见副矿物磷灰石中也发育有大量的出溶结构。2003年，Zhang & Liou报道过在苏鲁超高压变质带中具有独居石出溶结构的磷灰石。朱永峰和Huang在苏鲁超高压榴辉岩中发现了磷灰石晶体存在两组互相垂直的出溶棒结构，并通过能谱分析认定出溶棒主要由Fe和Mn两种元素组成，推测该出溶体为磁黄铁矿。随后，梁凤华等又在胶东荣成退变金红石榴辉岩中发现含铜磁黄铁矿（Fe,Mn）出溶结构的磷灰石。本文重点研究了青龙山地区的榴辉岩和退变榴辉岩中磷灰石的出溶结构以及出溶矿物的特征，以此来讨论该区超高压变质榴辉岩形成的地球化学条件和地质环境。

区域地质与岩石矿物

多硅白云母榴辉岩
主要矿物组合：石榴石、绿辉石、多硅白云母、黝帘石、磷灰石、金红石和钛铁矿。岩石比较新鲜，基本上没有发生退变质作用，石榴石、绿辉石和多硅白云母具有很好的紧密接触关系，反映了平衡共生关系。利用紧密共生的石榴石、绿辉石、多硅白云母矿物组合（矿物成分见表），根据U,V,W,T温压计算程序，对三组石榴石、绿辉石、多硅白云母矿物组合进行计算，获得该多硅白云母榴辉岩的形成温度为200°C，压力范围在35kbar ~ 38kbar。

大量的岩石学观察可已确定，在该类多硅白云母榴辉岩中的磷灰石与石榴石、绿辉石属同期共生矿物。磷灰石自形程度很好，多为完好的长方形和六边形，表明它是早期结晶矿物，粒度一般在0.8 ~ 1.8 mm。磷灰石晶体中发育有针柱状出溶晶体，但其出溶密度不大（图1）。

退变榴辉岩
本文所研究的退变榴辉岩，曾经遭受较强烈的退变质作用，其绿辉石已基本上被角闪石、辉石、长石取代。其主要矿物组合为：石榴石、帘石、角闪石、普通辉石、斜长石、磷灰石、金红石和钛铁矿等组成。在该类退变榴辉岩中磷灰石含量较高，而且磷灰石晶体中发育针柱状出溶晶体密度较大，定向排列，宽度相似，在0.1mm ~ 0.6mm。尽管该退变榴辉岩经历了强烈的后期退变质作用，磷灰石仍然稳定存在，是峰期变质矿物的残留体，而不是在后期热液交代作用或退变质作用过程中形成的。

图1 a）多硅白云母榴辉岩中磷灰石与石榴石和绿辉石共生，磷灰石晶体中发育有针柱状出溶晶体（单偏光显微图像）
图1 b）退变榴辉岩中磷灰石晶体中发育有大量的针柱状出溶晶体（单偏光显微图像）
Table 1  Microprobe analysis of chemical composition of clinopyroxene, garnet and phengite of eclogite from the Qinglongshan

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Fe³⁺ is calculated after Droop (1987)
磷灰石及针柱状出溶体成因讨论
在超高压变质带中，磷灰石是榴辉岩和超基性岩的一种常见的副矿物。磷灰石稳定的温压范围很宽，无论在超高压榴辉岩中，还是在遭受强烈退变质作用的退变榴辉岩中，均保存有磷灰石，因而磷灰石是最有可能保存超高压变质岩从俯冲到折返整个过程所有信息的矿物。那么我们用什么样的手段和方法去获取这些信息，怎样解读所获取的信息代表或记录了那一变质阶段，是我们今后深入研究的重点。在超高压榴辉岩中，磷灰石是在超高压变质作用峰期形成的矿物已成为研究者的共识。

Fig. 2 Line scan EDS spectra of exsolution rods in an apatite from the phengite eclogite. Major elements are Cu and S with a ratio of Cu/S = 2 : 1 according to quantitative analysis without standard sample calibration.

Fig. 3 Line scan EDS spectra of exsolution rods in an apatite from the retrograde metamorphic eclogite. Major elements are Cu and S with minor Fe. The ratio Cu/S + Fe/S is ~ 1 : 2 according to quantitative analysis without standard sample calibration.

Fig. 4 Line scan EDS spectra of exsolution rods in an apatite of the retrograded eclogite. Major elements are Cu and S with minor Fe. The ratio Cu/S + Fe/S is ~ 1 : 2 according to quantitative analysis without standard sample calibration.
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