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Magnetofabrics of eclogites and ultramafic rocks from the Chinese Continental Scientific Drilling (CCSD) project: evidence for ultrahigh-pressure (UHP) texture inheritance throughout retrogression

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Abstract: Ultrahigh-pressure (UHP) mafic and ultramafic rocks from the Chinese Continental Scientific Drilling (CCSD) in the Maobei eclogite body of the Sulu ultrahigh-pressure metamorphic belt in eastern China were studied for their magnetofabrics in order to constrain fluid rock interactions and related ductile deformation. Our magnetofabric data imply that the magnetic fabric of the mafic and ultramafic rocks mimics the UHP fabric and survived retrogression. Accordingly, the amphibolite to greenschist grade fabric is inherited from the UHP stage, and retrogression should not have been associated with substantial ductile deformation in these lithologies.

Keywords: magnetofabrics, texture evolution, retrogression, exhumation, mafic-ultramafic rocks, Chinese Continental Scientific Drilling (CCSD).

The site of the Chinese Continental Scientific Drilling (CCSD) project is located in the Triassic Sulu ultrahigh-pressure (UHP) metamorphic belt, which is a part of the much larger Qinling-Dabie-Sulu orogen (Fig. 1). The Sulu UHP-metamorphic belt, which is defined by the widespread occurrences of coesite-bearing eclogite, paragneiss, orthogneiss, marble and quartzite on the Shandong peninsula is part of the easternmost Qinling-Dabie-Sulu orogen (Ratschbacher *et al.*, 2003), which is a fault-bound 50-180 km wide strip extending along strike for about 750 km in a NE-SW direction. The CCSD site is located within the Maobei crustal slice, which is separated from the Donghai and Lianyungang crustal slices by ductile shear zones (figure 1; Xu *et al.*, 2006a). The Donghai, Maobei, and Lianyungang slices are considered to have been imbricated during early stages of exhumation, but became overprinted by top-to-NW shearing. Locally, asymmetric olivine and omphacite lattice-preferred orientations indicate top to S(E) shearing (Xu *et al.*, 2006b). The CCSD mainhole (MH) and a series of other drill holes intersected the steeply east-dipping Maobei eclogite body (Fig. 1). Drill cores were obtained from 100 m below surface to the final depth of 5158 m below surface with a core recovery of >80% (Xu *et al.*, 2006a). The drill cores were oriented using borehole image logging (Xu *et al.*, 2006a). Based on geochemistry and petrography four units are distinguished for the uppermost 1.2 km (Zhang *et al.*, 2006): unit 1) 100-530 m: quartz-rich eclogites, ilmenite-rutile-rich eclogites and thin gneiss layers; unit 2) 530-600 m: rutile- and ilmenite-rich eclogites; unit 3) 600-680 m: serpentinized ultramafic rocks with minor intercalations of eclogites and garnet pyroxenites; unit 4) 680-1160 m: interlayered paragneisses and eclogites.

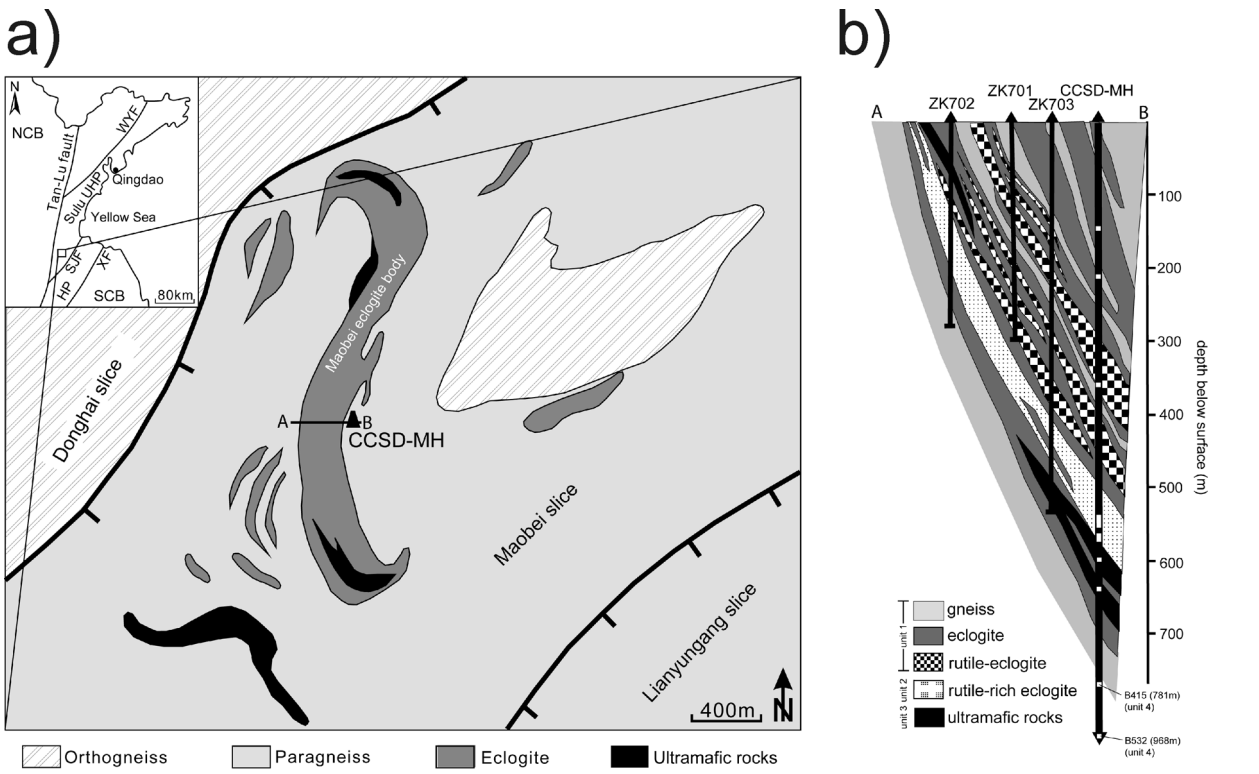

Figure 1. a) Overview map (inset upper left) of the Sulu UHP-metamorphic belt with bordering faults (XF: Xiangshui Fault; SJF: Shuyang-Jinping fault; WYF: Wulian-Yantai-Fault). The geologic overview map displays major mafic-ultramafic bodies in the UHP-metamorphic nappes ('slices'), which are separated by ductile shear zones with top to NW kinematics with barbs on hanging wall, b) cross section of the Maobei eclogite body showing the intersection of this mafic-ultramafic body by the different bore holes. White squares show sampling depths from the CCSD-MH. From Qi *et al.* (*in press*).

We studied the anisotropy of magnetic susceptibility (AMS) of retrogressed eclogites and ultramafic rocks from the uppermost 1000 m of the 5138 m deep drill hole of the Chinese Continental Scientific Drilling (CCSD) project (Fig. 1). Here, Fe-rich mafic-ultramafic rocks provide a good control on retrograde reactions because of the involvement of Fe- and Fe-Ti-oxides during the retrograde eclogite to amphibolite and amphibolite to greenschist grade reactions. Because magnetofabrics depend on both magnetic mineralogy and lattice- or shape-preferred orientations of minerals the AMS-method is a useful tool to study the retrograde fluid-rock interactions and ductile deformation during exhumation.

Results

Petrography and texture

Eclogites consist of garnet and omphacite with variable contents of Fe-Ti-oxides, Fe-sulphides, and phengite representing peak UHP rock composition. The eclogites of all units show variable degrees of retrograde amphibolite to greenschist facies metamorphic overprint focused in irregular veins. The retrograde mineral phases comprise bluish-greenish amphiboles of pargasitic composition (Riemann and Oberhänsli, 2007; Yang, 2004), fine-grained amphibole-plagioclase-symplectites, titanite, epidote, biotite, and albitic feldspar. Retrograde pargasitic amphibole coronas with newly grown magnetite occur as intergrain phases of non-isometric garnets. Magnetite is limited to the pargasitic amphiboles and outlines the former grain boundaries of garnet. The ultramafic rocks are serpentinized to various degrees with serpentinite veins separating relict olivine cores in a mesh texture. Magnetite is enriched along former grain boundaries of olivine and garnet, in serpentinite veins and as thin rims around garnet.

Magnetic mineralogy

The mean susceptibilities (K_{mean}) of the eclogites vary from 0.6 to 14.3×10^{-3} (SI) implying variable contributions of ferrimagnetic minerals within the different

eclogite samples and superposed para- and ferromagnetic fabrics. Except for one sample, which exceeded the measurement range (maximum 250×10^{-3} SI) of the Kappabridge, K_{mean} of the ultramafic rocks varies from 17.5×10^{-3} to 232.7×10^{-3}.

Magnetic susceptibility as a function of temperature was measured from representative lithologies from all sampled units for the temperature range of -192 °C to 700 °C in order to identify the minerals carrying bulk susceptibility. K(T)-measurements are also helpful to calculate the relative proportion of the respective para- and ferrimagnetic minerals. The calculated contribution of paramagnetic minerals to the bulk susceptibility varies from 24 to 89%. However, the contribution of the ferromagnetic subfabric to the bulk susceptibility of eclogites with $K_{mean}>5\times10^{-3}$ may approach 100%. The K(T)-curves of ultramafic rocks outline Ti-free and stoichiometric magnetite.

Magnetic fabric

The corrected degrees of anisotropy (P′) vary from 1 to 1.53. The shape factor T varies from -0.83 to 0.68. T increases strongly with decreasing densities and thus seems to be very sensitive to retrogression. P′ correlates positively with K_{mean} and thus with increasing magnetite content. In the ultramafic rocks P′ varies from 1.34 to 1.98. The shape factor T varies from -0.68 to 0.78. K_{mean} increases with increasing retrogression, but P′ decreases with increasing densities. This implies that more modal magnetite reduces the degree of anisotropy, which is caused by the serpentinization process and related mesh-texture formation. The low-field AMS measures the bulk fabric whereas the high-field AMS isolates the paramagnetic from the bulk fabric. Eclogites from all units outline paramagnetic or superposed para- and ferromagnetic fabrics. Therefore all oriented eclogite samples were measured in both a low-field with the KLY4-Kappabridge and a high-field with a torque magnetometer. The low-field AMS of all eclogites shows consistent N-S-trending K_{max}-axes with K_{int}- and K_{min}-axes distributed on an E-W-girdle. The orientation of the N-S-trending K_{max}-axis is independent of the primary eclogite composition, the degree of retrogression, and the highly variable P′-, K_{mean}-, and T-values. The serpentinized ultramafic rocks outline almost identical prolate ellipsoids with essentially N-S-trending subhorizontal K_{max}-axes and a girdle distribution for the K_{int}- and K_{min}-axes. An isolation of the paramagnetic subfabric was not possible due to the high susceptibilities, which produced torques that exceeded the sensitivity of the measurement device.

Discussion and conclusions

The eclogites of all units show different degrees and responses on retrograde metamorphic overprint, which is related to different primary modal and chemical composition, and variable degrees of fluid-rock interaction. Superposed para- and ferromagnetic fabrics characterize the magnetofabrics of CCSD-eclogites from the uppermost 1000 m of the CCSD-MH. The eclogite texture, primary eclogite composition and the retrograde formation of pargasitic amphibole-magnetite coronas around garnet are the major parameters that control the magnetofabrics of the CCSD-eclogites. The magnetofabrics mimic the eclogite texture via retrograde magnetite growth around shape-preferred garnet. The consistently N-S-trending K_{max}-axes, independent of variable primary eclogite composition, the different degrees of retrogression, and the highly variable P′-, T-, and K_{mean}-values also display texture inheritance. The serpentinized ultramafic rocks are characterized by very high susceptibilities with magnetite as carrier of the susceptibility. Shape-preferred orientation of relict olivine and garnet and the formation of thin magnetite rim around garnet and of syn-serpentinization magnetite growth within a mesh texture control the distribution of magnetite and thus the magnetofabrics indicating texture inheritance as well.

On a thin section scale evidence for ductile shearing is lacking in veins with a retrograde mineral assemblage. Evidence for ductile shearing in the veins is missing in the CCSD eclogites. Irregular vein geometries and boundaries at both thin-section and at specimen scale also corroborate that the veins were not shear zones or, vice versa, developed in shear zones. The veins thus probably represent preserved primary retrograde features, which originated from channelized fluid flow and mineral decomposition. The retrograde coronas around garnet indicate initial fluid flow along grain boundaries and follow the former UHP eclogite and peridotite texture. It is suggested that the mafic-ultramafic Maobei body behaved as a rigid body within a ductile quartzo-feldspathic matrix during exhumation and related retrogression. Internal strain is restricted to brittle fracturing, accompanied by fluid circulation and vein formation.

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