Ten years of research progress on the structure, *P–T* path and Fluid–Melt evolution of the deeply-subducted UHP continental crust in the Sulu belt

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Fundamental scientific questions about the tectonics of continental subduction during collisional orogenesis include: 1) the maximum depth from which the continental crust can be exhumed along the subduction channel, and 2) the evolution and role of fluid and melt in the deformation and metamorphism of the crust during burial and exhumation. To address these questions, we have studied one of the most deeply subducted slabs of continental crust to retrieve information about deformation and metamorphism at extreme pressures. In this presentation we summarize the results of our studies conducted during the past ten years from the Yangkou Bay–General's Hill area in the central Sulu belt. Here we have integrated structural mapping with microstructural, petrological, geochemical and geochronological studies on the most deeply-subducted (possibly >200 km[1]) UHP metamorphic rocks in the Sulu belt. The rocks preserve evidence of fluid evolution from nominally anhydrous minerals and partial melting during exhumation. Our studies have led to a new understanding of the structural history, *P–T–t* path and melting of UHP rocks during continental subduction and exhumation associated with collisional orogenesis.

Structural geometry and strain localization along the subduction channel

Detailed 1:200–1:1000 scale structural mapping of critical outcrops in the Yangkou Bay area has allowed us to define the structural geometry and strain localization features within the exhumed Mesozoic subduction channel. At least four stages of folding are recognized in the UHP eclogites and associated quartzo-feldspathic (QF) gneisses. Mylonitic to ultra-mylonitic QF gneisses and coesite/quartz-eclogite in shear zones separate small-scale 5–10 m thick 'nappes' of ultramafic–mafic UHP rocks from layered QF gneisses. Rootless prograde isoclinal F1 and post-peak isoclinal F2 folds are preserved locally in coesite-eclogite. Overall, the prograde to retrograde coesite-eclogite to quartz-eclogite, amphibolite and greenschist facies, D1 to D5 deformation sequence preserved in the eclogites and gneisses is explained by deep subduction of off-scraped thrust slices of upper continental crust from the down-going plate, caught between the North and South China cratons during the Mesozoic collision. The polyphase folding demonstrates that eclogite boudins were rolled in the subduction channel within the QF gneisses. During exhumation, the eclogites were migmatized and intruded by both in situ and exotic melts[2,3].

Coesite eclogite can be buried to >5.5 GPa and record evidence of fluid evolution during early exhumation

P–T estimates based on conventional thermobarometry in UHP eclogite may underestimate peak conditions. To overcome this difficulty, phase equilibrium modeling, including consideration of the influence of ferric iron (O) and H_2O on the phase equilibria, has been used for the first time on four representative coesite-eclogites from Yangkou Bay to constrain the peak *P–T* conditions and the *P–T* path. The highest *P–T* conditions retrieved are P > 5.5 GPa at T > 850 °C, although variation in mineral compositions suggests the maximum *P–T* conditions could have been higher. During exhumation, the retrograde *P–T* path passed through metamorphic conditions of P = 4.0–3.4 GPa at T = 850–800 ℃ and P = 2.4–1.7 GPa at T = 800–750 ℃, before reaching crustal levels at P = 1.3–0.9 GPa and at T = 730–710 ℃. Veins of coarse phengite and quartz (previously coesite) within low stress area of fine grained eclogite, are interpreted to have formed by precipitation of solutes from fluid migrating under UHP conditions, whereas symplectites and K-feldspar veinlets around phengite formed by local melting and crystallization during exhumation from HP eclogite to HP amphibolite facies conditions[3-4].

Variation in inherited H2O in NAMs and deformation partitioning control fluid distribution during exhumation

The Yangkou eclogites are unique as the first examples of UHP rocks with intergranular coesite[5], indicating a locally ‘dry’ environment throughout the exhumation. Intergranular coesite has survived in rootless intrafolial isoclinal F1 eclogite fold hinges, wrapped by a composite S1–S2 eclogite-facies foliation, in interlayered quartz-rich phengite schist. Comparison of the water content of nominally anhydrous minerals (NAMs), plus microstructural, petrological and structural features within and outside fold hinges, indicates these structures have the lowest inherited H_2O content and preserve the largest amount of intergranular coesite. The inherited drier environment limited fluid connectivity along garnet and omphacite grain boundaries in the fold hinges, which themselves acted as rigid high stress sites and remained immune to grain-scale fluid infiltration. These serendipitous conditions allowed coesite to survive. The grain boundary fluid was focused into high stress sites such as fold limbs in foliated and mylonitic eclogite, the surrounding quartz-rich phengite schists and along their mutual contacts. Evidence of UHP metamorphism may be preserved in similar structural settings in other collisional orogens[6].

Partial melting of UHP eclogite and gneiss forming migmatite

Wang et al. in 2014[3] were the first to report migmatites formed by partial melting of UHP eclogite and gneiss from General’s Hill. In the migmatized eclogite, microstructures demonstrate that intragranular droplets and grain boundary melt films develop into 3-d interconnected intergranular networks with increasing melt volume. The melt may segregate and accumulate in pressure shadows before merging to form channels and dikes that transport melt higher in the crust. Leucosomes and residues are complimentary, being enriched and depleted in light rare earth elements (LREE) compared with the protolith[3]. Si-in-phengite barometry combined with Ti-in-zircon thermometry yields crystallization *P–T* conditions for the leucosomes of 3.0–2.5 GPa at 830–770 °C. Zircon crystallization in leucosome and retrogressed eclogite occurred at *c*. 221 Ma, shortly after peak metamorphism[7]. The Sr–Nd isotope compositions of leucosomes indicate a mixed source of melt from eclogites and host gneisses[7].

Mechanism of melt generation during exhumation of continental crust from UHP conditions

Although melting is commonly related to hydrate-breakdown by reactions including phengite, at General’s Hill, at UHP conditions, exsolution of H_2O from nominally anhydrous minerals during initial exhumation generated a grain boundary supercritical fluid in both gneiss and eclogite. This fluid increased in volume and solute content as exhumation progressed, evolving into hydrous melt that crystalized at HP eclogite *P–T* conditions[7]. Towards the end of exhumation, minor phengite breakdown melting is recorded in leucosomes, quartz-rich phengite schist, phengite-bearing eclogite and gneiss[7-8].

We conclude that strain partitioning and inherited H_2O content of UHP rocks control fluid distribution during exhumation, and influence subsequent microfabrics, deformation mechanisms, degree of partial melting and retrogression at different structural locations. Fluid evolution in deeply subducted eclogite is an important process in determining the rheological structure and mechanical behaviour of the exhuming crust, controlling the flow of deep lithospheric material, and generating melt at upper mantle conditions, potentially contributing to syn-exhumation magmatism and growth of the continental crust[3].

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