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Decoupling of the Lu–Hf, Sm–Nd, and Rb–Sr isotope systems in eclogites and a garnetite from the Sulu ultra-high pressure metamorphic terrane: Causes and implications

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ABSTRACT

The whole-rock Hf, Sr and Nd isotope data of five high-Fe–Ti eclogites, nine high-Al eclogites, and a garnetite from the Sulu ultrahigh pressure (UHP) metamorphic terrane at eastern China were analyzed to resolve the causes for the decoupling of the Lu–Hf, Sm–Nd, and Rb–Sr isotope systems in these UHP rocks and to infer their protolith characteristics. Seven of the nine high-Al eclogites define an $^{87}Rb/^{86}Sr$–$^{87}Sr/^{86}Sr$ errorchron age of 192 ± 43 Ma (MSWD = 2.8), which is within the time span of retrograde metamorphism despite the large uncertainty. The high-Fe–Ti eclogites and garnetite, however, have low $^{87}Rb/^{86}Sr$ ratios of <0.031 with scattered $^{87}Sr/^{86}Sr$ ratios of 0.7042–0.7058. Accordingly, it is inferred that the Rb–Sr isotope system in the samples reflects the effects of processes postdating the UHP metamorphism. Despite having different constituent mineral assemblages and whole rock geochemistry, the samples, however, define a $^{147}Sm/^{144}Nd$–$^{143}Nd/^{144}Nd$ errorchron age of 232 ± 36 Ma (MSWD = 4.6). Although the uncertainty of ±36 Ma implies incomplete Nd isotope equilibrium among the samples, the large overlap between this errorchron age span and the mineral isochron ages of 245–210 Ma for the UHP metamorphism indicates the control of peak metamorphism on the Sm–Nd isotope system. The incomplete Nd isotope re-equilibration was accompanied by metamorphic modification on the Sm/Nd ratios as indicated by the U-shaped LREE patterns. The initial $\varepsilon_{Nd}(780)$ values of the protolith rocks calculated from the Sm/Nd ratios of the samples deviate from the igneous initial $\varepsilon_{Nd}(t)$–$\varepsilon_{Hf}(t)$ trend to significantly lower values, consistent with the metamorphic increase in the Sm/Nd ratios. In contrast, the Lu/Hf ratios are generally within the range for basalts and do not vary systematically with the $^{176}Hf/^{177}Hf$ ratios. The protolith $\varepsilon_{Hf}(780)$ values calculated from the Lu/Hf ratios of the samples are nearly identical to the initial $\varepsilon_{Hf}(t)$ values of the ~780 Ma magmatic zircon cores from the Yangtze craton, suggesting the dominance of protolith characteristics on the Lu–Hf isotope system. Being controlled by different processes, the Rb–Sr, Sm–Nd, and Lu–Hf isotope systems of the investigated samples are therefore decoupled. The $\varepsilon_{Nd}(220)$–$\varepsilon_{Hf}(220)$ compositions of the samples deviate from the $\varepsilon_{Nd}(t)$–$\varepsilon_{Hf}(t)$ trend of intraplate lavas to high $\varepsilon_{Hf}(220)$ at a given $\varepsilon_{Nd}(220)$ and are within the arc lava field. The protolith $\varepsilon_{Nd}(780)$–$\varepsilon_{Hf}(780)$ compositions calculated from metamorphic initials using igneous Sm/Nd and Lu/Hf ratios show a similar distribution pattern, strengthening the arc affinity of the eclogites. These arc signatures together with the felsic–mafic bimodal geochemical features of the UHP rocks from the Sulu terrane are explained as the characteristics of protoliths generated by backarc rifting.

1. Introduction

Radiogenic isotope systems in metamorphic rocks are keys to date metamorphism. They also provide constraints on protolith characteristics and compositional changes during metamorphism. For the ultrahigh-pressure (UHP) metamorphic rocks from the Dabie–Sulu terrane in eastern China, fruitful mineral isochron data have led to vigorous discussion on the models of metamorphic history (e.g., Chavagnac and Jahn, 1996; Li et al., 1993, 1999, 2000; Schmidt et al., 2008; Zhao et al., 2006). Moreover, the Nd, Sr and O isotope compositions of the minerals in the Dabie–Sulu UHP rocks have been used to evaluate isotope equilibrium/dis-equilibrium and the associated controlling factors (Chen et al., 2007a; Wang et al., 2010; Xie et al., 2004, 2006; Zheng et al., 2002). In contrast, whole-rock isotope systems have not been as intensively investigated for geochronological purposes mainly due to isotope disequilibrium between peak metamorphic and retrograde phases (e.g., Li et al., 1999, 2000). More frequently, whole-rock radiogenic isotope data, especially metamorphic initial ε_{Nd} values, have been used to identify the nature of protoliths (e.g., Jahn, 1999).

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Protoliths with a continental affinity have led to models that postulated subduction of light continental crust to UHP conditions and its exhumation back to surface (e.g., Chavagnac and Jahn, 1996; Ernst et al., 1997; Fan et al., 2004; Wang et al., 2005). However, protoliths formed from intra-continental rifting and subduction magmatisms cannot be readily distinguished by metamorphic initial ε_{Nd} alone, hampering the reconstruction of the tectonic evolution. Being less mobile, the whole-rock Lu–Hf isotope system might better preserve protolith characteristics. In addition, the difference in the ε_{Nd}–ε_{Hf} compositions between subduction- and rift-related magmatisms (Vervoort et al., 1999) has the potential to distinguish the protoliths originated in these different settings (Ker et al., 2015). Nevertheless, in the Dabie–Sulu eclogites the whole-rock Lu–Hf isotope system and its relationship with other radiogenic isotopes have not been thoroughly investigated.

In addition to elucidating protolith characteristics, whole-rock ages and radiogenic isotopic data, which represent time-integrated variations in daughter/parent element abundance ratios, can be combined with mineral isochron ages and trace element variations to reveal the processes that caused element fractionation (e.g., Hoffmann et al., 2011; John et al., 2004; Martin et al., 2010; Polat et al., 2003; Xia et al., 2008). Despite this advantage, such an approach has not been applied to the Dabie–Sulu metamorphic terrane.

In this contribution, we report Hf isotope data for five high-Fe–Ti eclogites, nine high-Al eclogites and a garnetite from the Sulu UHP metamorphic terrane. Combining these Hf isotope data with the documented Sr and Nd isotope ratios and trace element variations, we discuss (1) the causes for the decoupling of the Rb–Sr, Sm–Nd, and Lu–Hf isotope systems, (2) element fractionation during the UHP metamorphism, and (3) the tectonic environment for protolith generation.

2. Geological and geochronological background

The Sulu terrane in east-central China is the eastern extension of the Qinling–Dabie orogenic belt (Fig. 1, upper insert) formed by the convergence between the North China and Yangtze cratons during early Mesozoic. This ~2000 km orogenic belt was subsequently disrupted by the NE-trending Tanlu fault that offsets the Sulu terrane ~500 km northward into its present position (Fig. 1, lower insert). The Sulu terrane is bounded by the Wulian–Qingdao–Yantai Fault (WQYF) in the northwest and by the Jiashan–Xiangshui Fault (JXF) in the southeast (Fig. 1, lower insert).

The Sulu terrane mainly consists of quartzofeldspathic gneisses, migmatites and granitoids, with minor but widespread eclogites, amphibolites, ultramafic rocks, marbles and quartzites. It is divided into the northern UHP and southern high-pressure (HP) metamorphic zones (e.g., Liu et al., 2004; Fig. 1, lower insert). The UHP zone is characterized by coesite-bearing eclogites and serpentinized peridotites occurring as layers, blocks, and nodules in gneisses, schists, and marbles (e.g., Kato et al., 1997; Zhang et al., 1995). The relationship between the UHP eclogites and their host rocks has long been debated. Early researchers suggested that the UHP eclogites and their country rocks were metamorphosed at different P–T conditions and then juxtaposed by faulting due to a lack of evidence of UHP metamorphism in the country rocks (e.g., Smith, 1988). Later, the observation of structural coherence through many eclogite-host rock contacts and the discovery of tiny coesite inclusions in gneisses, dolomites, and quartzites led to models postulating a common evolution for the UHP eclogites and their host rocks (e.g., Carswell et al., 2000; Schertl and Okay, 1994; Zhang and Liou, 1996). P–T estimations on equilibrium mineral assemblages in

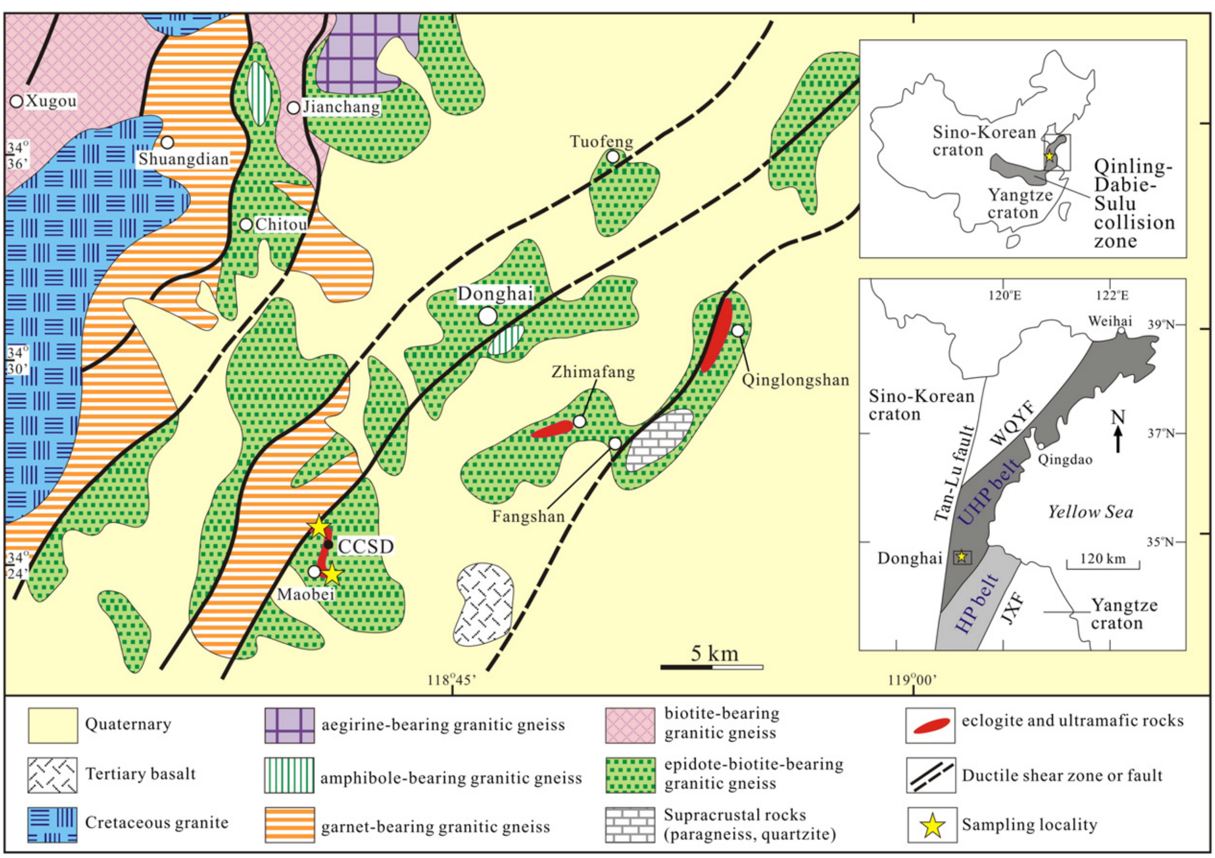

Fig. 1. A simplified geological map (modified after Chen et al., 2007b) showing the major lithologic units and eclogite outcrops near the Donghai County in the Sulu metamorphic terrane at eastern China (the rectangular area in the upper insert). The two stars indicate sampling localities, which are ~1000 m southeast and ~300 m northwest of the CCSD site (34°25′N, 118°40′ E). The lower insert shows the UHP and HP belts and fault systems (Tanlu fault, WQYF, and JXF) bounding the Sulu metamorphic terrane.