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Crustal large-scale serpentinized mantle peridotite body in the Sulu ultrahigh-pressure metamorphic belt, eastern China: Evidence from gravity and magnetic anomalies

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ABSTRACT

From analysis of the geological and geophysical data (gravity, magnetic, seismic and petrophysics), we propose that geophysical anomalies are produced by a serpentinized mantle peridotite body (SMPB) situated in the middle to lower crust in the Sulu Belt. The SMPB was formed by crustal emplacement of mantle peridotites accompanied by ultrahigh-pressure (UHP) metamorphism. Our finding suggests an emplacement mechanism for the serpentinized mantle wedge (SMW), early in the subduction process. This is different from the classic view, which holds that the serpentinized forearc mantle is formed by in situ hydration processes (Blakely et al., 2005). The petrophysical properties of the SMPB are similar to those of the serpentinized forearc mantle or SMW in modern subduction-zones worldwide, but the formation mechanisms for SMPB and SMW are different. This observation is important for understanding the geodynamic processes that operated in the large UHP metamorphic belt in the Dabie-Sulu area, eastern China.

1. Introduction

The emplacement of ultra-high-pressure (UHP) rocks in the upper–middle crust of the orogen makes it difficult to reconstruct their tectonic histories (Butler et al., 2011). This has motivated the development of a novel method to reconstruct the history of exhumation of UHP rocks in subduction zones. Serpentinization of the forearc mantle is widely thought to be common in zones of continent–oceanic collisions (Suyehiro et al., 1996; Bostock et al., 2002; Brocher et al., 2003; Blakely et al., 2005). Petrological models suggest that dehydration of subducting slabs during metamorphism releases water that serpentinizes the overlying forearc mantle. The presence of SMWs is indicated by prominent geophysical anomalies, including low velocity, high Poisson's ratio, low density, high magnetic anomalies and high electrical conductivity (Toft et al., 1990; Suyehiro et al., 1996; Kamiya and Kobayashi, 2000; Bostock et al., 2002; Brocher et al., 2003; Blakely et al., 2005; Tetsuzo, 2005; Soyer and Unsworth, 2006). Serpentinized forearc mantle has been reported from 12 to 120 km depth in several subduction zones including the Aleutian trench (Fliedner and Klemperer, 1999), central Andes (Myers et al., 1998), Cascadia (Bostock et al., 2002), Izu-Bonin-Mariana (Suyehiro et al., 1996; Takahashi et al., 1998; Tibi et al., 2008), and central Japan (Kamiya and Kobayashi, 2000). Serpentinized forearc mantle is interpreted as the cause of deep-seated magnetic highs and associated gravity lows in some subduction zones and this feature is important for the study/analysis of the deep geodynamics of these zones (Blakely et al., 2005).

Serpentinization leads to a significant reduction in rock density, which is very important for buoyancy (Pilchin, 2005). Magnetization of peridotites is acquired during the serpentinization process, which involves the reaction of the silicate minerals of peridotites (mostly olivine) with water to produce serpentine and magnetite (Carlut and Horen, 2007). Exhumation is widely recognized as the main geological process leading to the appearance of UHP rocks and low-temperature metamorphic rocks at the Earth's surface (Guillot et al., 2001; Pilchin, 2005; Ernst, 2006; Xu et al., 2009). However, there is still a lack of systematic studies of the relationships

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between serpentinization in the forearc mantle (or mantle wedge and mantle peridotite bodies) and the exhumation of the HP-UHP metamorphic rocks within large-scale continent–continent collision zones (Hermann et al., 2000).

In this paper, we propose a new model for the crustal emplacement of a large-scale SMPB, using gravity and magnetic anomaly models to study the relationship between SMPB and exhumation of the HP-UHP metamorphic rocks in the Sulu UHP metamorphic belt, eastern China.

2. Geological background

The Sulu-Dabie orogen is one of the world's largest UHP metamorphic belts (e.g., Xu et al., 2009). It formed by the collision of the Yangtze Craton with the North China Craton in the Triassic (Ames et al., 1993), resulting in northward deep subduction. It contains abundant 'orogenic' peridotitic bodies (Fig. 1) (Yang and Jahn, 2000; Zhang et al., 2000; Zheng et al., 2005). The UHP peridotitic bodies represent ultramafic magmas or cumulates intruded into the lower crust and subsequently subjected to UHP metamorphism during collision and the subduction of the continental slab (Yang and Jahn, 2000). These peridotites, such as those from Zhimafang and Xugou in the Sulu UHP metamorphic belt (Zhang et al., 2000, 2003) were initially derived from the upper lithospheric mantle (or mantle wedge), and at least some of them (i.e., the Zhimafang peridotites) have experienced high-pressure (HP) or UHP metamorphism during the Triassic collision of the North China and Yangtze cratons (Ye et al., 2009). The southern Sulu tectonic slice (UHP_S) is composed of high-pressure (HP), very high pressure (VHP) and ultrahigh pressure (UHP) metamorphic rocks, mainly supracrustal gneiss and granite gneisses intercalated with eclogites and ultramafic lenses.

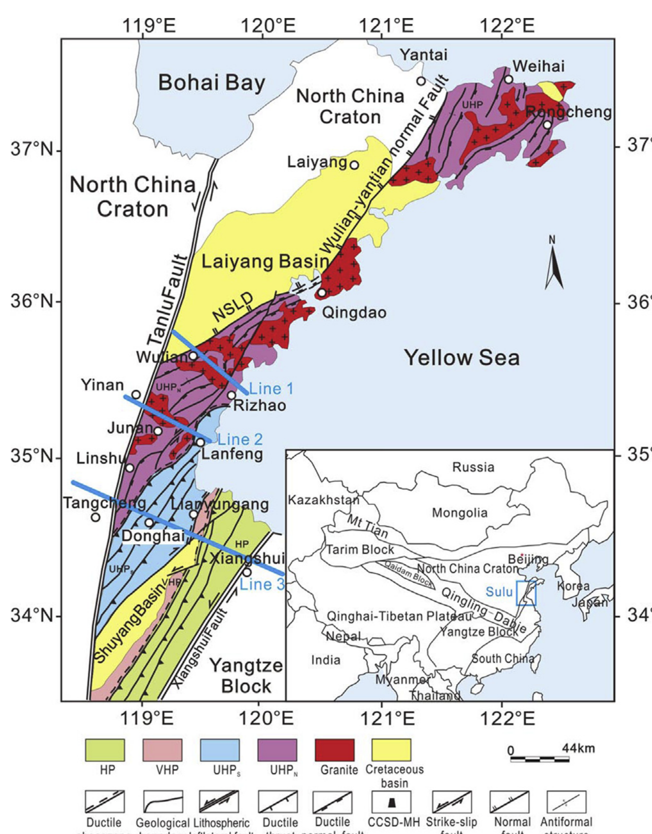

Fig. 1. Generalized geological map of the Sulu subduction zone (Xu et al., 2009).

The northern Sulu UHP tectonic slice (UHP_N) is dominated by granite gneiss (Fig. 1) (Zhou C. and Zhou G., 2003; Xu et al., 2009).

3. Geophysical observations

3.1. Gravity and magnetic measurements

In aeromagnetic and gravity anomaly maps of eastern China, we find prominent gravity and magnetic anomalies that are associated with the fossil Sulu subduction zone (Wu, 2001) (Figs. 1 and 2). Magnetic anomalies, that are higher than 200 nT with background values generally lower than 100 nT (Fig. 2a), and low-gravity anomalies, commonly from −15 to 5 mGal (on a background value >10 mGal) (Fig. 2b) mainly occur in the northern Sulu UHP metamorphic belt (label UHP_N). The observed gravity and magnetic anomalies reflect superposition of the field source observed from different depths and scales. Therefore, the reliability of data interpretation largely depends on the separation of field sources with different scales. Magnetic and gravity anomalies with intermediate wavelengths (<100 km) extracted by matched filtering are shown in Figs. 3 and 4. Prominent high-magnetic and low-gravity anomalies overlap in the UHP metamorphic zone (Figs. 1, 3 and 4). Syberg (1972) first applied the matched filter to study this process. Fourier-domain filters have been developed to separate the magnetic field of a thin, shallow layer with azimuth-dependent power from the magnetic field of a deeper magnetic half-space having different azimuth-dependent power. Using the frequency spectrum analysis method, the average depth of the large-scale deep-seated field source has been calculated to be approximately 20 km. In the southern part of the Sulu UHP metamorphic belt (label UHP_S), the specific magnetic and gravity anomalies are more complex than those of UHP_N, probably because of the presence of eclogites with higher densities and different magnetic signatures underlying the subduction zone (Fig. 1 and Table 1) (Liu et al., 2007, 2009, 2010, 2012).

3.2. Physical properties of rocks

Magnetic rocks from both surface exposures and the Chinese Continental Scientific Drilling main holes (CCSD-MH) in the Sulu UHP metamorphic belt consist of serpentinized garnet peridotites, various gneisses, eclogites (including both fresh and partially-retrogressed eclogites) and mafic basement of the North China Craton. Granite, various gneisses and serpentine have low densities (generally <3.0 g cm^{-3}), while the densities of the various eclogites are commonly higher than 3.0 g cm^{-3} (Table 1) (Liu et al., 2009; Yang, 2009). However, strong magnetization has been observed in a small number of serpentinized garnet peridotites and eclogites with exsolved lamellar textures (Table 1) (Liu et al., 2010, 2012). In 0–2050 m of the CCSD-MH, eclogites and orthogneisses comprise the principal lithological type, which makes up around 83% of the entire hole; other rock types comprise paragneiss, ultramafic rock (i.e., serpentinized garnet peridotite, about 3%) and, rarely, schist and quartzite (Zhang et al., 2006). All crustal rocks contribute to the gravity and magnetic anomalies in study area. The main objective of this paper is to identify which aspects of the regional gravity and magnetic anomalies reflect the presence of the SMPB in the crust of the Sulu UHP metamorphic belt.

4. Geophysical model

In the Sulu area, seismic reflection profiles crossing the CCSD-MH site at the UHP_S, and Boli to Zhucheng located at UHP_N, have revealed a fine structure from the upper to middle crust. However, it does not provide information on the presence of SMPB (Yang,