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Serpentinization of the fore-arc mantle along the Taiwan arc-continent collision of the northern Manila subduction zone inferred from gravity modeling

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ABSTRACT

Serpentinized peridotite in the fore-arc has been observed in a number of subduction zones, including the northern Manila subduction zone which terminates northward in the Taiwan arc-continent collision. How this zone of serpentinization changes northward from the subduction of thinned continental lithosphere to full arc-continent collision in the Taiwan orogeny is not well known. In this paper we present 2-D gravity modeling along three P-wave (Vp) transects across the Taiwan orogeny. Two of these transects were collected with ocean-bottom seismometers. These two transects provide good constraints on the velocity structure to the west of, and on land, southern Taiwan. Conversion of Vp to density in this area allows us to model the gravity anomaly with very little misfit. Along the subduction zone, however, the velocity models are poorly constrained in the upper mantle, where an anomalous density unit has to be used in order to model the short wavelength gravity anomaly in this area. A third transect across central Taiwan that is derived from the TAIGER local tomography data, provides good control on the crust and upper mantle Vp structure that we use to place provide density constraints for modeling the gravity anomaly in this part of the collision zone. In order to model the short wavelength gravity anomaly across the Longitudinal Valley and the southern Longitudinal trough, an anomalous density block is required beneath the fore-arc region. We interpret that the source of this anomalous density material could be serpentinized fore-arc mantle, similar to what is interpreted for the northern Manila subduction zone farther south. Water released from the subduction of the extended crust of the continental margin results in the serpentinization of the fore-arc area and may be driving the uplifting of the high-pressure rocks.

1. Introduction

A wide range of geophysical and geological data indicate that serpentinization of the fore-arc mantle wedge is a common feature of many subduction zones worldwide (Bostock et al. 2002; Hyndman and Peacock 2003). To identify serpentinization in the fore-arc mantle region of subduction zones, velocity and density modeling provide useful tools for determining both the presence and the amount of serpentine that is present (e.g., Xia et al. 2015; Zhao 2012; Hacker et al., 2003). This is aided by laboratory measurements that illustrate a significant reduction in the seismic velocity and density of peridotite with an increase in the modal abundance of serpentine (Christensen 1966, 2004; Horen et al. 1996; Hyndman and Peacock 2003) (Fig. 1).

In the northern Manila subduction zone, where the thinned continental crust of the Eurasia Plate (EUP) margin is subducting below the northern Luzon arc on the Philippine Sea Plate (PSP), forward gravity modeling along two TAIGER transects (T1 and T2) led Doo et al. (2015) to interpret an area of relatively high density materials in the fore-arc region. The relatively higher density of this area compared to the overlying fore-arc and its lower density compared to the adjacent mantle led Doo et al. (2015) to interpret this observation as a partly serpentinized mantle that is being exhumed along the subduction interface. Farther north, where the full thickness of the continental crust is now in the subduction zone (Chen et al. 2004; Lin 2009), an area of relatively high Vp below the fore-arc has also been interpreted to be serpentinized mantle (Van Avendonk et al. 2014) or a combination of this lithology and mafic eclogite that are being exhumed along the subduction zone (Brown et al. 2015). This area of high Vp is also marked by a short wavelength low in the free-air anomaly that extends from the northern part of the Longitudinal Valley into the southern Longitudinal trough offshore southeast Taiwan (Fig. 2). 2D forward gravity modeling across the Taiwan arc-continent collision adds new constraints to the interpretation of the material in the fore-arc region that

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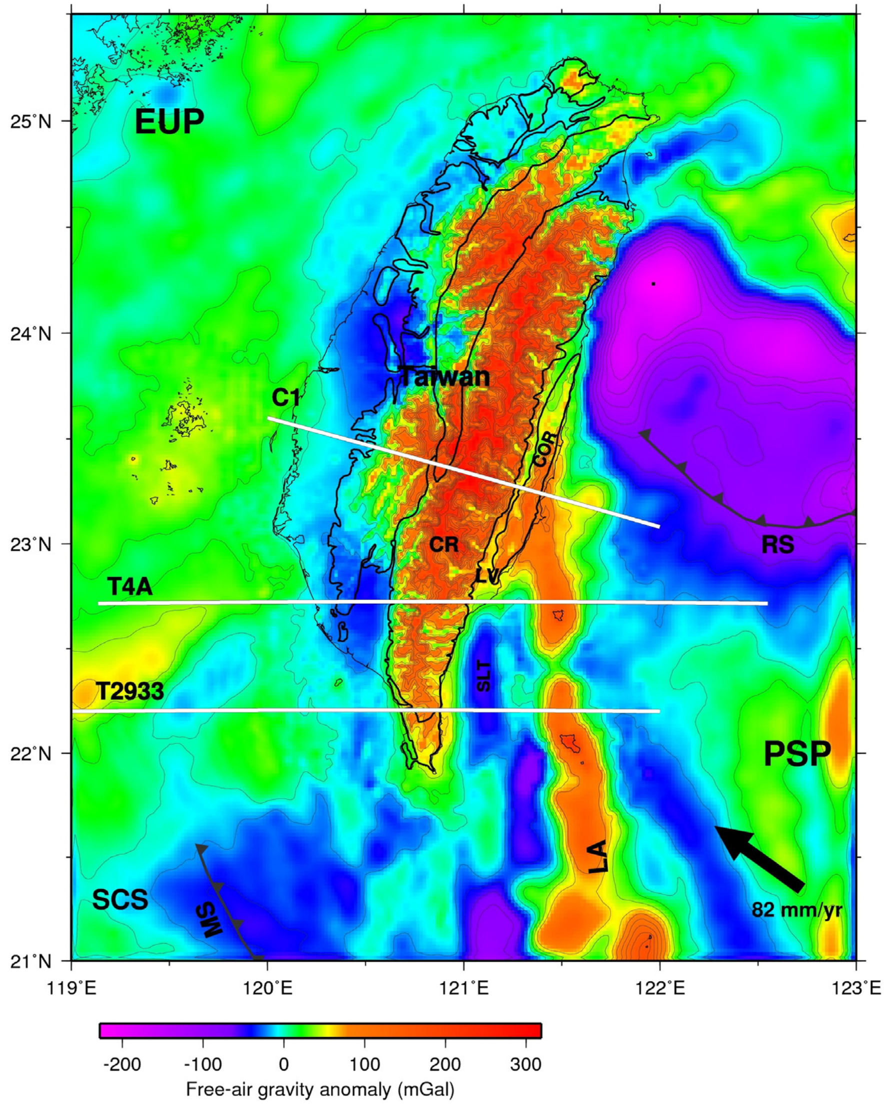

Fig. 1. Free-air gravity anomaly map (Hwang et al. 2014) of the Taiwan region. The black arrow indicates the relative plate motion. The locations of 2-D gravity modeling transects shown in Figs. 2, 3 and 4 are indicated by thick white lines labeled T2933, T4A and C1. Abbreviations - CR: Central Range; COR: Coastal Range; EUP: Eurasia Plate; LA: Luzon arc; LV: Longitudinal Valley; MS: Manila subduction zone; RS: Ryukyu subduction zone; PSP: Philippine Sea Plate; SLT: southern Longitudinal trough; SCS: South China Sea.

is causing this low and strengthens the interpretations based on the velocity structure.

In this paper we present the results of 2-D gravity modeling along three velocity transects that cross the central and southern Taiwan (Fig. 2) with the goals of better constraining the shallow lithological structure of the fore-arc region in eastern Taiwan and subsequently investigating the possible implications of serpentinite in the exhumation of mantle and high-pressure rocks from the northern Manila subduction zone to the Taiwan arc-continent collision.

2. Tectonic background

The Taiwan orogen is forming as a result of the subduction of the EUP continental margin beneath the Luzon arc on the PSP along the northernmost part of the Manila Subduction zone (Fig. 1). The convergence between these two plates is roughly northwestward. Of interest to this paper, the contact between the two colliding plates in eastern Taiwan is a zone of oblique faulting, with the exhumation of high-pressure rocks, parts of the volcanic arc, and partially serpentinized mantle taking place since the Late Miocene (Beyssac et al. 2008). In the geophysical data sets, this is marked by a velocity high that extends eastward to at least 50 km beneath the Luzon arc (Huang et al. 2014). A tight clustering of seismicity is observed along the upper margin of this velocity high that extends to the Moho beneath the arc. In addition, a short wavelength gravity low is found across this area. Modeling this low can provide further insights into the possible composition of the rocks along the shallow part of the subduction interface as well as the processes occurring there.

A number of studies have used either active-source or earthquake seismic data to produce P-wave seismic velocity images of Taiwan and its surrounding oceans (Hetland and Wu 1998; Kim et al. 2006; McIntosh et al. 2005; Wu et al. 2007; Kuo-Chen et al. 2012; Huang et al. 2014). Several tomography studies (Lin et al. 1998; Kuo-Chen et al. 2012; Van Avendonk et al. 2014; Huang et al. 2014) have shown that there is a high-velocity zone present in the crust of the Central Range and in the crust and upper mantle beneath the Luzon arc. Lin et al. (1998) and Lin (2002) interpreted these high-velocity zones to be the same feature and to be related to crustal exhumation. This feature was interpreted by McIntosh et al. (2013) to be accreted transitional crust (ATC) within the Central Range of the orogen. However, due to poor resolution of the velocity model in the deeper part of the Central Range and fore-arc region, McIntosh et al. (2013) could not interpret the structure in these areas. In other interpretations, Cheng (2009), for example, found two prominent high-velocity areas in the middle to lower crust

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