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Crustal thickness variation from a continental to an island arc terrane: Clues from the gravity signatures of the Central Philippines

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ABSTRACT

Offshore and ground gravity data were utilized to estimate crustal thickness across the Central Philippines where a transition from continental to island arc terrane occurs. Significant differences in gravity anomalies were observed between the Palawan Microcontinental Block (PCB) and the Philippine Mobile Belt (PMB), two major terranes that came together through arc-continent collision. Islands of the PCB (Mindoro, Tablas, Romblon, Sibuyan and western Panay), made up of an assortment of continent-derived sedimentary and igneous rocks and slivers of ophiolitic bodies, register lower Bouguer anomalies compared to that displayed by Masbate Island in the PMB. The calculated crustal thickness of this region exhibits a complex Moho topography of non-uniform depth across the collision zone with the thickest parts (~32 km) corresponding with ophiolitic units emplaced consequent to arc-continent collision. On the other hand, relatively thinner crust (~21 km) within the collision zone coincides with areas surmised to have undergone attenuation following intra-arc rifting. The same characteristics are observed offshore of western Mindoro and within the Marinduque Basin, areas known to have experienced crustal thinning following regional tectonic rearrangements that triggered riftings and intra-basin openings.

1. Introduction

Several studies about the thickness of the Earth's crust have been carried out to determine the rate and mechanisms governing crustal growth (e.g. Dimalanta et al., 2002; Tirel et al., 2004; Pamukçu et al., 2007). Differences in crustal thickness are also reportedly related to the prevailing stresses in the lithosphere (e.g. Kusznir and Park, 1987; Zoback, 1992). The most recent crustal thickness model by Mooney et al. (1998) is based on seismic refraction measurements with sediment and ice thickness corrections. This model, however, has a resolution of 5°, hence, additional data acquired at local scales are better for crustal thickness studies of complex tectonic regimes.

According to the Crust 5.1 model of Mooney et al. (1998), the thickest portion of the Earth's crust is ~70 km calculated over the Himalayas, while the thinnest part is recorded along mid-oceanic ridges, at approximately 6 km. For the Philippines, a 23 km-thick crust was calculated at N12°/E120° to N12°/E122°, where the crust is considered to be part of the continental slope. Further east, at N12°/E124°, the crustal material is of island arc type with an estimated thickness of 31 km.

The composition of crustal materials in the Philippine archipelago greatly varies from continental fragments in the west to island arc materials in the east. Furthermore, differently-aged crust-mantle rock sequences are emplaced on different islands (e.g. Rangin et al., 1985; Pubellier et al., 2004; Yumul et al., 2009, 2013). These complexities translate to difficulties in the interpretation of the archipelago's subsurface configuration.

Previous studies of crustal thickness in the Philippines calculated from available geophysical and geochemical data show that the archipelago is underlain by a 25–29 km-thick crust (Dimalanta and Yumul, 2003). In this model, local crustal thickening is defined along magmatic arcs, where the crust extends up to 65 km. However, with the compilation of more recent data, crustal thickness of the archipelago is found to range from 12 km to 32 km (Fig. 1A). This result is consistent with the Moho depth of 18–34 km reported by Besana et al. (1995) in south Luzon using shear-wave velocity studies. It is also in good agreement with

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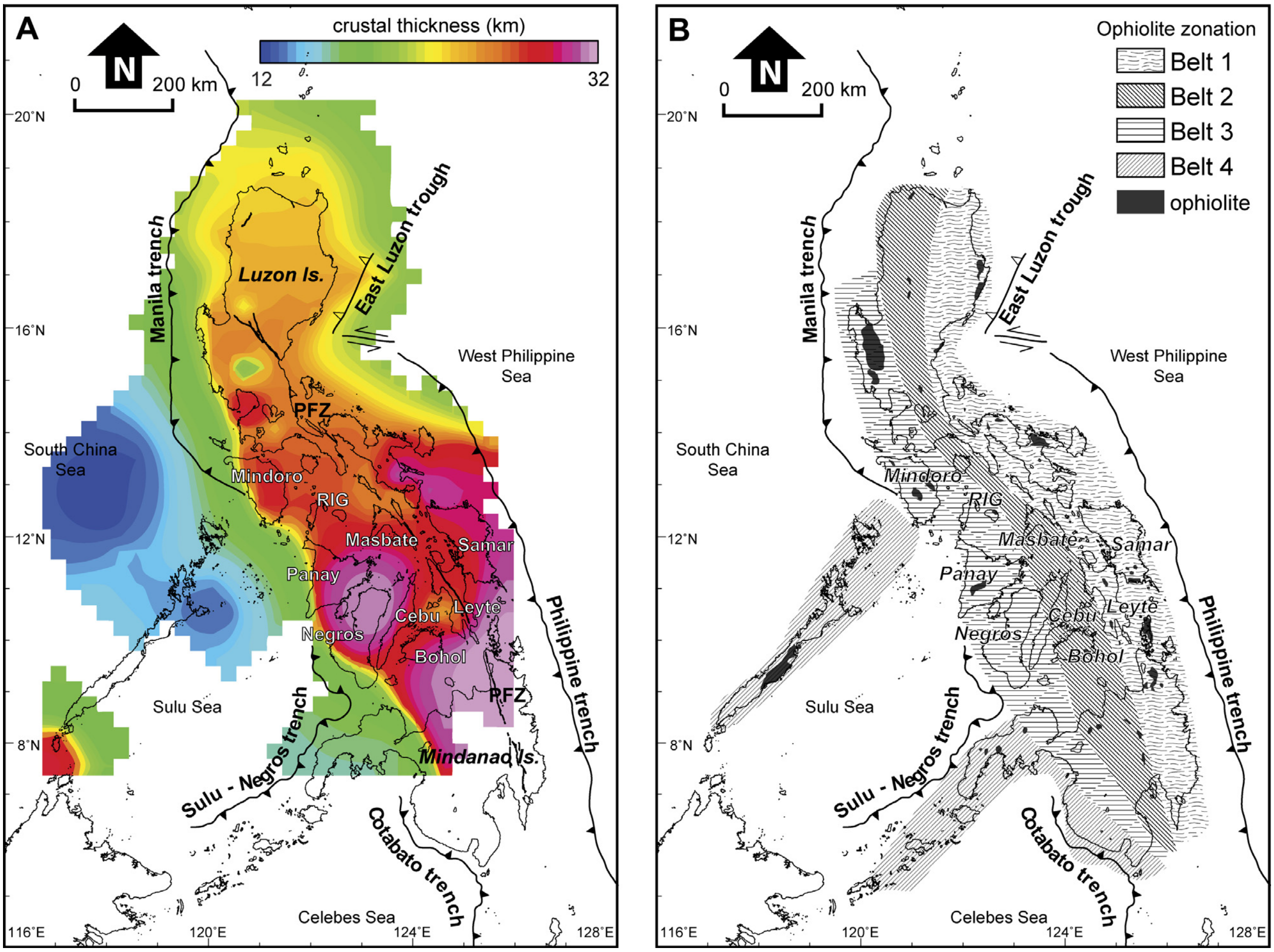

Fig. 1. A. New crustal thickness map which incorporates onshore geophysical and geochemical data showing regional thickening towards the southeast. B. Regional tectonic setting of the Philippines. The Philippine island arc is bounded by oppositely dipping subduction zone systems, with a left lateral strike-slip fault traversing the whole archipelago. Active faults and the Philippine Fault Zone (PFZ) are from Tsutsumi and Perez (2013). Philippine ophiolites are classified based on spatial and temporal relationships (modified from Yumul, 2007).

the ~20 km faulting depths from earthquake data and geodetic inversions carried out by previous studies (Beavan et al., 2001; Silcock and Beavan, 2001). However, a major concern in previous studies is that geophysical information is almost entirely based on on-land information alone. The incorporation of crustal thickness data from surrounding marginal basins would give a better and more complete picture of the crustal structure.

Arc-magmatism and different mechanisms of ophiolite emplacement have contributed to the crustal growth of the Philippine archipelago (Dimalanta and Yumul, 2006). At present, the collision of the Palawan Microcontinental Block (PCB) with the Philippine Mobile Belt (PMB) allows the continuous addition of crustal materials (Stephan et al., 1986; Rangin et al., 1988). The effects of this arc-continent collision are mostly observed in the western islands of the Central Philippines, such as Mindoro, Tablas, Romblon, Sibuyan and Panay, where the emplacement of ophiolites has been related to the collision (e.g. Rangin et al., 1985; Dimalanta et al., 2009; Gabo et al., 2009) (Fig. 1B). Yumul (2007) classified the Philippine ophiolites with respect to their observed temporal and spatial relationships. According to this classification, the Amnay Ophiolite exposed in Mindoro Island belongs to Belt 4, which corresponds to ophiolite complexes emplaced along continental margins. The Sibuyan Ophiolite in Sibuyan Island and the Antique Ophiolite in western Panay belong to Belt 3, which is defined by Cretaceous through Eocene to Oligocene ophiolite complexes emplaced along the arc-continent collision zone. The extent of this collision zone has varied as more data were gathered throughout several years of study (e.g. Rangin et al., 1985; Faure et al., 1989; Yumul et al., 2003; Dimalanta et al., 2009). The most recent findings indicate that the islands of Mindoro, Tablas, Romblon, Sibuyan and the western part of Panay are part of this continental terrane.

Ophiolites in the Central Philippines are not limited to those that were emplaced during the arc-continent collision. In Masbate Island, east of Sibuyan, the Balud Ophiolitic Complex was mapped. Using the classification of Yumul (2007), the Balud Ophiolitic Complex belongs to belt 2 ophiolites which are characterized by Early to Late Cretaceous dismembered units. Belt 1 ophiolites, which are exposed in the easternmost part of the Philippines, are characterized by complete ultramafic–mafic sequences with associated metamorphic soles. Examples of these ophiolites are the Malitbog Ophiolite in southern Leyte, Tacloban Ophiolite in northern Leyte and the Samar ophiolite in southern Samar (Florendo, 1987; Suerte et al., 2005; Dimalanta et al., 2006) (Fig. 1B).

The juxtaposition of the collision-related ophiolites with the non collision-related ophiolitic units indicates the transition from a continental to an island arc terrane. The understanding of the subsurface configuration of this transition is integral to the tectonic models that are being constructed in the region. In this study, we investigate the subsurface geometries across the islands of the Central Philippines using gravity techniques. The extent of crustal growth and its variation across the region will also be related to its geology and tectonic history.