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Geothermal structure of the Miura–Boso plate subduction margin, central Japan

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ABSTRACT

We have constrained the geothermal structure of the Miura–Boso plate subduction margin, located in central Japan, using maximum paleo-temperature data derived from vitrinite reflectance measurements. We established that higher maximum paleo-temperatures are restricted to the western part of the early Miocene Hota accretionary complex (Hota and Hayama groups), indicating a spatial difference in the amount of slip upon the out-of-sequence thrust potentially associated with the Izu–Bonin Island Arc collision. The weakly deformed sedimentary sequences overlying the highly deformed Hota Group strata have much lower vitrinite reflectance values than the latter. This variation indicates that the sedimentary sequences of the trench slope experienced a markedly lower maximum burial depth than the relatively deep-buried and uplifted Hota accretionary complex. Conversely, maximum paleo-temperatures obtained for tectonic blocks hosted by the neighboring Mineoka ophiolite complex are very high: ca. 140 °C for the large, early Miocene Haccho Formation blocks, and 65–90 °C for the other blocks. This result suggests that the individual tectonic blocks enclosed in the ophiolite complex were subjected exhumation from depths of 3–5 km.

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1. Introduction

The study of modern plate subduction margins deals with the processes of their formation, their architecture, the evolution of physical properties of margin rocks during tectonic loading, and fluid–rock interaction (e.g. Karig, 1986; Moore, 1989; Maltman et al., 1993; Moore et al., 1998). Recent ocean drilling research has focused on earthquake-related phenomena, such as frictional heating associated with seismic slip near the seafloor (Sakaguchi et al., 2011; Yamaguchi et al., 2011; Fulton et al., 2013), other frictional properties associated with seismic slip (Tsutsumi et al., 2011; Ujiie et al., 2013), the stress drop (Lin et al., 2011, 2013), and the decrease of effective pressure along a shallow plate interface (Tanikawa et al., 2013). As it is difficult to evaluate the lateral variations in these structural and physical properties in drillcore alone, research has focused on land-based structural complexes associated with subduction margins, such as accretionary prisms. Examples include the Shimanto, Kodiak, and Franciscan accretionary prisms (e.g. Sample and Moore, 1987; Ujiie, 2002; Meneghini and Moore, 2007; Rowe et al., 2009; Yamaguchi et al., 2014). Nevertheless, the effects of subsequent mechanical overprinting and metamorphism mean that many of these land-based complexes have lost the initial structural features and physical properties typical of sediments that make up the shallow part of the accretionary prism.

In this respect, the accretionary complex and forearc system exposed on land on the Miura and Boso peninsulas, central Japan, is particularly interesting, as it is young and unmetamorphosed. The early Miocene and late Miocene to Pliocene accretionary complexes exposed in this area still contain 30%–50% of their initial porosity and low *P*-wave velocity structures (Yamamoto, 2006). Based on its age and physical properties, the Miura–Boso subduction margin is considered to be an onland analogue of the Nankai accretion-style subduction margin. Previous research on the Miura–Boso subduction margin focused on primary deformation and the resulting evolution of physical properties (Yamamoto, 2006), the intensity of frictional heating associated with ancient seismic rupture near the seafloor (Kameda et al., 2013), and experimental studies of the relation between deformation style and sediment characteristics in the shallow versus deep parts of the system (Gadenne et al., 2014; Schumann et al., 2014). These studies were conducted using onland samples and the results were subsequently compared with the results of ocean drilling programs.

Although the Miura–Boso subduction margin is a suitable region to study with the aim of developing a space–time model of a subduction zone, its genesis and detailed geological architecture are not yet fully understood. In this paper, we present the maximum paleo-temperatures for each geological unit of the margin, in order to constrain its tectonic

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history and place in a broader context the plate subduction and island arc collision that occurred in this area.

2. Geological setting

The current tectonic setting of central Japan consists of two discrete subduction systems. The Philippine Sea Plate (PHS) is being subducted beneath the North America (NAP)/Eurasia Plate (ERP), and the Pacific Plate (PAP) is being subducted beneath both of these (Fig. 1A). The Izu–Bonin island arc, hosted by the Philippine Sea Plate, collided with the Honshu arc, producing a northward bending and rapid uplift of the latter (e.g., Koyama and Kitazato, 1989; Yamamoto and Kawakami, 2005). As a result, young unmetamorphosed sedimentary sequences that occur in these subduction systems (e.g., accretionary complex, forearc basin, and trench–slope basin) have been rapidly uplifted and exposed on the Miura and Boso peninsulas of central Japan (Fig. 1B).

The Mineoka ophiolite complex divides the Miura and Boso peninsulas into two broad areas of contrasting geology. To the north of the complex lies a post-middle-Miocene forearc basin (Mitsunashi et al., 1979; Nakajima et al., 1981; Nakajima and Watanabe, 2005) composed of the middle Miocene to upper Pliocene Miura Group in its southern part, and the upper Pliocene to Pleistocene Kazusa Group in its northern part (Nakajima and Watanabe, 2005). The two areas are separated by the Kurotaki unconformity (ca. 3 Ma) that formed due to a change in the movement direction of the Philippine Sea Plate (Koike, 1951; Takahashi, 2006). The area south of the ophiolite complex consists of an early Miocene to Pliocene accretionary complex and trench-slope cover sediments (Saito, 1992; Yamamoto et al., 2005; Yamamoto and Kawakami, 2005; Kawakami and Shishikura, 2006). The accretionary complex is further subdivided into the early Miocene Hota accretionary complex and the late Miocene to Pliocene Miura–Boso accretionary prism, separated by the Ishido Fault (Nakao et al., 1986; Saito, 1992). The former consists of the Hota (Boso Peninsula) and Hayama (Miura Peninsula) groups, whereas the latter comprises the Nishizaki (Boso) and Misaki (Miura) formations. The relationship between the Miura–Boso accretionary prism and the unconformably overlying trench slope sediments has been clearly identified in terms of their structural, stratigraphic, and paleomagnetic characteristics (Yamamoto and Kawakami, 2005; Kawakami and Shishikura, 2006; Yamamoto et al., 2012). However, the boundary between the Hota accretionary complex and the trench-slope cover sediments is unconstrained because of their lithological similarity. Chiyonobu et al. (in press) established a calcareous nannofossil biostratigraphy for the trench-slope sediment overlaying the Hota accretionary complex, identified significant age gaps in its deposition, and constrained its paleo-bathymetry.

The Mineoka ophiolite complex has been interpreted as a trench-slope break, which separates the forearc basin from an oceanward sedimentary basin (Soh et al., 1991). Tectonic blocks composed of ultramafic rocks, basalt, dolerite, limestone, and chert are enclosed within sheared serpentinite or sheared Hota Group sedimentary rocks (Nakajima et al., 1981; Ogawa and Taniguchi, 1987; Saito, 1992; Hirano et al., 2003; Takahashi et al., 2012). One of the larger tectonic blocks exposed in the ophiolite complex is the early Miocene Haccho Formation, which consists of alternating diagenetic shale and sandstone.

3. Geothermal analysis based on vitrinite reflectance data

The distribution of maximum paleo-temperatures in the Miura–Boso subduction margin was determined using vitrinite reflectance measurements.

3.1. Methodology

The thermal maturity of organic matter is a useful indicator of thermal history in low-temperature metamorphic settings (Middleton, 1982; Laughland and Underwood, 1993). The vitrinite reflectance value (R_O) increases exponentially with temperature and records the highest temperature experienced by organic matter (Burnham and Sweeney, 1989), reflecting also the duration of heating (Sekiguchi and Hirai, 1980; Sweeney and Burnham, 1990).

We collected 47 samples of organic matter from sandstone and siltstone in the study area (Fig. 2; Table 1). For each sample, coal fragments were separated and concentrated using heavy liquids (a sodium polytungstate solution with a specific gravity of 1.8). The separated grains were then mounted in resin and polished using 0.06-μm alumina powder. The measurements were conducted with a silicone-diode microphotometer using 546 nm non-polarized light, in line with the regulations of the International Organization for Standardization (ISO 7404-5), the American Society for Testing and Materials (ASTMD 2798-99), and the Japan Industrial Standard (JIS M 8816). A concentrated spot beam of 1.6-μm diameter was used to measure the reflectance. We measured mean random

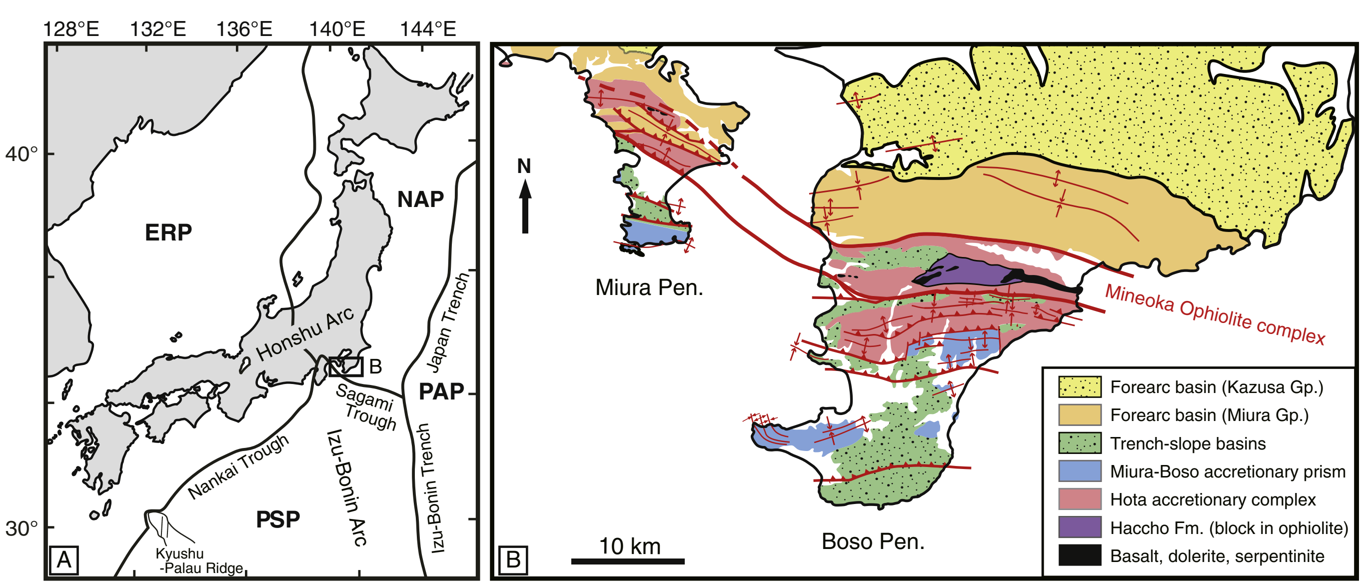

Fig. 1. (A) Tectonic setting of Japanese Islands. PAP: Pacific Plate, PSP: Philippine Sea Plate, NAP: North American Plate, ERP: Eurasia plate. The rectangle indicates the position covered by Figs. 1B and 2. (B) Geological map of the Miura–Boso subduction margin, located east of the collision zone.

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