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Three-dimensional estimate of the lithospheric effective elastic thickness of the Line ridge

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ABSTRACT

Using a new bathymetry grid formed with vertical gravity gradient anomalies and ship soundings (BAT_VGG), a 1° × 1° lithospheric effective elastic thickness (*Te*) grid of the Line ridge was calculated with the moving window admittance technique. As a comparison, both the GEBCO_08 and SIO V15.1 bathymetry datasets were used to calculate *Te* as well. The results show that BAT_VGG is suitable for the calculation of lithospheric effective elastic thickness. The lithospheric effective elastic thickness of the Line ridge is shown to be low, in the range of 5.5–13 km, with an average of 8 km and a standard deviation of 1.3 km. Using the plate cooling model as a reference, most of the effective elastic thicknesses are controlled by the 150–300 °C isotherm. Seamounts are primarily present in two zones, with lithospheric ages of 20–35 Ma and 40–60 Ma, at the time of loading. Unlike the Hawaiian-Emperor chain, the lithospheric effective elastic thickness of the Line ridge does not change monotonously. The tectonic setting of the Line ridge is discussed in detail based on our *Te* results and the seamount ages collected from the literature. The results show that thermal and fracture activities must have played an important role in the origin and evolution of the ridge.

1. Introduction

The effective elastic thickness (*Te*) is sensitive to the thermal–mechanical properties of the lithosphere under the submarine features. The study of *Te* of the lithosphere under seamounts can further our understanding of the evolutionary process of the lithosphere. According to the cooling plate model (Parsons and Sclater, 1977; Stein and Stein, 1992), the strength of the lithosphere should increase with age. Many studies have suggested that the oceanic *Te* is determined to a first order by the age of the lithosphere at the time of loading and is approximately represented by the depth of the 450 ± 150 °C isotherms (Calmant et al., 1990; Watts, 1978, 2001).

The Line ridge is a seamount chain located in the center of the Pacific Ocean, as shown in Fig. 1. The ridge has several branches, such as the Keli Ridge, which formed at nearly the same time as the main chain (Davis et al., 2002). Volcanisms along the ridge do not display linear age progressions, like the Hawaiian-Emperor chain, and can't be attributed to hot spots sustained by deep mantle plumes. The long durations of volcanism and quasi-synchronous activity over great distance call for a more complicated explanation.

Wilson (1963) argued that the seamount chains are caused by "hot spot" activity. The Hawaiian-Emperor chain is a typical example generated by the activity of a single hot spot. At present, the hot spot is situated at the southeast end of the chain. Based on the study of rough bathymetry, Morgan (1972) suggested that the Line ridge, together with the Tuamotu Islands, is a seamount chain generated by a single hot spot, similar to the Hawaiian-Emperor chain. Schlanger et al. (1984) noted that the Line ridge may have been generated by one or more hot spots based on the lithology and age of the seamounts, obtained from the Deep Sea Drilling Project (DSDP). The Line ridge may not have been produce by a single hot spot, like the Hawaiian-Emperor chain. Although the lithology of the seamounts along the Line ridge is similar to the Hawaiian-Emperor chain, there are certain significant differences. First, the geomorphology of the Line ridge is more complex than that of the Hawaiian-Emperor chain and has more distinct branches along the ridge. Second, the ages of the Line ridge seamounts are diverse and irregular.

According to the fracture zones shown in Fig. 1, as well as the magnetic anomaly data to the north of the Line ridge, Nakanishi (1993) inferred that the main chain of the ridge may be parallel to a vanished mid-ocean ridge. Winterer (1976) also suggested that the Line ridge was the product of a mid-ocean ridge. But the hypothesis that the Line ridge was constructed by the activity of a mid-ocean ridge is not

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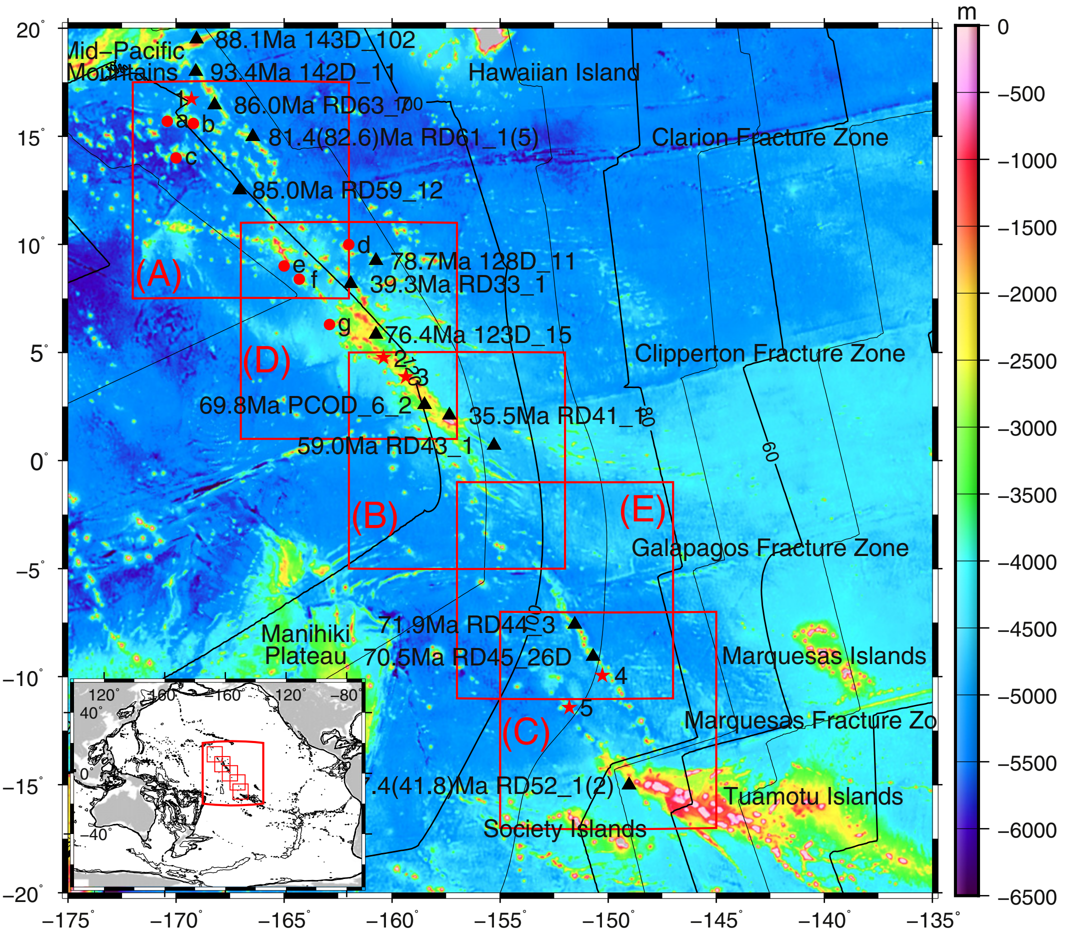

Fig. 1. A 1 × 1 minute bathymetry model created using ship soundings and vertical gravity gradient anomaly data (BAT_VGG) (Hu et al., 2014). Seafloor age data from Müller et al. (2008) are shown as contours (unit: Ma). The red boxes delineate the areas used to calculate the admittance curves in Fig. 4. Anotations: The red stars denote the islands of the Line Seamounts: 1 Johnston Atoll, 2 Washington Island, 3 Fanning Island, 4 Caroline Island, and 5 Flint Island. The red circles denote seamounts whose ages have been determined by Davis et al. (2002): a Keli Ridge West, b Keli Ridge East, c Smt.14 N 170 W, d Smt.10 N 162 W, e Smt.9 N 165 W, f S.P. Lee Guyot, and g Kingman Reef. The black triangles denote samples from Schlanger et al. (1984); the names and ages of the samples are given in the figure and details are provided in Table 3a, 3b.

supported by seafloor magnetism because most of the lithosphere under the Line ridge formed during the Cretaceous normal superchron (Atwater et al., 1993). Furthermore, the lithology of the Line ridge is similar to the Hawaiian-Emperor seamounts, and researchers have not found mid-ocean ridge basalt (Davis et al., 2002; Schlanger et al., 1984).

Despite the fact that the “hot spot” theory has been widely accepted, scholars note that “hot spots” are not the only tectonic activity that causes seafloor volcanism. Asthenospheric magma may erupt along fault zones and fracture zones caused by tensile forces. Natland (1976) argued that the generation of certain branches of the ridge may be associated with a rift in the seafloor. Lynch (1999) suggested that certain seamounts on the Pacific lithosphere may be related to tensional cracking based on the study of their geomorphology.

Based on the study of seamount ages and the lithology of the northern Line ridge, Davis et al. (2002) suggested that the formation of the Line ridge was influenced by Cretaceous super volcanic activity in the southern Pacific and argued that the multiple periods of volcanic activity along the ridge were caused by the eruption of mantle material in areas with weaker lithosphere. Zhang et al. (2006) studied the influences of fractures and Cretaceous magmatic activity on the construction of seamounts in the center of the Pacific. They suggested that fractures may weaken the local lithosphere, and magma may break through these weak zones.

To sum up: Volcanism along the Line ridge can't be explained by the hot spot theory. The morphology of the ridge may have been influenced by cracks of the lithosphere and fractures. However, these lithosphere-surface processes provide few explanations for magma generation. Ballmer et al. (2009) proposed an alternative mechanism to explain the non-hot spot intraplate volcanism. They argued that the small-scale sublithospheric convection (SSC) explains volcanism with no age progressions well. Volcanism over a “hot line” induced by SSC may continue for at least 10–20 Ma and occurs on seafloor ages of about 20–60 Ma. This mechanism reconciles quasi-synchronous eruption of seamounts over great distances along the Line ridge. Conrad et al. (2011) linked the intraplate volcanism to rapid asthenospheric shear. They find a correlation between recent intraplate volcanism and areas of the asthenosphere experiencing rapid shear by comparing the geographic distribution of intraplate volcanism with asthenospheric shear introduced by a global mantle flow model. They suggested that the driving mechanism for intraplate volcanism lies in the asthenosphere.

Because of its remote location, there have been few attempts to calculate the elastic thickness beneath the features of the Line ridge (Kalnins and Watts, 2009; Watts, et al., 2006). Kalnins and Watts (2009) introduced the moving window admittance technique (MWAT) to determine the spatial variation of *Te* in the Western Pacific, based on GEBCO_08 (General Bathymetric Charts of the Oceans) and