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Submarine lava fields in French Polynesia

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ABSTRACT

Shipboard multibeam survey is powerful tool to locate submarine volcanoes especially having small volume. Small submarine volcanoes may represent the initial stages of hotspot activity, but they may also form via lithospheric flexing, regional convection of the mantle, and the presence of fracture zones. Here we describe several volcanoes, flood lavas, and volcanic clusters in French Polynesia using data from archives of multibeam data. The clusters of small volcanoes are similar to petit-spots, and they are not considered to represent the initial stages of a hotspot as they are composed of both young and old edifices, and because the sites are located far from any known hotspot. These newly discovered submarine volcanoes are located in areas with low-velocity seismic shear waves at depths of 60 and 100 km. These lava fields will therefore facilitate geochemical mapping of the mantle in areas unrelated to hotspots, because these lavas may have developed from melts in the shallow mantle beneath French Polynesia.

1. Introduction

Hotspots are believed to develop over stationary plumes that rise from the deep mantle beneath tectonic plates (Morgan, 1971), although other explanations for their origin have been proposed, such as anti-plumes from the deep mantle. These hotspots lead to the formation of lines of seamounts and/or oceanic islands with a progressive increase in age along the direction of plate motion. However, the bathymetric characteristics and radiometric dating of seamounts are not always consistent with this simple model of a hotspot trail (Clouard and Bonneville, 2001). The Hawaiian hotspot on the Pacific plate has existed for more than 70 Myr, but its position below the plate has not remained stationary in the mantle (Tarduno et al., 2003), whereas the Louisville hotspot has been nearly stationary for 70 Myr (Koppers et al., 2012). Most seamount trails that formed in the western Pacific during the Cretaceous show short-lived progressions in age (e.g., a few millions or a few tens of millions of years; Koppers et al., 2003).

The initial phase of a hotspot volcano may be represented by small submarine volcanoes that form prior to the development of a large, possibly subaerial volcano over a hotspot, and indeed, such activity has been observed on the Loihi Seamount in the Hawaiian chain (e.g., Moore et al., 1979), the Macdonald Seamount in the Austral chain (e.g., Johnson, 1970), the Adams Seamount in the Pitcairn chain (Devey et al., 2003), and the Vailulu'u Seamount in the Samoan chain (e.g., Hart et al., 2000). Determining the location of submarine volcanoes is therefore critical to identifying possible hotspots. In addition to hotspot-related volcanoes, other new and unexpected kinds of volcano, such as petit-spot volcanoes and arch lavas, have been reported from the submarine environment, and these were first discovered on the subducting Pacific plate off northeastern Japan and on the flexural Hawaiian arch 300–500 km from the Hawaiian Islands, respectively (Holcomb et al., 1988; Hirano et al., 2006). These discoveries relied on the use of submarine acoustic surveys, which are vital for such work. Hotspot geochronology and the distribution of volcanic activity have been recorded from subaerial lavas on the islands of French Polynesia, as well as from a few submarine lavas. Further exploration of the submarine volcanoes in the French Polynesia region is vital if we are to elucidate the hotspot geology and mantle structure below this area.

2. Regional setting

In French Polynesia, active hotspots have been identified around the Society, Marquesas, Macdonald, and Pitcairn islands (Fig. 1). The hotspots correspond to the sites of zero-aged volcanoes which may be seated on hotspot trails arising from the deep mantle (McNutt and Fischer, 1987). The age progression characteristics of both the Society and Pitcairn hotspots (along the Society Islands and the Pitcairn–Gambier island axes, respectively) are well known (Gripp and Gordon, 2002). However, along the Cook–Austral seamount trail, the age progression is complicated, because several zero-aged volcanoes occur at loci of magmatism that are thousands of kilometers from the reconstructed positions of the Macdonald Seamount hotspot (Johnson, 1970). Some seamounts along the chain were either rejuvenated or

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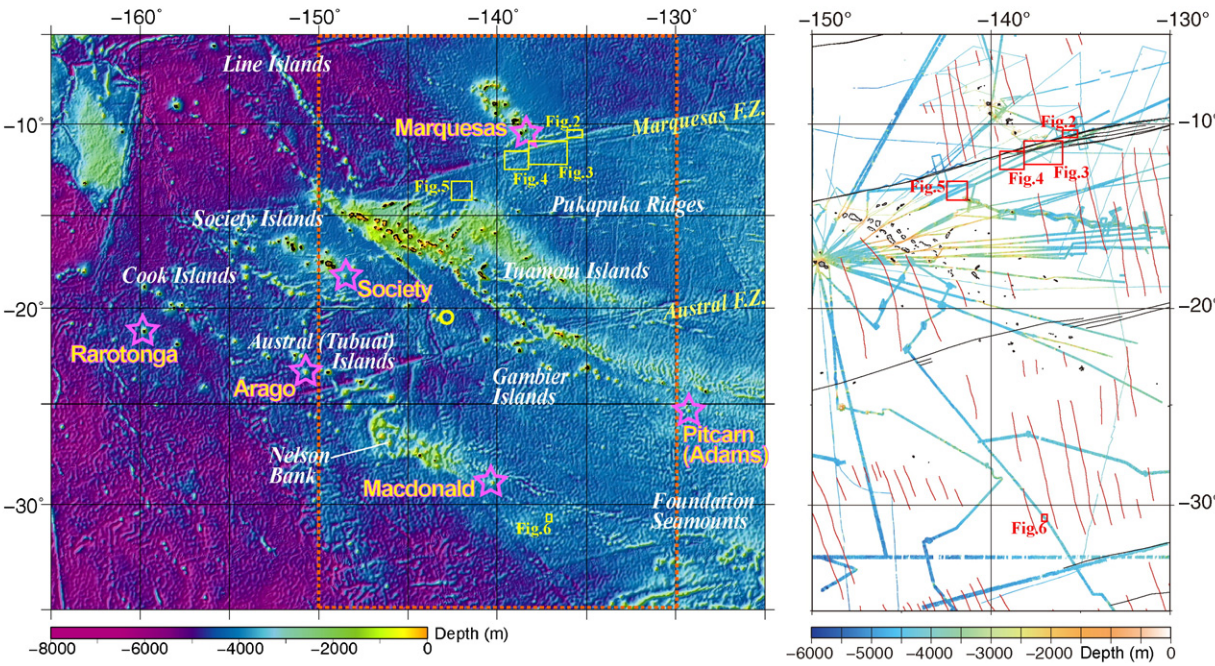

Fig. 1. Bathymetric map of French Polynesia (left) and shipboard bathymetry (right) for the region indicated by the large square in the left panel. Bathymetric data based on satellite gravity measurements are from Smith and Sandwell (1997). Pink stars correspond to sites of stationary hotspots identified from zero-aged (active) volcanoes (Clouard and Bonneville, 2001). Major fracture zones shown by solid lines in the right panel are truncated in the French Polynesian region (Matthews et al., 2011). The red lines in the right panel show the paleomagnetic isochron (Cande et al., 1989). The yellow circle is the potential site of the submarine lavas described by Searle et al. (1995).

resumed volcanism as a result of multiple overlapping volcanoes that erupted during the Quaternary (Dickinson, 1998; Bonneville et al., 2002).

Most studies on the geochronological characteristics of these chains have been restricted to subaerial lavas, even though the hotspots are actually located below the ocean at the southeastern extensions of their associated seamount chains (e.g., Cheminee et al., 1989; Binard et al., 1991; Hekinian et al., 1991; Bonneville et al., 2002; Hekinian et al., 2003). However, dating of submarine samples from the Nelson Bank has not helped to explain the hotspot model along the Austral Islands (Bonneville et al., 2006). We note, too, that tiny submarine eruptions of lava do exist in submarine French Polynesia, as described by Searle et al. (1995) on the basis of data from the GLORIA towed sidescan (the location of the survey is indicated by the small solid circle in Fig. 1).

3. Methods

The spatial resolution of the bathymetric information derived from satellite gravity data is too low to use in the detection of very small volcanic edifices less than 2–3 km in diameter. In addition, the extent of the areas covered by sonar surveys of the ocean floor is limited. The multibeam data shown on the right of Fig. 1 were obtained mainly from the databases of the Scripps Institution of Oceanography (http://siox.sdsc.edu/search.php) and the National Centers for Environmental Information, National Oceanic and Atmospheric Administration (NCEI/NOAA, http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html). Other data in Fig. 1 were obtained from two cruises of the R/V *Mirai* (MR08-06 and MR09-01), run by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

We selected data from four cruises (MR08-06, PANR06MV, WEST13MV, and AMAT03RR; Figs. 2–6) from all of the available databases (Fig. 1) in order to make discussions in this paper. To focus on small submarine volcanoes, we excluded data obtained by multibeam echo sounder system without the acoustic backscatter function. During detailed multibeam surveys of the ocean floor, areas identified by acoustic backscatter as having a high acoustic reflectivity typically indicate areas of hard ocean floor that are overlain by just a thin layer of soft pelagic sediment. Although it is not possible to compare the absolute and relative values in the backscatter data (Masetti et al., 2011), this technique can be used to identify areas of volcanic activity because the reflectivity of a volcano is typically more than three times that of the surrounding abyssal plain covered by a thick layer of fine-grained pelagic sediment in approximately the same angle of swath (e.g., Hirano et al., 2008). Sidescan data in multibeam echo sounder (MBES) are obtained by using the differing amplitudes of the echoes returned from the bottom by the various proprietary systems. However, it is common for this information not to be clearly documented by the system manufacturers. Sidescan data of most MBESs are not generally calibrated. Therefore, it is difficult to make a common scale of sidescan data recorded by different MBESs. We focus here on the relative magnitude of the sidescan data in a single track to find potential submarine volcanoes. Consequently, we did not make a common scale of sidescan data obtained by different MBESs.

In this study, we used multibeam bathymetry data from French Polynesia obtained during four research cruises. The R/V *Mirai* cruise (MR08-06 Leg 1) covered the area from south of the Tuamotu Islands to the eastern Austral Islands in the southern Pacific Ocean, and was undertaken by JAMSTEC. The survey conditions during collection of the bathymetry data during MR08-06 Leg 1 were reported by Abe et al. (2013). Data from around the Marquesas Islands in northern French Polynesia were collected during cruises by the R/V *Melville* (PANR06MV and WEST13MV) and the R/V *Roger Revelle* (AMAT03RR), and are archived in the Geological Data Center at the Scripps Institution of Oceanography and NCEI/NOAA, respectively. The R/V *Mirai* and R/V *Melville* were equipped with a SeaBeam 2112 multibeam system with 151 beams and a SeaBeam 2000 multibeam system with 121 beams. The swath width and beam width of both systems were 120° from 4000 to 4500 m and 2° × 2° (beam interval = 1°), respectively. Their footprint of 2° × 2° at a depth of 4000 m covers an area of roughly 140 × 140 m (4000 m × tan 2°). The R/V *Roger Revelle*, on the other hand, was equipped with a Kongsberg EM120 multibeam system with 191 beams. The swath width and beam width were 150° and 1° × 2°