Investigating igneous piercements/pipes in the Ontong Java Plateau

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Abstract

Oceanic plateaus are thought to be one of the most important targets to elucidate the link between major dynamics in the Earth's deep interior and their impact on the Earth's surface through volcanic activity. Drilling of the plateau basements during past DSDP and ODP cruises have significantly increased our knowledge of their structure, composition and age. However, the origin of oceanic plateaus is still controversial mainly due to the difficulty in drilling to depths of more than a few hundred meters into igneous basements. We recently demonstrated that fragments of almost entire section of lithosphere beneath the world's largest oceanic plateau, Ontong Java Plateau (~122 Ma) were brought to the surface as xenoliths entrained by late-stage magmatism (~34 Ma) which shows some affinity to cratonic kimberlites. Although little is known about the abundance and distribution of such late-stage magmatism over the entire region of the Ontong Java Plateau, previous seismic surveys indicate that the igneous piercement structures, interpreted to be volcanic vents (pipes) rising into the sedimentary sequence are common. If they represent late-stage magma that originated from the lithospheric base under the plateau (depths >120 km), they could potentially contain abundant xenolithic materials from variable depth intervals, analogous to continental kimberlites. Thus, complementary further seismic studies that reveal the distributions of the igneous piercements and detailed crust-mantle velocity structure, future drilling into the igneous piercements using new "Chikyu" riser drilling system, would provide important information on the vertical and lateral variations in the lithospheric structure beneath the plateau, and may provide major breakthrough in understanding the enigmatic origin of the Ontong Java Plateau.

The nature and origin of the large igneous provinces (LIPs) have been intensely debated because of widespread interest to link major dynamics in the Earth's deep mantle with a global environmental impact on the Earth's surface (e.g. Coffin and Eldholm, 1994). The Cretaceous Ontong Java Plateau (OJP) in the western Pacific, which is the largest of the world's LIPs with an area of ~2 x 10^6 km^2 and a maximum crustal thickness >30 km, is one of the most attractive targets because of its huge magma flux and the temporal coincidence with Cretaceous magnetic superchron and greenhouse climate change (e.g. Larson, 1991). With the aim of constraining the cause of the OJP magmatism, particularly for testing a widely accepted the plume-head hypothesis (e.g. Richards et al., 1989), several DSDP and ODP cruises have sampled the igneous basement in the widely distributed sites (Figure 1). Geochronological, petrological and geochemical data of the recovered basalts, together with the data from obducted southwestern margin of the OJP crust in the eastern Solomon Islands (Santa Isabel, Malaita and San Cristobal) revealed that they have an extremely limited variations in age (122±3 and 90±4 Ma), compositions (low-K tholeiites with flat primitive-mantle-normalized incompatible element patterns and OIB-like isotopic signature) and inferred eruptive environments (emplacement beneath the calcite compensation depth). This information does not allow us to approach a singular working model. Conversely, a considerable debate over the plume-head hypothesis has been grown, especially with questioning of the existence of mantle plumes (Fitton and Godard, 2004; Tejada et al., 2004, and references therein).

One great difficulty with research to date can be attributed to the insufficient knowledge of the deep crust-mantle structure beneath the OJP, where the drilling hole cannot access. However, we recently demonstrated that xenoliths entrained by late-stage magmatism, such as 34-Ma alnöite intruding crust of the southern OJP on Malaita, offer the opportunity to reconstruct the lithospheric stratigraphy (vertical distribution of rock types) beneath the OJP (Figure 2), analogous to long-established investigations of continental lithosphere by the studies of kimberlite-borne xenoliths (Ishikawa et al., 2004, and references therein). Our on-going research on geochemistry and geochronology of the Malaitan xenoliths documents possible mechanisms and timing for creating the observed lithospheric structure in the context of OJP formation (Ishikawa et al., 2007; Ishikawa et al., 2005). Thus, further investigation with the aim to discover other xenoliths localities over the OJP would be desirable for obtaining a more complete picture of the sub-plateau lithosphere in terms of the lateral variation.

Seismic reflection profiles of the OJP obtained during Research Vessel traverses revealed a number of what have been termed ‘igneous piercements’ (Kroenke, 1972; Nixon, 1980). The size and structure of the ‘piercements’ show them to be volcanic vents (pipes) up to 3 km in diameter and with internal post-volcanic collapse features (Figure 3), although images on the microfilms vary from sharp to diffuse depending presumably on the proximity of the seismic traverse to the ‘piercements’. Ocean floor sedimentation has taken place within the collapsed craters and is preserved by post-volcanic settlement. These vent features are typical of central volcanoclastic eruptions rather than highly voluminous fissure type effusions. They could be alnöites from their abundance, size and volcanoclastic nature. Undoubtedly if some were located off shore to Malaita they are likely to be alnöites. But the nature of those in the central parts of OJP several hundred km away would be dependent upon the thickness of the lithosphere – likely to be thicker than the 120 km determined petrologically for the peripheral thinner lithosphere beneath Malaita.

The potential existence of a thick lithospheric keel has been inferred by previous seismological studies. A three-dimensional tomographic model of the S-velocity structure beneath the OJP indicated the presence of a low-velocity root reaching a depth of 300 km (Figure 4), and the seismic characteristics of this root suggest that they represent a chemical anomaly because the observed deficiency of shear velocity is too large to attribute to a thermal perturbation (Richardson et al., 2000). Although size and shape of this root is not well constrained due to poor resolution, the mantle root can be interpreted as a remnant of the OJP residuum, which has traveled with the OJP since its formation. This hypothesis seems to be consistent with the interpretation of xenolith studies that certain xenolith appear to represent fragments of fossil OJP “plume” showing chemically anomalous nature (Ishikawa et al., 2004). Thus if the depth of the root is reasonably represented by the previous seismic studies, the igneous piercements penetrated where the lithosphere is inferred to be of maximum thickness i.e. a structurally central ‘cratonic’ location (continental terminology) would be kimberlitic, that might have brought abundant xenolithic material from the depth interval of ~300 km to the surface. Therefore I propose, complementary further seismic studies that reveal (1) the distributions of the pipe structures over the OJP and (2) detailed crust-mantle structure with ocean bottom seismometers, future drilling into the igneous piercements in order to obtain the xenolithic samples from the thickest part of the OJP. The studies of such material are essential to understand seismic data and may provide new insights to the nature and origin of the slow velocity root and the OJP itself.

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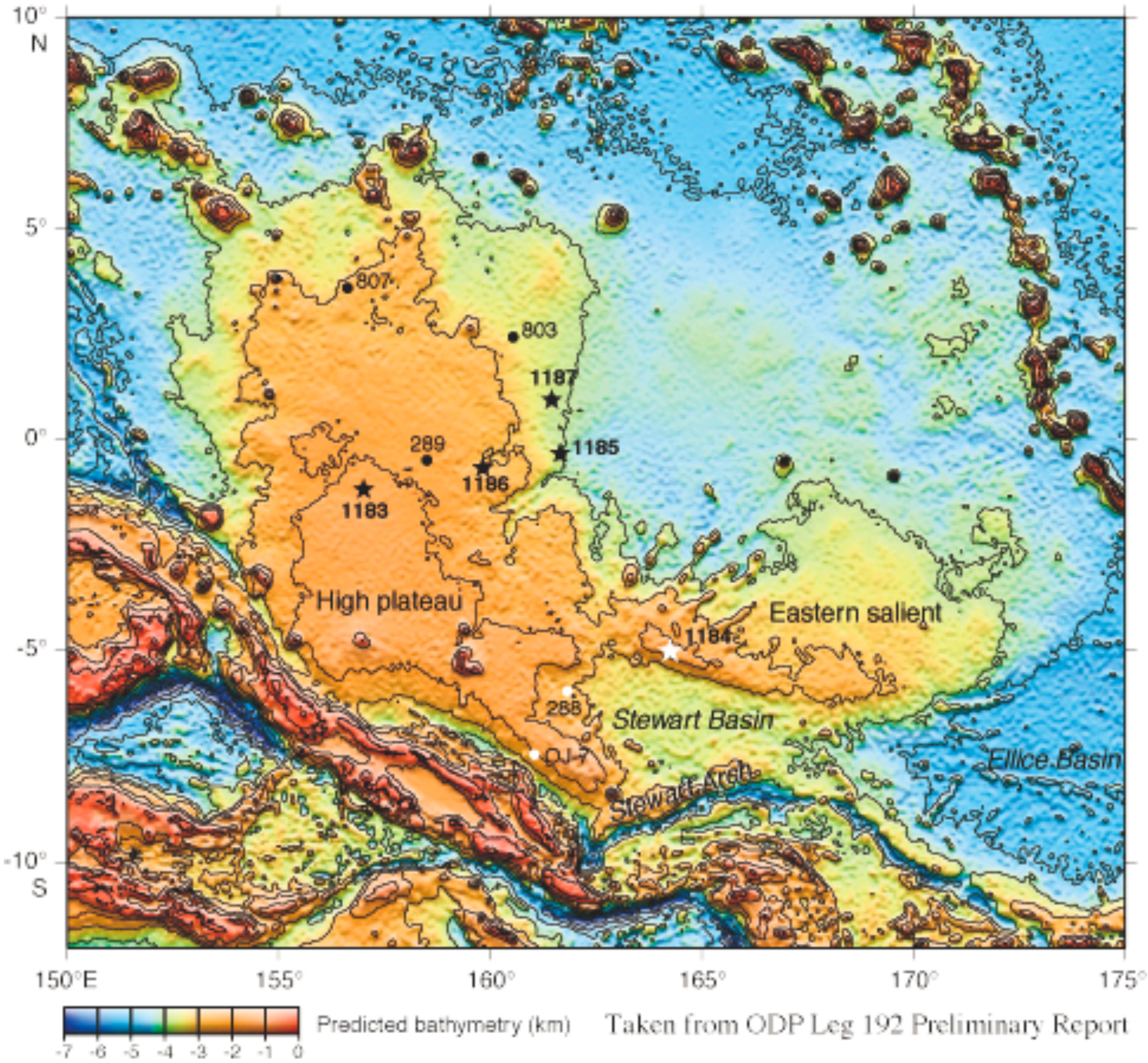

Figure 1. Predicted bathymetry (after Smith and Sandwell, 1997) of the Ontong Java Plateau showing the location of sites drilled on previous DSDP and ODP cruises. Solid stars = sites penetrating lava sections. Open star = Site 1184, where a volcanoclastic sequence was recovered. Solid circles = ODP and DSDP drill sites before Leg 192) that reached basement. Open circles = Site 288, which did not reach basement but bottomed in Aptian limestone, and Site OJ-7, which was proposed for Leg 192 but not drilled. The bathymetric contour interval is 1000 m.

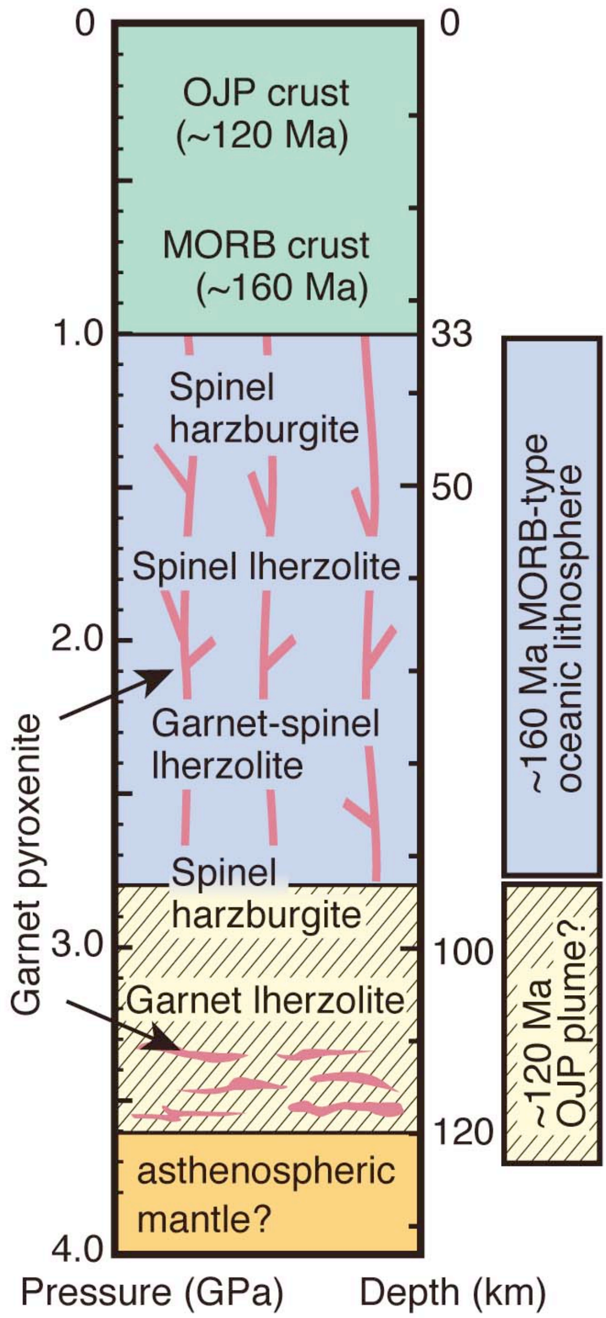

Figure 2. Schematic column displaying the inferred stratigraphic succession beneath the Ontong Java Plateau based on P-T estimates for Malaitan xenoliths (Ishikawa et al., 2004).

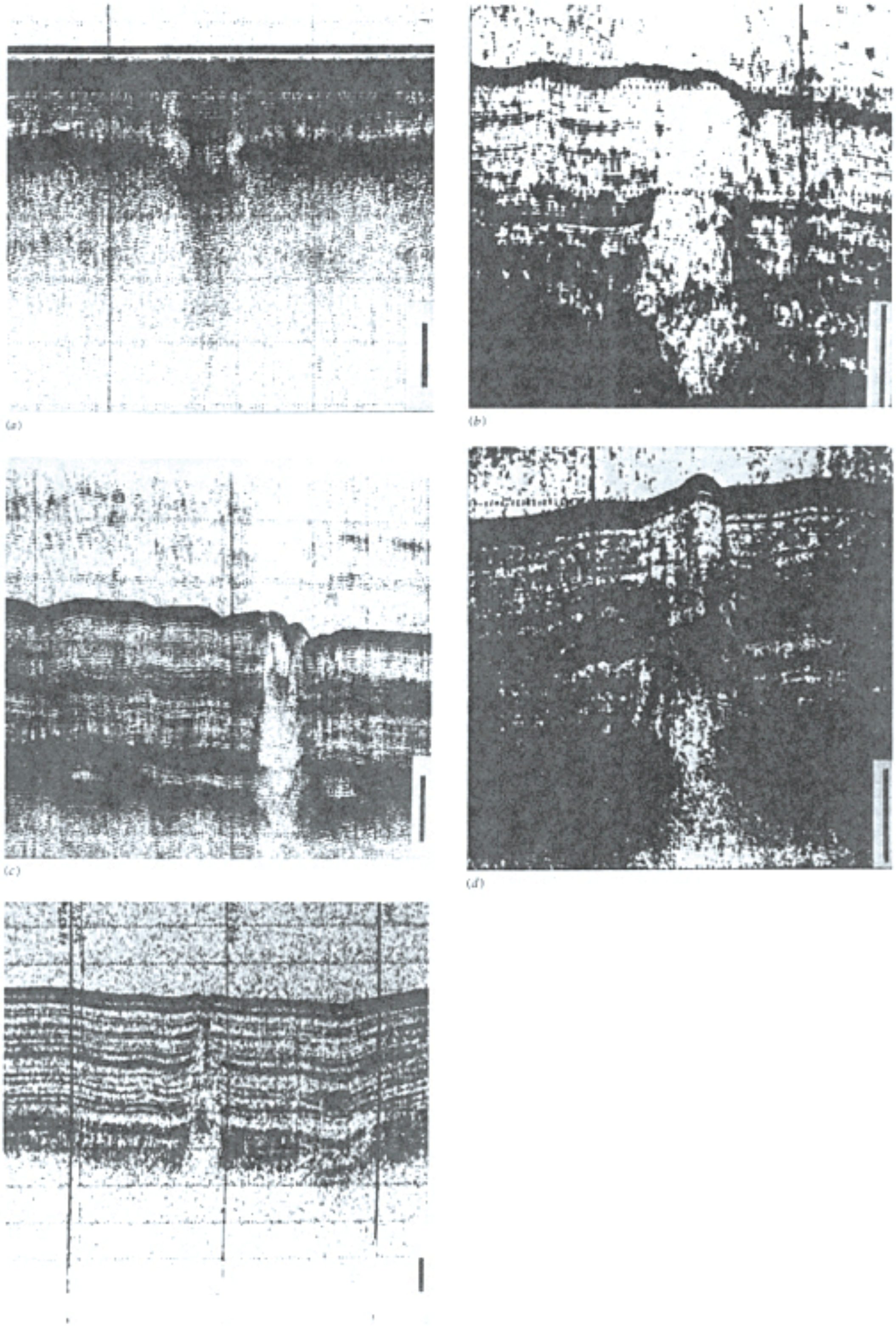

Figure 3. Seismic reflection profiles of plug-like features on Ontong Java Plateau (from microfilm supplied to P.H. Nixon by Hawaii Institute of Geophysics). Vertical scale given by bar (= 250 m) on bottom-right side of each picture; vertical exaggeration about x 12.

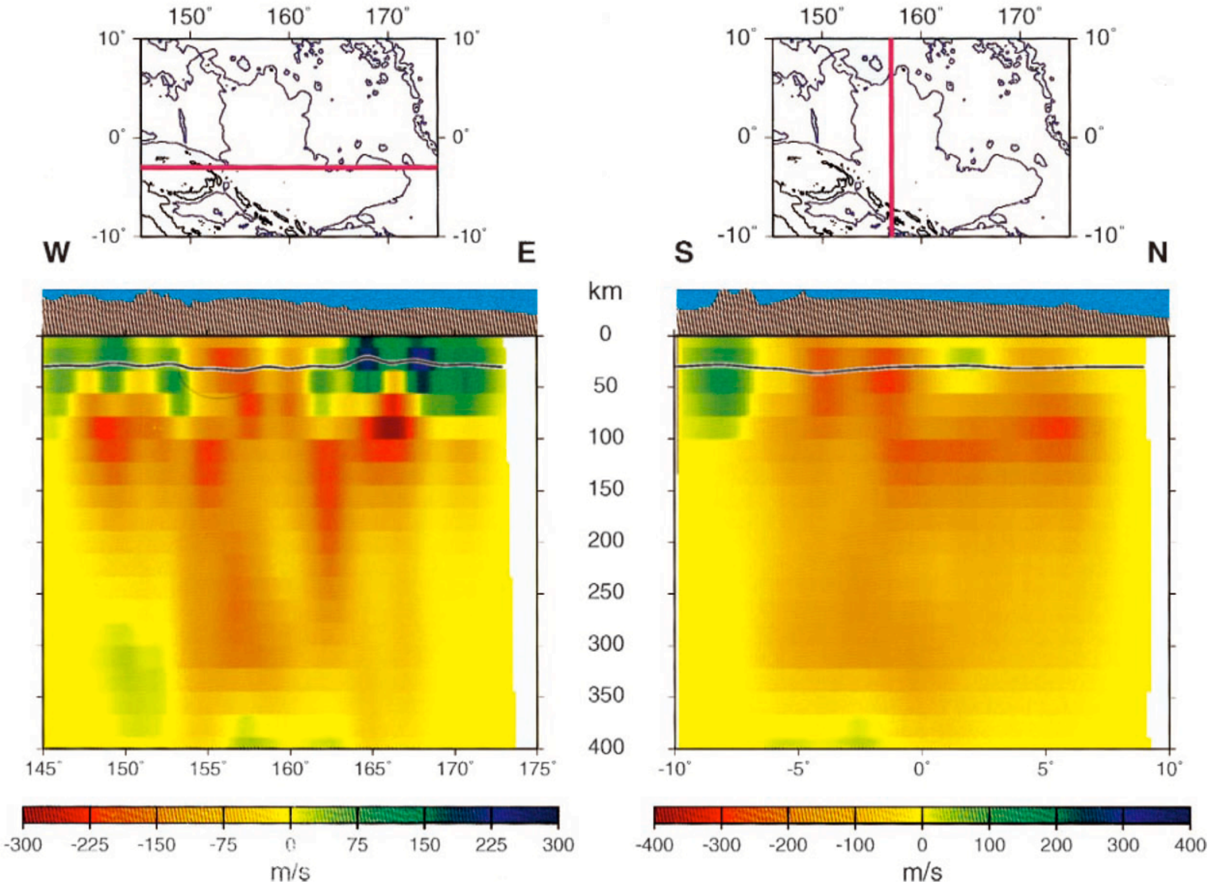

Figure 4. S-velocity profiles of the OJP root (Richardson et al., 2000).