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Plume versus plate origin for the Shatsky Rise oceanic plateau (NW Pacific): Insights from Nd, Pb and Hf isotopes

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ABSTRACT

Shatsky Rise, an early Cretaceous igneous oceanic plateau in the NW Pacific, comprises characteristics that could be attributed to either formation by shallow, plate tectonic-controlled processes or to an origin by a mantle plume (head). The plateau was drilled during Integrated Ocean Drilling Program (IODP) Expedition 324. Complementary to a recent trace element study (Sano et al., 2012) this work presents Nd, Pb and Hf isotope data of recovered lava samples cored from the three major volcanic edifices of the Shatsky Rise. Whereas lavas from the oldest edifice yield fairly uniform compositions, a wider isotopic spread is found for lavas erupted on the younger parts of the plateau, suggesting that the Shatsky magma source became more heterogeneous with time. At least three isotopically distinct components can be identified in the magma source: 1) a volumetrically and spatially most common, moderately depleted component of similar composition to modern East Pacific Ridge basalt but with low $^3He/^4He$, 2) an isotopically very depleted component which could represent local, early Cretaceous (entrained) depleted upper mantle, and 3) an isotopically enriched component, indicating the presence of (recycled) continental material in the magma source. The majority of analyzed Shatsky lavas, however, possess Nd–Hf–Pb isotope compositions consistent with a derivation from an early depleted, non-chondritic reservoir. By comparing these results with petrological and trace element data of mafic volcanic rock samples from all three massifs (Tamu, Ori, Shirshov), we discuss the origin of Shatsky Rise magmatism and evaluate the possible involvement of a mantle plume (head).

1. Introduction

The origin of Large Igneous Provinces (LIPs), including intraplate oceanic plateaus and the underlying mantle processes, which cause widespread volcanism and emplacement over short geological time intervals, is highly debated (e.g. Bryan and Ernst, 2008; Coffin and Eldholm, 1994; Foulger et al., 2005). Oceanic plateaus cover large parts of the Pacific and Indian Oceans and their emplacement may be linked to widespread oceanic anoxic events and mass extinctions (e.g. Courtillot and Olson, 2007; Kerr, 1998, 2005; Rampino and Prokoph, 2013; Snow et al., 2005). Despite several decades of research on oceanic plateaus, the processes required for producing the voluminous mafic magmas and in particular their relationship to regional tectonics and seafloor spreading remain unclear (Bryan and Ferrari, 2013). Proposed models suggest an origin by the arrival of a mantle plume head at the base of the lithosphere (e.g., Duncan and Richards, 1991; Mahoney and Spencer, 1991; Richards et al., 1989) or formation by shallow mantle processes at plate boundaries (such as spreading ridge reorganizations) or ridges crossing particularly fertile (e.g. eclogitic) upper mantle anomalies (e.g., Anderson et al., 1992; Foulger, 2007; Foulger et al., 2005). Almost all large oceanic plateaus remaining in the ocean basins (Ontong Java, Manihiki, Hess Rise, Kerguelen, Caribbean, Madagascar) were formed during the Cretaceous Normal Superchron (C34) (e.g. Coffin and Eldholm, 1994; Hoernle et al., 2004, 2010; Mahoney et al., 1993; Tarduno et al., 1991), a period from 120 to 83 million years ago with no magnetic field reversals (Cande and Kent, 1995). Thus, their relationship to contemporaneous spreading ridge tectonics cannot easily be determined. In addition, it is debatable how fusible eclogitic lithologies can be preserved in the convecting upper mantle and if they can produce the immense magma volumes and eruption rates required for generating large oceanic plateaus such as Ontong Java (Cordery et al., 1997).

In contrast to the aforementioned oceanic plateaus, Shatsky Rise is the only intraoceanic plateau that formed during the early Cretaceous, a time period with frequent reversals of the Earth's magnetic field,

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allowing a reconstruction of the original tectonic setting and temporal evolution of the plateau within its geodynamic framework to be studied in detail (e.g. Nakanishi et al., 1999). The geometry of the magnetic lineations M20 (146 Ma) to M4 (127 Ma) reveals that Shatsky Rise formed at a rapidly spreading triple junction in the northwest Pacific (Fig. 1), suggesting a temporal association between an active spreading center and the formation of this oceanic plateau. On the other hand, the anomalously voluminous volcanism for a spreading center and the decreasing volume of the individual volcanic massifs of Shatsky Rise with decreasing age (possibly representing the transition from plume head to plume tail) suggest involvement of a mantle plume (Sager et al., 1999). Therefore, Shatsky Rise is a unique example to investigate oceanic plateau formation, since it shares characteristics of both model endmembers: plate tectonic-controlled formation at a triple junction and temporal evolution from a mantle plume.

The He isotopic composition of oceanic plateau lavas can be used to distinguish between shallow (upper mantle) and deep (lower mantle) sources. Whereas mid-ocean ridge basalts (MORBs), formed by melting of the depleted upper mantle beneath oceanic spreading centers, generally have depleted Sr, Nd, Pb and Hf isotopic compositions (high, radiogenic Nd and Hf but low, unradiogenic Sr and Pb isotope ratios), most intraplate ocean island basalts (OIBs), which are commonly associated

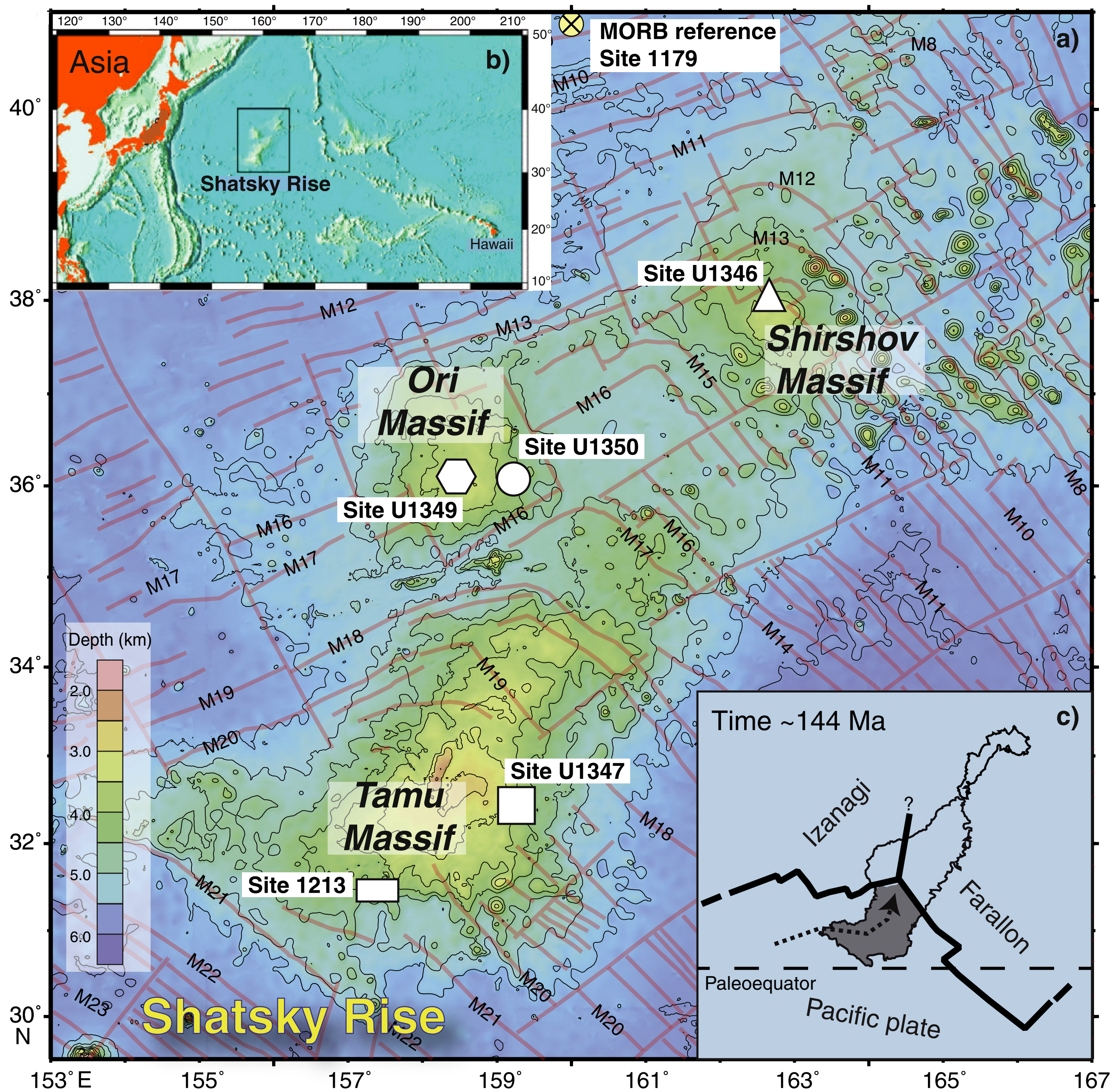

Fig. 1. a) Bathymetric map of Shatsky Rise with location of ODP and IODP drill sites and magnetic lineations (M) in red. Depth contour lines are given in kilometers. Insets showing b) current Location of Shatsky Rise in the NW Pacific and c) reconstructed location in the central Pacific in respect to plate boundaries at ~144 Ma during time of Tamu edifice formation (gray infill). Triple junction separates Izanagi, Farallon and Pacific plates with stippled arrow illustrating the migration of the triple junction. Unfilled area indicates subsequently formed edifices Ori and Shirshov.
Panel a: modified from Nakanishi et al. (1999); panel b: modified after Shipboard Scientific Party (2002); panel c: simplified after Sager et al. (2010) with approximate location of paleoequator after Tominaga et al. (2012).