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Geochemistry and age of Shatsky, Hess, and Ojin Rise seamounts: Implications for a connection between the Shatsky and Hess Rises

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Abstract

Shatsky Rise in the Northwest Pacific is the best example so far of an oceanic plateau with two potential hotspot tracks emanating from it: the linear Papanin volcanic ridge and the seamounts comprising Ojin Rise. Arguably, these hotspot tracks also project toward the direction of Hess Rise, located ~1200 km away, leading to speculations that the two plateaus are connected. Dredging was conducted on the massifs and seamounts around Shatsky Rise in an effort to understand the relationship between these plateaus and associated seamounts. Here, we present new $^{40}Ar/^{39}Ar$ ages and trace element and Nd, Pb, and Hf isotopic data for the recovered dredged rocks and new trace elements and isotopic data for a few drill core samples from Hess Rise. Chemically, the samples can be subdivided into plateau basalt-like tholeiites and trachytic to alkalic ocean-island basalt compositions, indicating at least two types of volcanic activity. Tholeiites from the northern Hess Rise (DSDP Site 464) and the trachytes from Toronto Ridge on Shatsky's TAMU massif have isotopic compositions that overlap with those of the drilled Shatsky Rise plateau basalts, suggesting that both Rises formed from the same mantle source. In contrast, trachytes from the southern Hess Rise (DSDP Site 465A) have more radiogenic Pb isotopic ratios that are shifted toward a high time-integrated U/Pb (HIMU-type mantle) composition. The compositions of the dredged seamount samples show two trends relative to Shatsky Rise data: one toward lower $^{143}Nd/^{144}Nd$ but similar $^{206}Pb/^{204}Pb$ ratios, the other toward similar $^{143}Nd/^{144}Nd$ but more radiogenic $^{206}Pb/^{204}Pb$ ratios. These trends can be attributed to lower degrees of melting either from lower mantle material during hotspot-related transition to plume tail or from less refractory shallow mantle components tapped during intermittent deformation-related volcanism induced by local tectonic extension between and after the main volcanic-edifice building episodes on Shatsky Rise. The ocean-island-basalt-like chemistry and isotopic composition of the Shatsky and Hess rise seamounts contrast with those formed by purely deformation-related shallow mantle-derived volcan-

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ism, favoring the role of a long-lived mantle anomaly in their origin. Finally, new $^{40}Ar/^{39}Ar$ evidence indicates that Shatsky Rise edifices may have been formed in multiple-stages and over a longer duration than previously believed.

Keywords: Shatsky Rise; Hess Rise; Ojin Rise seamounts; Toronto Ridge; Cooperation Seamount; Oceanic plateau; Earthwatch Seamount

1. INTRODUCTION

One of the outstanding problems with a plume origin model for many oceanic plateaus is the absence of a link to a post-plateau, time-progressive hotspot track. This is especially true for the Ontong Java Plateau (OJP), the largest oceanic plateau on Earth. However, Shatsky Rise in the Northwest Pacific Ocean is the best Pacific example of an oceanic plateau with two potential hotspot tracks emanating from it: the relatively continuous North Flank-Papanin ridge and the seamounts trail comprising Ojin Rise (Fig. 1; Sager et al., 1999). Shatsky Rise is a massive oceanic plateau, covering an area of 4.8×10^5 km^2 similar to the size of California (Sager et al., 1999; Sager, 2005) and consists of three discrete volcanic edifices (Fig. 1a): the TAMU Massif, the ORI Massif, and the Shirshov Massif (Sager et al., 1999), that become younger (Geldmacher et al., 2014; Heaton and Koppers, 2014) and smaller in volume toward the northeast (Sager et al., 1999), consistent with the southwestward trajectory of the Pacific plate's motion from 145 to 125 Ma (Larson et al., 1992; Kroenke, 1996; Sager, 2007; Sager et al., 2015). The northeast flank of the Shirshov Massif is truncated by a WNW-trending graben. Across this graben, Shatsky Rise continues with the prominent NE–SW oriented Papanin Ridge, which extends to 43°N where it bends eastward, toward the Hess Rise, a similar large, neighboring oceanic plateau (Fig. 1b). Immediately east of the Shirshov Massif sprawl the Ojin Rise Seamounts, capping a broad, discontinuous, ESE-trending swell (Fig. 1; Sager et al., 1999; Nakanishi et al., 1999).

Previous geophysical studies attribute the origin of Shatsky Rise to the interplay of a mantle plume from the lower mantle with a spreading center triple junction (Nakanishi et al., 1989; Sager and Han, 1993; Sager et al., 1999) but whether or not the melting anomaly continued on to the Hess Rise, via North Flank-Papanin Ridge or via the Ojin Rise is still speculative. The decreasing size from TAMU to Shirshov, which tapers into the North Flank and Papanin Ridge, has been suggested to reflect a waning magmatic activity of the mantle plume that produced the Shatsky Rise (Sager et al., 1999; Sager, 2005). On the other hand, the Ojin Rise seamounts emanating from Shirshov could be construed as hotspot track representing the "plume head to tail" stage of hotspot development (Sager et al., 1999; Nakanishi et al., 1999). Hess Rise could potentially link to one of these two possible hotspot tracks (Fig. 1b), leading to speculations that it could represent a second large magmatic outpouring of the melting anomaly that formed Shatsky Rise about 30–35 m.y. earlier.

Seismic and bathymetric data also reveal the presence of subsidiary volcanic cones around and on the Shatsky Rise massifs (Sager et al., 1999, 2013; Zhang et al., 2015). Some of these cones appear to disturb Cretaceous sediments deposited on the plateau, suggesting that the cones post-date formation of the plateau basement. The data also reveal a profusion of seamounts to the north and east of the Shirshov Massif and the presence of northeast-southwest-trending seamounts cutting across the rise between the TAMU Massif in the south and ORI and Shirshov massifs to the north. One example is Cooperation Seamount, located between the ORI Massif and TAMU Massif (indicated by dredge haul D11 on Fig. 1a). Whether or not these and similar features are also part of the primary volcanism that formed Shatsky Rise is unknown. This study is an initial step toward understanding the origin and potential relationship of the Shatsky Rise and Hess Rise to the seamounts associated with them.

We conducted trace element and Nd–Hf–Pb isotopic studies and $^{40}Ar/^{39}Ar$ dating of volcanic rocks recovered by dredging during the Cruise TN037 of the *R/V Thomas G. Thompson* in 1994 (Sager et al., 1995, 1999; Table 1; Fig. 1). This cruise recovered basalts from two of the seamounts on Shatsky Rise [Cooperation Seamount in the Helios Basin between Tamu and Ori Massifs (D11), Earthwatch Seamount on the North Flank of Shatsky Rise (D4)] and two Ojin Rise Seamounts [Victoria Seamount (D2) and Seamount 6 (D1)]. Samples were also recovered from the eastern summit of ORI Massif (D9) and the Toronto Ridge on TAMU Massif (D13 and D14). The isotopic compositions of two dredged samples from ORI and TAMU have been reported previously (Mahoney et al., 2005) but their ages are reported here for the first time. New Nd–Hf–Pb isotopic and trace element data are also reported for Deep-Sea Drilling Project (DSDP) Sites 464 and 465A samples from Hess Rise, complementing the sparse available geochemical dataset for these neighboring oceanic plateaus (Mahoney, 1987; Mahoney et al., 2005). The main goal is to elucidate the relationship, if any, of the dredged seamounts to Shatsky Rise and whether or not they represent post-plateau magmatic activity of the proposed plume head that formed the rise.

Our results confirm that the tholeiitic basalts from the northern part of Hess Rise have similar isotopic compositions to the plateau basalts from the main Shastky Rise massifs, consistent with double flood basalt event model for the two rises. In addition, both rises seem to progress from older tholeiitic and isotopically depleted to younger alkalic and isotopically more enriched volcanism. The transition from plateau to ocean island type volcanism could be explained by (a) decreasing degree of melting with declining temperature or increasing depth of melting, or both; (b) preferential sampling of enriched components in a heterogeneous source as the degree of melting declines; and (c)