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Composition and timing of carbonate vein precipitation within the igneous basement of the Early Cretaceous Shatsky Rise, NW Pacific

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ABSTRACT

Numerous calcium carbonate veins were recovered from the igneous basement of the Early Cretaceous Shatsky Rise during Integrated Ocean Drilling Program (IODP) Expedition 324. The chemical (Sr/Ca, Mg/Ca) and isotopic ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $\delta^{18}O$, $\delta^{13}C$) compositions of these veins were determined to constrain the timing of vein formation. A dominant control by seawater chemistry on calcite composition is evident for most vein samples with variable contributions from the basaltic basement. Slightly elevated precipitation temperatures (as inferred from oxygen isotope ratios), indicative of hydrothermal vein formation, are only observed at Site U1350 in the central part of Shatsky Rise. The highest $^{87}Sr/^{86}Sr$ ratios (least basement influence) of vein samples at each drill site range from 0.70726 to 0.70755 and are believed to reflect the contemporaneous seawater composition during the time of calcite precipitation. In principle, age information can be deduced by correlating these ratios with the global seawater Sr isotope evolution. Since the Sr isotopic composition of seawater has fluctuated three times between the early and mid Cretaceous, no unambiguous precipitation ages can be constrained by this method and vein precipitation could have occurred at any time between ~80 and 140 Ma. However, based on combined chemical and isotopic data and correlations of vein composition with formation depth and inferred temperature, we argue for a rather early precipitation of the veins shortly after basement formation at each respective drill site.

1. Introduction

The circulation of seawater through igneous oceanic crust and both the dissolution of elements by, and precipitation from these fluids within the basement rocks, comprise major aspects of global element budgets including the long-term carbonate cycle (e.g. Brady and Gislason, 1997; Alt and Teagle, 1999; Coggon et al., 2010). The isotopic and chemical signature of seawater, e.g. ratios of dissolved cations or Sr isotopic composition, varies over geological time and reflects global changes in the Earth environment. The systematic changes of $^{87}Sr/^{86}Sr$, as recorded in marine carbonates, have long been used for constraining the ages of marine limestones and fossil carbonate shells (e.g. Peterman et al., 1970; Burke et al., 1982). Carbonate minerals that were precipitated from fluids that circulate through cracks and cavities and form calcium carbonate veins in the igneous upper oceanic crust are seldom considered in this regard since they form in direct interaction with the basement rocks and can contain a significant lithospheric (often hydrothermal) contribution. Recently, however, it was shown that important seawater parameters (Sr isotopic composition, Mg/Ca, Sr/Ca ratios) are reliably recorded in calcium carbonate veins, if precipitated at near ambient seawater temperature (Coggon et al., 2004; Coggon et al., 2010; Rausch et al., 2013) or can be reconstructed if the precipitation temperature is known (Coggon and Teagle, 2011). In this paper we report Mg/Ca and Sr/Ca ratios, trace element and isotopic compositions ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $\delta^{18}O$, $\delta^{13}C$) of carbonate veins drilled at four sites of different age on Shatsky Rise, a large oceanic plateau formed in the early Cretaceous in the NW Pacific. The global seawater Sr-isotope stratigraphy will be used to discuss possible vein precipitation ages, which in turn can be compared with measured or assumed basement formation ages. In addition, the data provide insights into fluid circulation and alteration history of one of the oldest in-situ oceanic plateaus on Earth.

2. Regional geology and previous work

Shatsky Rise is a large igneous province located in the NW Pacific ca. 1500 km east of Japan (Fig. 1) and is the third-largest oceanic plateau

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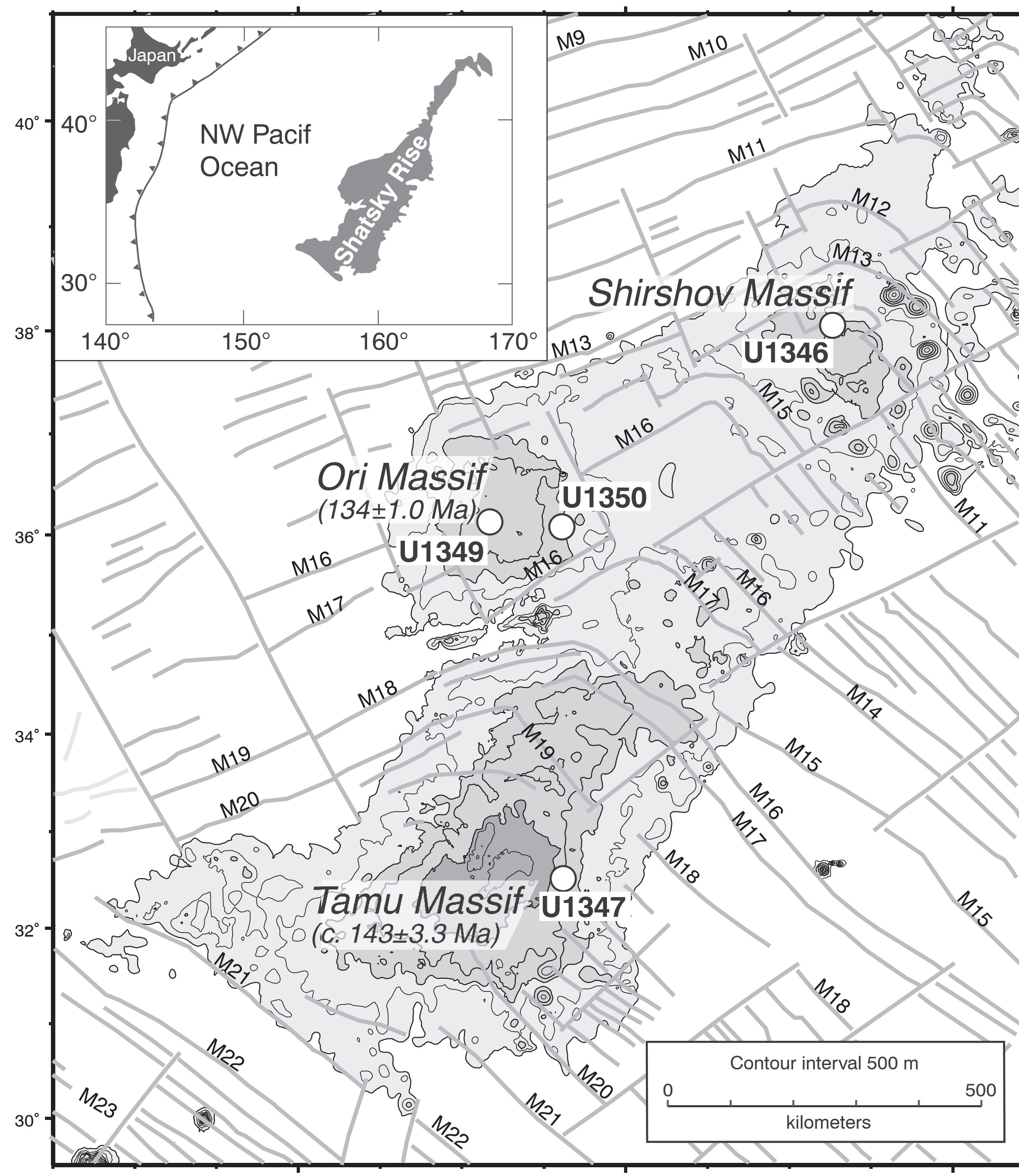

Fig. 1. Location of IODP drill sites on Shatsky Rise from which veins were studied. Bathymetry after Sager et al. (2010) and magnetic anomalies after Nakanishi et al. (1999). Preliminary ages for Tamu and Ori Massifs from Geldmacher et al. (2014) and Heaton and Koppers (2014) respectively. Only contours above 5 km depth are shown for clarity (contour lines at 500 m intervals).

(after Ontong Java and Kerguelen) in the present oceans. Based on paleomagnetic reversals combined with bathymetric data, the plateau's three main volcanic edifices Tamu, Ori and Shirshov massifs are proposed to have successively formed by massive volcanism along a southwest–northeast moving, rapidly spreading triple junction (Nakanishi et al., 1999). The enormous size of the plateau (~4.8×10^5 km^2 comprising ~4.3×10^6 km^3 basalt, Sager et al., 1999) and the apparent decrease in effusive activity with time, however, would be also consistent with a formation by a (starting) mantle plume head (e.g. Sager, 2005). The proposed NW-directed age progression across Shatsky Rise is solely based on the interpretation of magnetic reversals since only a single radiometric age determination of