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Long-term reworking of volcanic ash deposited in the abyssal ocean based on uranium and thorium isotope measurements

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ABSTRACT

A red-clay core from north of New Zealand contains a 21 cm-thick layer of the 340 thousand-year old Rangitawa ash. Uranium and thorium isotope measurements on this core show that ash continuously contributes to sediments overlying the ash layer, ranging from ~58% immediately above the ash to ~8% at the core top. Rather than from an upward bioturbation or subsequent volcanic eruptions, the ash in sediments is most likely sourced from suspended Rangitawa ash in the nepheloid layer that has steadily re-deposited at the core site ever since the Whakamaru super-eruption. We suggest that this lateral transport bears important influence on interpreting marine sediment proxy records.

1. Introduction

One of the central concerns in paleoceanographic research is to reconstruct oceanic particle fluxes properly from sedimentary records. It has long been realized that calculation of material fluxes simply based on mass accumulation rates averaged between dated horizons can overestimate the vertical fluxes derived from the overlying waters (Bacon, 1984; Marcantonio et al., 2001; Francois et al., 2004). Significant contributions can be brought in by lateral fluxes from bottom currents that accumulate or attenuate sediments along specific topographic settings on the seafloor.

Excess thorium-230 activity ($^{230}Th_{xs}$) has been proposed to identify and quantify the lateral input or removal of marine sediments (Marcantonio et al., 2001; Henderson and Anderson, 2003). Produced by the decay of ^{234}U in water columns and then efficiently scavenged by particulates to the seafloor, $^{230}Th_{xs}$ can be reasonably treated as a constant-flux proxy in the ocean, and therefore be used to monitor the fluxes of other sedimentary constituents. If the sediments were deposited during the late Quaternary, syndepositional redistribution can be taken into account by applying this ^{230}Th normalization method (Francois et al., 2004). Yet, postdepositional redistribution is often less well attended, unless a disturbed stratigraphy and chronology can be clearly recognized in the cores. This may lead to an overlooked sediment accumulation rate, in particular for pelagic sediments without significant physical features.

Volcanic ash particles are frequently found in marine sediments. Ashes from large-magnitude explosive eruptions can be widely dispersed, to a distant geographic region thousands of kilometers away from the source (Froggatt et al., 1986). Once settled in marine sediments, ash layers are often used as stratigraphic markers through comparing ash lithological and mineralogical characteristics. Even on occasions that ash materials are not distinctly observed in the sediments, geochemical fingerprints can still be employed to trace the eruption sources, and ash dispersion and preservation (Ninkovich, 1968; Shane, 2000).

Here, we report a uranium and thorium isotopic study on sediment samples from a pelagic clay core (VM33-121) in a marginal basin of the southwest Pacific (Fig. 1), which contains a thick ash layer. We observed a down-core linear increase in ^{232}Th content, but a gradual decrease of $^{230}Th_{xs}$ in its logarithmic value and abnormal ($^{234}U/^{238}U$) activity profile up to the sediments immediately underneath the ash layer. Likely, clay materials in this core have continuously incorporated ashes during their depositions. We therefore, argue that the very large Rangitawa ash originated from the Quaternary Taupo volcanic zone (TVZ), New Zealand, has been steadily re-deposited into the core sediments over the past 340 thousand years (kyrs), probably through a deep sea nepheloid zone rich in re-suspended ash particles.

2. Sediment core and analytical methods

Red clay core VM33-121 was retrieved from a depth of 4569 m in the South Fiji Basin directly north of New Zealand (26°50′S, 174°47′E). The core sediments are dominated by fine, brownish terrigenous red clay, with negligible carbonates (typically <1%). The core however contains a 21 cm-thick grayish ash layer from 88 to 109 cm depth, which consists of abundant volcanic glass shards and biotite fragments.

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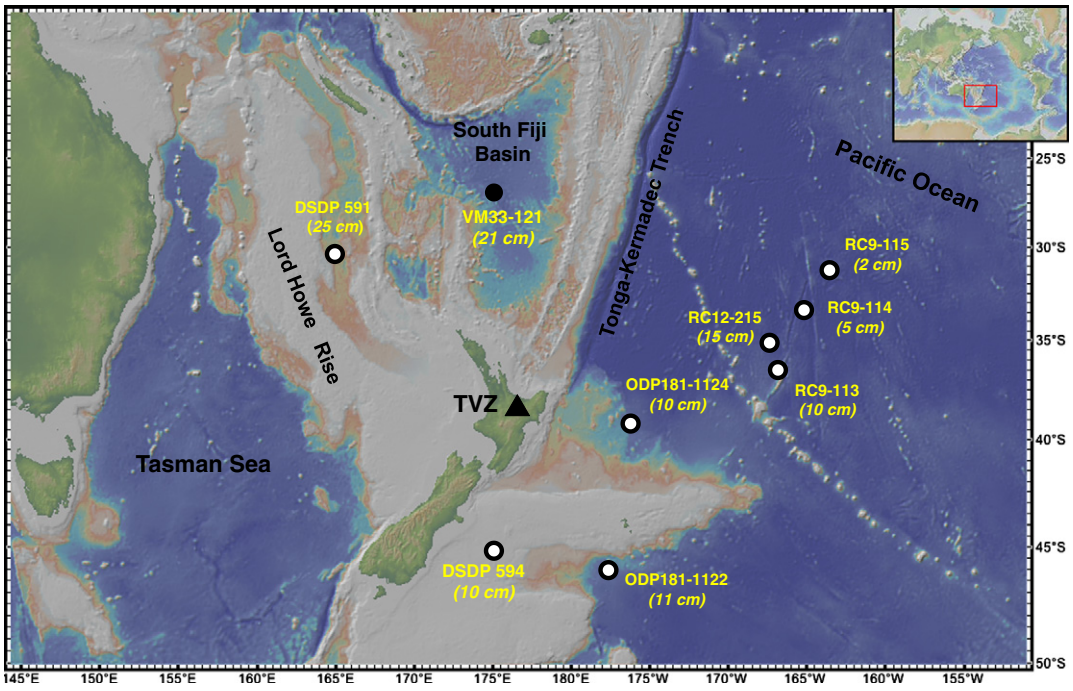

Fig. 1. Location map of red clay core VM33-121. The core site is marked by a solid circle, together with the thickness of the Rangitawa ash layer. Open circles denote a few other marine sediment cores where the Rangitawa ash was documented (Froggatt et al., 1986; Matthews et al., 2012). Ash layer thicknesses in respective cores were also shown. Solid triangle represents the location of Taupo volcanic zone (TVZ), the source region of the Rangitawa tephra.

Analysis of the ash by Phil Shane at the University of Auckland showed it to be correlative with New Zealand's Rangitawa tephra of mid-Pleistocene age (Shane, 2000; Lowe et al., 2001; P. Shane, pers. commun., 2011).

The Rangitawa tephra was produced by the rhyolitic Whakamaru super-eruption, from the TVZ in central North Island (Froggatt et al., 1986). Due to the prevailing westerly winds, volcanic ashes from this voluminous eruption were mainly dispersed over much of the North Island, and across the Southwest Pacific Ocean to the sub-Antarctic (Matthews et al., 2012). However, Rangitawa tephra beds were also found to the N and NW of North Island, in deep-sea cores from the Tasman Sea and the South Fiji Basin (Froggatt et al., 1986; Hesse, 1994; Broecker, 2008), which suggests that its ejection column was at least 20 km high (Shane, 2000). Numerous efforts have been made to determine the age of Rangitawa tephra, and the current best estimate is 340 ± 7 kyrs (Pillans et al., 1996; Pillans, 2007). Based on this age, the average rate of accumulation for VM33-121 piston core is about 0.25 cm/kyr. That by the trigger weight core is about 0.16 cm/kyr (Fig. 2). The difference reflects some combination of under collection by the trigger weight core and over collection by the piston core. A similar difference was reported by Broecker et al. (1999) for trigger weight-piston core pairs from the deep equatorial Atlantic.

Clay powder samples were prepared from both the piston and trigger weight cores. They were digested in a mixed acid (HNO_3 + HF + $HClO_4$), and spiked with ^{233}U–^{236}U–^{229}Th at the Minnesota Isotope Laboratory. The rest of the chemical process, such as Fe co-precipitation and column chromatography to separate and purify uranium and thorium, is similar to those described in Edwards et al. (1987) and Shen et al. (2002). The isotope ratio measurements were then conducted using a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS, a Neptune) and following the methods in Cheng et al. (2013). Standards and duplicate samples were measured to ensure consistent results. Chemical blanks were also monitored, and their values are negligible compared to those of samples.

We report here the mass concentrations of ^{238}U and ^{232}Th in the samples (Table 1). Because the materials are nearly pure clay, we calculate $^{230}Th_{xs}$ from total ^{230}Th activity by subtracting detrital ^{230}Th, which is assumed to remain in secular equilibrium with ^{238}U in lithogenic phases (Ku, 1976; Henderson and Anderson, 2003). The measured activity ratio of ($^{234}U/^{238}U$) is presented in δ notation, $\delta^{234}U = ((^{234}U/^{238}U) - 1) \times 1000‰$.

3. Results

Both U and Th contents increase in the core sediments along depth (Table 1). For instance in VM33-121 piston core, ^{232}Th rises from

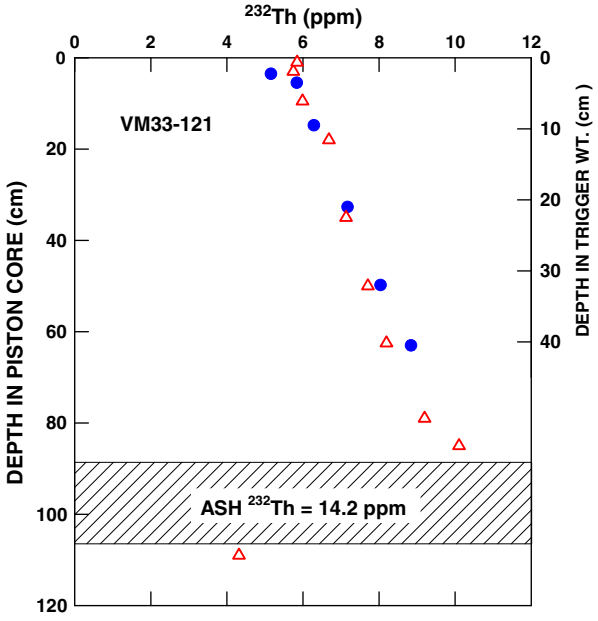

Fig. 2. The ^{232}Th content of VM33-121 as a function of depth. The triangles are for the piston core and the circles are for the trigger weight core. Note the difference between the depth scales (see text). Most error bars are smaller than the symbols.