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Data report: $^{87}\text{Sr}/^{86}\text{Sr}$ in pore fluids from IODP Expeditions 372 and 375, Hikurangi margin¹

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Keywords: International Ocean Discovery Program, Expedition 372, Expedition 375, *JOIDES Resolution*, Hikurangi subduction margin, Site U1517, Site U1518, Site U1519, Site U1520, Sr isotopes, rock-fluid reactions, pore fluid

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Abstract

We report on the Sr isotopic compositions of pore fluids recovered during International Ocean Discovery Program (IODP) Expeditions 372 and 375. Pore fluid samples were acidified and loaded directly onto columns containing EICHROM Sr spec resin, followed by analyses using a NU multicollector inductively coupled plasma–mass spectrometer (MC-ICP-MS). The strontium systematics in this margin point to a series of processes that include carbonate diagenesis, ash alteration, and diffusive exchange with the underlying oceanic crust. The role of ash alteration is evidenced at all drilled sites by a decrease in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in the upper 130 m of the sediment column to values as low as 0.70846. In the calcareous early Paleocene to late Miocene sediment from Site U1520, the pore fluid strontium concentration shows a marked increase to 1280 μM at 647.3 meters below seafloor (mbsf), but the corresponding $^{87}\text{Sr}/^{86}\text{Sr}$ ratios do not show a significant change in this unit. In the early Late Cretaceous sediment at this site, there is an increase in dissolved strontium concentration with a corresponding decrease in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios to 0.706312 at the bottom of the cored section.

Introduction

International Ocean Discovery Program (IODP) drilling during Expeditions 372 and 375 was aimed at fully characterizing the region offshore the North Island of New Zealand along a transect from the incoming Pacific plate through the upper plate sequences of the Hikurangi margin. This program was designed to test a suite of hypotheses regarding the occurrence of slow slip events and their relationship to great earthquakes along the subduction interface. Expedition 372 also explored the active creeping deformation of the Tuaheni Landslide Complex on the upper slope of the margin.

Overarching hypotheses guiding the ongoing Hikurangi margin experiments center on the premise that slip on the subduction

thrust is modulated by fluid pressure and sediment properties along the plate interface. Similarly, changes in fluid pressure influence the behavior of submarine slides. Here we report the concentration and isotopic composition of dissolved strontium in pore fluids recovered from Site U1517 during Expedition 372 and Sites U1518, U1519, and U1520 during Expedition 375. These data constitute a tracer for the identification of fluid-rock reactions, migration pathways, and fluid sources. Potential source materials responsible for Sr enrichment and changes in isotopic composition of interstitial waters are continental detritus, biogenic calcite, and oceanic crust; each source is characterized by a strontium isotope signature that allows for tracing of fluid origins (e.g., Elderfield, 1986; Teichert et al., 2005; Torres et al., 2015, 2019). Recent studies offshore Nankai have shown that the Sr isotopic signal of pore fluids can be used to fingerprint ash alteration reactions (Sample et al., 2017; Murray et al., 2018), which play an important role in the nature, amount, and characteristics of fluids and formation of secondary phases (e.g., smectite, zeolite) resulting from this reaction. It is also becoming apparent that changes in pH from ash alteration, may enhance carbonate cementation, which significantly impacts the physical sediment properties (Sample et al., 2017; Torres et al., 2019).

Site descriptions

The composition and lithostratigraphy of the sediment recovered during Expeditions 372 and 375 were described by the shipboard sedimentologists. Site U1517 is detailed in Barnes et al. (2019a), and sediment from the additional sites are described in the [Site U1518](#), [Site U1519](#), and [Site U1520](#) chapters (Saffer et al., 2019; Barnes et al., 2019b, 2019c). We briefly summarize their results to provide context for the strontium data presented here. The strontium isotope data for Site U1517 was published in Screaton et al. (2019) and are included in this data report for completion.

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Site U1517

Site U1517 was drilled during Expedition 372 at 720 m water depth to sample sediments of the Tuaheni Landslide Complex (TLC). The lithostratigraphy at this site consists of clayey silt with sandy intervals that reflect bedded turbidite sequences, mass transport deposits, and an undetermined amount of background hemipelagic sedimentation. The sediment sequence was divided into five lithologic units. The upper unit of homogeneous mud (Unit I, 0–3.00 meters below seafloor [mbsf]) reflects the most recent hemipelagic sediment drape. Lithologic Units II (3.00–40.74 mbsf) and III (40.74–66.38 mbsf) comprise the Tuaheni slide mass, which appears to be primarily an intact block that was mobilized from the upper slope sedimentary sequences. Underlying the base of the TLC, Unit IV (66.38–103.16 mbsf) is a massive greenish gray to dark greenish gray clayey silt with variable amounts of clay; authigenic minerals from alteration of volcanoclastic material, such as phillipsite, were also identified in this unit, the base of which corresponds to the top of the first significant sand bed. Unit V (103.16–187.53 mbsf) is composed of alternating sand and mud and intervals of massive clayey silt or silty clay; a very fine to silt sized fraction is composed mainly of detrital quartz, altered volcanic fragments, and glass shards.

Site U1518

Site U1518 is located on the lower continental slope in ~2630 m of water. The site was cored during Expedition 375 to sample a thrust fault on the frontal accretionary wedge. The 494 m sediment sequence consists of silty clay(stone) alternating with thin beds of silt(stone) that contain variable amounts of sand. Distinctions among the three lithologic units that define this sequence are based primarily on the character of coarser event beds and soft-sediment deformation features. Unit I (0–304.53 mbsf) is composed of greenish gray silty clay to clayey silt sediment with centimeter-scale interbeds of normally graded sandy silt to silty sand and includes 18 felsic ash layers that were probably deposited by air fall. Unit II (304.53–370.4 mbsf) is defined on the basis of a sharp reduction in silt size and corresponds to a significant change in biostratigraphy, defined by an age inversion with sediment overlying younger sediment associated with a thrust fault. The main fault zone was identified from 304.5 to 322.4 mbsf and a second (subsidiary) fault zone extends from 351.2 to 361.7 mbsf. Unit III (370.4–492.26 mbsf) is composed of mudstone with thin beds of normally graded siltstone and sandy siltstone and is characterized by its soft-sediment deformation.

Site U1519

Site U1519 was drilled on the upper continental slope at a water depth of ~1000 m. The sediment section was spot cored during Expedition 375 to provide data in support of an observatory installed at this location to monitor changes in formation properties that can be associated with slow slip events. Lithofacies analysis was hampered by large coring gaps and poor recovery. Two lithostratigraphic units were defined at this site. Unit I (0–282.66 mbsf) consists of dark greenish gray mud and mudstone (silty clay to clayey silt) thought to represent hemipelagic deposition. The uppermost part of this unit contains a 1 m thick deposit of light gray unconsolidated silicic volcanic ash. Unit II (282.66–635.65 mbsf) is described as mudstone with scattered interbeds of silt(stone) and very fine sand(stone), medium to coarse sand(stone), contorted mudstone, and matrix-supported mass transport deposits.

Site U1520

Site U1520 was drilled during Expedition 375 to characterize the entire input sedimentary sequence prior to subduction, ~16 km east of the deformation front, in 3520 m of water. The 1054.1 m of sediment recovered at this site was divided into six lithostratigraphic units. Unit I (0–110.5 mbsf) is greenish gray hemipelagic mud punctuated by graded coarser beds likely deposited by turbidity currents on the Hikurangi Trough. Unit II (110.5–222.0 mbsf) consists of silty clay to clayey silt distinguished from Unit I by a noticeable reduction in the number and thickness of sand and silt interbeds. Unit III (222.0–509.82 mbsf) is composed of silty clay to clayey silt with silicic tephra deposits, which provide the most definitive contrast with the lithologies in Unit II. Unit IV (509.82–848.45 mbsf) is composed mostly of marl, calcareous mudstone, and chalk; secondary constituents include debris flow deposits and volcanic ash/tuff. Unit V (848.45–1016.24 mbsf) is a granule-size volcanoclastic conglomerate of mostly subangular clasts of basalt ranging in size from a few millimeters to 6 cm with pervasive alteration of the basalt clasts to palagonite and clay minerals. An interval of marl interrupts the volcanoclastic succession between 949.76 and 953.65 mbsf. Unit VI (1016.24–1045.75 mbsf) is a disjointed blend of lithologies containing alternating volcanoclastic conglomerate and mudstone with a distinctive dark blueish gray to greenish gray color.

Methods

Sediment cores were collected, cut into sections, capped, and taken to the laboratory on the ship for retrieval of pore fluids immediately upon recovery. Pore fluids were extracted from the cores with the use of a titanium squeezer, which had been modeled after the stainless steel squeezer of Manheim and Sayles (1974). Strontium concentrations were analyzed on board using an inductively coupled plasma–optical emission spectrometer (ICP-OES). Detailed sampling protocols can be found in [Geochemistry](#) in the Expedition 372B/375 methods chapter (Wallace et al., 2019a) and in the Expedition 372A methods chapter (Pecher et al., 2019).

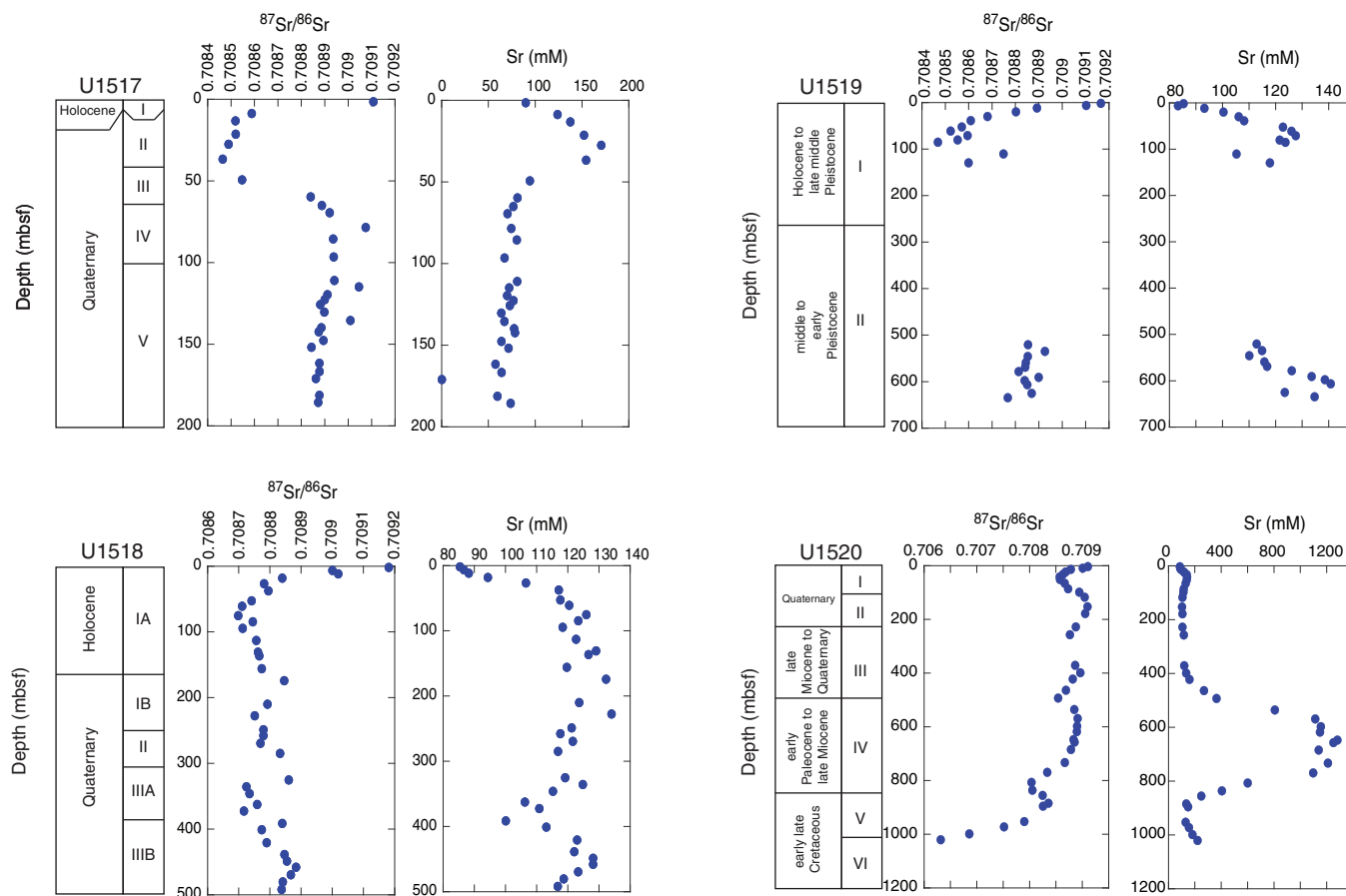
Subsamples for strontium isotopic composition were preserved by acidification with Optima grade HNO_3 (16 M) to a pH of 2. Strontium isotopes were isolated using a 60 μL column filled with strontium spec resin (EICHROM). Samples were collected directly from the column into acid-washed Teflon vials and acidified in a 2 M nitric acid matrix. Isotopic ratios were measured using an inductively coupled plasma–mass spectrometer (ICP-MS) located in the Keck Collaboratory Huntair Clean Room laboratory at Oregon State University (USA). Normalization of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were performed using the National Bureau of Standards 987 (NBS 987) standard, with the value 0.710254 ± 0.00005 (2σ mean; $n = 91$). A secondary internal standard with the value 0.708170 ± 0.000051 (2σ mean; $n = 91$) was used as a calibration check for instrument drift throughout the analytical runs.

Results

The strontium isotope data generated in this study are shown in Table T1 and Figure F1, which also includes the strontium concentrations, lithologic units, and sediment ages from Pecher et al.

Table T1. Strontium concentrations and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in pore fluids from Expeditions 372 and 375. [Download table in CSV format.](#)

Figure F1. Strontium concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratio measured in pore fluids from Sites U1517–U1520. Lithologic units and ages correspond to those from Barnes et al. (2019a, 2019b, 2019c) and Saffer et al. (2019).



(2019) for Site U1517 and Wallace et al. (2019) for Sites U1518–U1520.

At Site U1517, Unit I (0–3 mbsf) is Holocene age and the Quaternary extends from 3 to 185.5 mbsf. Dissolved strontium concentration increases from a seawater value of 87.0 μM at 1.40 mbsf to the maximum of 170.3 μM at 27.5 mbsf. This maximum in strontium concentration corresponds to a marked decrease in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, which decrease from a near-seawater value of 0.709107 at 1.4 mbsf to 0.708464 at 36.6 mbsf. This minimum value corresponds to the bottom of Unit II. In Units II and III, Sr concentration decreases and varies between 50 and 85 μM to the maximum cored depth of 185.5 mbsf. Below the Tuaheni slide mass (Units IV and V) the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in pore fluids increases from 0.708546 to a value that fluctuates between 0.708839 and 0.708935 to the bottom of the cored section.

Strontium concentration increases in the Holocene sediment of Subunit IA (0–180 mbsf) at Site U1518 from 85.36 μM at 1.5 mbsf to a maximum of 133.99 μM at 227.3 mbsf. Within this unit, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in pore fluids decrease from 0.709181 at 1.5 mbsf to a minimum value of 0.708698 at 74.9 mbsf. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios then remain between 0.708712 and 0.708883 from 94.3 mbsf to the bottom of the cored section at 491.5 mbsf. Dissolved strontium concentration from Subunits IB to IIIB (Quaternary sediment) fluctuates between 100.07 and 128.08 μM .

At Site U1519, dissolved strontium concentrations in Holocene to late middle Pleistocene sediments of Unit I increase from 85.26

μM at 1.4 mbsf to 127.48 μM at 70.7 mbsf and slightly decrease to 123.6 mbsf. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in pore fluids from this sediment section decrease from a maximum of 0.709165 at 1.4 mbsf to a minimum value of 0.708467 at 123.6 mbsf, suggestive of alteration of volcanogenics. No sediment was recovered from a sample hiatus from 123.6 to 530.33 mbsf. Dissolved strontium concentrations in the middle to early Pleistocene sediment at the bottom of Unit II increase from 112.8 μM at 520.3 mbsf to a maximum of 140.67 μM at 606.3 mbsf. The corresponding $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in pore fluids remain consistent between 0.708925 and 0.708766 from 520.3 mbsf to the bottom of the cored section at 634.0 mbsf.

At Site U1520, dissolved strontium concentration in the upper 41.63 mbsf increases from seawater value to a maximum of 139.04 μM . The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the corresponding pore fluids decrease from an initial value of 0.709102 to 0.708568, suggestive of ash alteration. In the remaining sediments of Unit I, dissolved strontium decreases to 11.44 μM and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios increase to 0.708938. In Units II and III (116.9–398.1 mbsf), dissolved strontium fluctuates between 101.72 and 117.95 μM and the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range from 0.708761 to 0.709094. In the calcareous early Paleocene to late Miocene sediment of Unit IV, pore fluid strontium concentration markedly increases from 158.33 μM to a maximum of 1280.08 μM at 647.3 mbsf, decreasing to 127.67 μM from 656.4 to 951.9 mbsf at the bottom of Unit IV. The corresponding $^{87}\text{Sr}/^{86}\text{Sr}$ ratios do not show a marked change in this unit and then decrease slightly from 0.708908 at 535.2 mbsf to 0.708034 at 835.6 mbsf. In the early Late Creta-

ceous sediment of Units V and VI, dissolved strontium concentration increases from 153.65 μM at 972.0 mbsf to 218.67 μM at the bottom of the hole. There is a corresponding decrease in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from 0.708333 at 768.8 mbsf to 0.706312 at the bottom of the cored section at 1019.7 mbsf.

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