**IODP Expedition 376: Brothers Arc Flux**

**Site U1527 Summary**

## Background and Objectives

Site U1527 (proposed Site NWC-1A) is located on the rim of the northwest caldera wall of Brothers volcano in a water depth of 1464 m. Drilling targeted what was considered either the margin of an older, modified seawater hydrothermal upflow zone, or a recharge zone to the currently active discharge areas several hundred meters away either side of the drill site. A key objective of Expedition 376 is to quantify the mechanisms and extent of fluid-rock interaction, and the consequences for mass transfer of metals into the ocean in both seawater-dominated and magmatically-dominated hydrothermal systems within the caldera of Brothers volcano. Hence, the main objective of Site U1527 was to drill through the margin of the inferred upflow zone of a modified seawater system.

## Operations

We conducted operations in three holes at Site U1527 (proposed Site NWC-1A). Hole U1527A is located at 34°51.6528′S, 179°3.2397′E, in a water depth of 1464.2 m. In Hole U1527A, we used a rotary core barrel (RCB) to core from the seafloor to 101.4 m with poor recovery of 1.27 m (1.3%). The downhole conditions encountered in Hole U1527A determined the preparations for running a reentry system. At Hole U1527B, located at 34°51.6519′S, 179°3.2526′E, in a water depth of 1464.2 m, 10¾ inch casing was drilled in to 95.5 m with final penetration of the drilling assembly to 105.5 m. Upon releasing from the casing, the reentry system hung up on the underreamer arms which failed to retract, and the entire assembly returned to the surface where it was recovered.

Hole U1527C is located at 34°51.6625′S, 179°3.2534′E, in a water depth of 1464.1 m. After installing 95.5 m of casing, we RCB cored continuously from 99.9 to 238.0 m and recovered 25.9 m (19%). There was extremely poor to no recovery in unconsolidated volcanic deposits until a formation change at 187 m, when average recovery increased to 49% for the rest of coring in cemented volcaniclastic rocks. Unstable hole conditions forced abandonment of Hole U1527C and, once again, the reentry system was unintentionally retrieved due to clogging of the hydraulic release tool and upper casing sub.

## Principal Results

*Igneous Petrology and Volcanology*

Igneous rocks cored at Site U1527 are subdivided into two units. Igneous Unit 1 was recovered in Hole U1527A (29.10–67.81 m) and Hole U1527C (108.40–176.16 m). It consists of a plagioclase-clinopyroxene phyric and Fe-Ti oxide-bearing, black dacite lava with a glassy trachytic groundmass, and stratigraphically related fresh scoria and pumice lapilli.

Igneous Unit 2 was recovered in Hole U1527C (185.20–234.38 m). The contact between Units 1 and 2 was not recovered. Igneous Unit 2 consists of progressively hydrothermally altered lapilli-tuffs and tuff-breccias, and divides into four subunits (2a–2d) based on changes in degree of alteration, matrix-to-clast ratio, and color. Igneous Subunit 2a (185.20–185.44 m) is a breccia consisting of fresh dacitic clasts surrounded by a brown fine-grained matrix, probably representing altered tuff. Igneous Subunit 2b (185.44–220.98 m) is composed of matrix-supported monomict and polymict lapilli-tuffs and tuff-breccias. Igneous Subunit 2c (220.98–226.49 m) is made up of clast-supported polymict tuff-breccias and lapilli-tuffs, while Igneous Subunit 2d (228.40–234.38 m) is composed of both altered matrix-supported and clast-supported tuff-breccias and lapilli-tuffs.

Igneous Unit 2 rocks contain various clasts of volcanic origin: (i) fresh to slightly altered dacite, found in Subunit 2a; (ii) volumetrically significant, greenish-gray altered volcanic clasts (type 1), found in Subunits 2b, 2c, and 2d; (iii) fine-grained, dark green altered clasts (type 2) found in Subunit 2b; and (iv) various types of rare dark gray volcanic clasts found in Subunits 2b, 2c, and 2d. The matrix of the volcaniclastic rocks and the groundmass of volcanic clasts (types 1–3) in Igneous Unit 2 appear very similar to the trachytic groundmass of the dacite clasts in Igneous Unit 1, but is increasingly replaced by secondary chlorite, clays, and quartz with depth. All clasts contain varying amounts of plagioclase, clinopyroxene, and Fe-Ti oxides, strongly resembling the primary phenocryst assemblage of the dacite lavas of Igneous Unit 1. Although the degree of alteration increases downhole, as indicated by the increasing degree of silicification, plagioclase crystals remain relatively stable and only slightly altered, whereas clinopyroxene alters significantly or disappears, and Fe-Ti oxides alter to sulfides.

*Alteration*

Three distinct types of alteration have been observed in core material recovered from Site U1527.

Alteration Type I (0–185.44 m) occurs in intervals of fresh to slightly altered volcanic rocks and is characterized by low-temperature alteration mineral assemblages. This alteration type is split into two distinct subtypes: Type Ia and Type Ib. Alteration Type Ia (0–185.20 m) consists of unaltered to slightly altered vesicular dacitic lava. Alteration is characterized by the formation of zeolite in vesicles and the occurrence of palagonite, iron-oxyhydroxide, and trace pyrite partly

replacing volcanic glass. Alteration Type Ib (185.20–185.44 m) solely pertains to the volcaniclastic breccia of Igneous Subunit 2a, being slightly to moderately altered. The clasts exhibit only trace alteration and retain primary plagioclase and clinopyroxene phenocrysts, but the degree of alteration within the matrix increases compared to Alteration Type Ia. The alteration material in the matrix consists of iron-oxyhydroxide and illite, with minor zeolite, smectite, magnetite, and pyrite.

Alteration Type II (185.72–234.38 m) is characterized by a pervasive alteration of most primary minerals within the clasts and matrix of volcanic breccia, replaced by clay minerals, silica, and pyrite. This alteration type is also subdivided into two subtypes. Alteration Type IIa (185.72–234.38 m; intercalated with Type IIb and Type III) features a pervasive green-gray chlorite-smectite mineral assemblage, with increasing amounts of silica/quartz infilling pore spaces, and increasing abundance of disseminated pyrite with depth. The moderate to intense alteration occurs in both clasts and matrix of the primary breccia. The degree of alteration within this interval increases downhole. Alteration Type IIb (186.40–208.06 m; intercalated with Type IIa) is characterized by several centimeter- to meter-scale zones of yellow-brown alteration which overprint the greenish Alteration Type IIa. The overprinting boundary is sharp. The iron-oxyhydroxide and occasionally oxidized pyrite give this alteration type its characteristic yellow-brown color. Throughout both the green and yellow-brown altered intervals, clasts display a range of degrees of alteration and resorption, from slightly altered clasts with primary igneous textures and sharp boundaries, to intensely altered clasts with diffuse boundaries to the surrounding matrix.

Alteration Type III (220.98–226.49 m) represents a more heterogeneous alteration type that is intercalated with Alteration Type IIa. In this type of alteration, both clasts and matrix are pervasively altered. The matrix contains dark gray silica and chlorite, disseminated pyrite (up to 3%), and magnetite. Vugs are partially filled with clay minerals and silica.

*Geochemistry*

Unaltered volcanic rocks from Hole U1527A and the shallower sections of Hole U1527C (Igneous Unit 1) represent dacites that are compositionally similar to those previously reported from Brothers volcano. However, two distinctly different trend lines for fluid-immobile incompatible trace element ratios (Zr/Y and $Zr/TiO_2$) suggest that the unaltered dacites from Holes U1527A and U1527C may derive from different magma sources.

Most of the pervasively altered breccias recovered from Hole U1527C (Igneous Unit 2) share the incompatible element composition of the overlying Igneous Unit 1 from the same hole, based on Zr, Y, and $TiO_2$ abundances. These findings indicate an origin from a common parental magma, despite petrographic differences. Geochemical analyses of the highly altered, variously colored volcaniclastic rocks demonstrate the mobility of alkali elements during high- and low-temperature hydrothermal alteration of the rock. Analyses of Ba, $K_2O$, Mg, and Si contents define a complex history of rock fragmentation marked by multiple alteration stages.

Geochemical changes recorded in Hole U1527C are consistent with petrographic observations, including the formation of pyrite and replacement of groundmass and matrix by clay in deeper, more altered volcaniclastic rocks.

Organic carbon comprises the bulk of measured total carbon concentrations. Only detectable from 185–205 m in Hole U1527C, this organic carbon may originate from seawater-derived fluid circulation and/or microbial biomass. Headspace analysis of gases evolved from Hole U1527C hard rock samples indicates higher-than-ambient $H_2$ contents that may be produced by mechanochemical sampling artifacts, such as generation during RCB drilling and/or crushing rock samples prior to headspace sampling.

*Structural Geology*

Site U1527 is characterized by moderate to steeply dipping alteration boundaries, fractures, and faults in addition to shallowly dipping shears and relatively few veins. Alteration boundaries are sharp and range in dip from 0° to 74° (average and median of 48°) and demarcate the transition from Alteration Type IIa to Alteration Type IIb. Fractures also have a moderate to steep dip with a range from 37° to 90°, an average of 68°. The density of veins and fractures is low, but increases slightly downhole. Fractures almost always have a brown/orange alteration halo overprinting all other types of alteration, indicating that formation of fractures is late. The presence of brown/orange alteration along fractures and defining Alteration Type IIb may indicate the ingress of seawater utilizing late-forming fractures. Faults were observed only in Hole U1527C and have a steep dip, ranging from 45° to 83° (average of 66°) and are most abundant in Igneous Subunit 2c. All faults represent discrete, centimeter-scale zones and have a normal sense of shear. Shallowly dipping shears are defined by elongate ribbons of white clays, which could represent flattened and altered volcanic clasts. White ribbons wrap around larger volcanic clasts, which may indicate some crystal-plastic deformation. The shallowly dipping shears, which average out at a dip of 22°, are overprinted by brittle faults. The overall lack of veins and indications of fractures being late suggest that alteration is not structurally controlled and may instead be due to pervasive flow.

*Paleomagnetism*

The two igneous units from Site U1527 have different natural remanent magnetization (NRM) intensities before demagnetization, with Igneous Unit 1 showing a more intense NRM (>0.5 A/m) than Igneous Unit 2. However, both units show a consistent direction of magnetization, with an average inclination of –59°, which is very close to the inclination of a geomagnetic axial dipole (GAD) of –60° at the latitude of Brothers volcano. This suggests a coherent young age for these rocks, most certainly during the current normal polarity Brunhes Geomagnetic Epoch. Igneous Unit 1 also shows significantly larger magnetic coercivities. Thermal demagnetization experiments from Igneous Unit 2 show a more complex pattern when compared to similar experiments from Igneous Unit 1, but coherently indicate magnetite or titanomagnetite as the main magnetic mineral in both lithologic units. In addition, susceptibility

measurements and isothermal reamanence magnetization (IRM) experiments suggest a comparable magnetite content in both units, with a slight decrease in Igneous Subunits 2c and 2d.

*Physical Properties*

Igneous Unit 1, consisting of fresh dacitic volcanics, shows an inverse correlation between porosity and bulk density, but not between porosity and *P*-wave velocity, nor between bulk density and *P*-wave velocity. Igneous Unit 2 (185.20–234.38 m; Hole C), consisting of variably altered volcanic breccia, displays an inverse correlation between porosity and bulk density, and between porosity and *P*-wave velocity. Mean bulk density (2.2 g/cm$^3$), porosity (30%) and *P*-wave velocity (3330 m/s) generally show small variations throughout Igneous Unit 2 and do not appear to be affected by transitions between alteration types. Alteration subtypes IIa and IIb are clearly identifiable on reflectance colorimetry. A sharp increase in *P*-wave velocity at the boundary between Igneous Subunits 2b and 2c (~4000 m/s and 4200 m/s on archive-half sections and discrete samples, respectively) is observed, followed by a downhole decrease in *P*-wave velocity to the end of Igneous Subunit 2c. This variation in *P*-wave velocity within Igneous Subunit 2c is reflected in a similar trend in bulk density, and matching inverse variation in porosity, which appears to be associated with deformation and shear in this unit.

Magnetic susceptibility (MS) measured on whole-round and section halves are compatible with discrete measurements. MS in Igneous Subunits 2a and 2b is overall higher than in Igneous Subunit 2c and 2d. Thermal conductivity values range from 1.09 to 2.35 W/(m·K) with an average of 1.72 W/(m·K). Igneous Unit 2 has higher values of thermal conductivity than Igneous Unit 1. Thermal conductivity in Igneous Unit 2 also contains variations over smaller scales, which reflect changes in type and distribution of alteration minerals. Low values of thermal conductivity occur where alteration is dominated by the presence of water-rich clay minerals (e.g., a low of 1.53 W/(m·K) in Igneous Subunit 2b at ~203.40 m). Meanwhile, the highest value of thermal conductivity is consistent with increases in pyrite, silica, and magnetite concentrations in Igneous Subunit 2c. Hence, thermal conductivity data reflect the heterogeneity of mineral compositions and alteration assemblages throughout the core.

*Microbiology*

Five whole-round samples and six headspace gas samples were collected from hydrothermally altered, relatively hard materials from Hole U1527C. The whole round samples (each 9–19 cm long) were processed and preserved as subsamples for shore-based investigations, which will include quantification of microbial and viral biomass; molecular analysis of extracted environmental DNA and RNA (eDNA and eRNA); estimation of microbial metabolic activity and viral production; and cultivation of subseafloor microbial components. Quantification of contamination tracer perfluoromethyl decaline (PFMD) was conducted for the drilling fluid as well as for the exterior and interior of whole-round samples. PFMD was routinely detected,

although barely above detection levels, indicating that penetration of drilling fluids to the interior of whole-round samples is minimal.