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Site U1529[1]

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Summary

Background and objectives

Site U1529 (proposed Site WC-1A) is located on the western side of the caldera floor of Brothers volcano at a water depth of 1765 m. The primary objective for this site was to drill a second hole (the first is at Site U1527) into the margin of the W Caldera upflow zone of a Type I hydrothermal system dominated by modified seawater-derived fluids. This site was planned not only to penetrate deeper into a Type I hydrothermal system but also to obtain a record of the recent eruptive history in the caldera.

Operations

We conducted operations in two holes at Site U1529. Hole U1529A is located at 34°52.5161′S, 179°3.5139′E at a water depth of 1735.0 m. We used the rotary core barrel (RCB) system to core from the seafloor to 12.0 meters below seafloor (mbsf) with a recovery of 1.86 m (16%). The downhole conditions encountered in Hole U1529A were extremely difficult because of unconsolidated volcaniclastic material, which caused high torque and tight hole conditions that ended drilling of this hole. In Hole U1529B, located at 34°52.5217′S, 179°3.5207′E at a water depth of 1733.0 m, RCB coring under similarly difficult hole conditions penetrated to only 34.4 mbsf with poor recovery of 0.6 m (1.7%). After encountering a tight hole, we attempted to work the drill string back to ~15 mbsf but lost circulation because the bit and jets were plugged with volcaniclastic material. This resulted in abandonment of Hole U1529B. An 8.2 m long ghost core was recovered from the core barrel that was in place while working the drill string out of the hole. In total, 44 h, or 1.8 days, was spent at Site U1529.

Principal results

Igneous petrology and volcanology

A single igneous unit was recovered in Holes U1529A (0–2.52 mbsf) and U1529B (0–24.82 mbsf). Igneous Unit 1 consists of decimeters-thick, alternating intervals of unaltered, black, plagioclase-pyroxene-phyric dacite lava and unconsolidated, black, monomict lapilli tephra. The contacts between the lava and the tephra were not recovered. The moderately vesicular (~10 vol%) lava was recovered as individual pieces 0.5 to 6 cm in length. The lava has a hypohyaline texture with a groundmass rich in flow-aligned plagioclase microlites and has fine fracture networks indicative of incipient breakup. The lapilli tephra consists of fine-ash– to medium-lapilli–sized angular to subangular fragments of dacite lava, as well as fragments of plagioclase and pyroxene crystals. Dacite lava at Site U1529 resembles the dacites recovered at Site U1527.

The ghost core from Hole U1529B, which contains material from anywhere between 0 and 34.4 mbsf, similarly consists of unconsolidated, unaltered, black, lapilli-ash ranging in size from ash to medium lapilli. Ash- and lapilli-sized clasts are subangular and angular with a vesicularity and mineral assemblage (plagioclase-clinopyroxene phenocrysts and glomerocrysts) consistent with the lapilli tephra being a mixture of Igneous Unit 1 volcanic rocks.

Alteration

The volcanic rocks of Igneous Unit 1 appear fresh to slightly altered. Alteration Type I is the only alteration type recognized at this site, and it occurs within the lapilli tephra and coarser fragments of dacitic lava. It is defined by the presence of minor smectite and Fe oxyhydroxide replacing phenocrysts and groundmass and lining some vesicles. A few individual clasts in Unit 1 are more strongly

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altered and contain microcrystalline silica, Fe oxyhydroxide, and a green clay mineral.

Geochemistry

Unaltered to slightly altered clasts and lapilli from Igneous Unit 1 are typical dacites, with SiO_2 ranging from 62.3 to 65.4 wt% and $Na_2O + K_2O$ ranging from 6.61 to 7.07 wt%. They are similar in major element composition to fresh dacites from Site U1527 and consistent with the low compositional range previously reported for dacites at Brothers volcano.

The uppermost sample (0.06 mbsf) from Hole U1529A and two samples from the ghost core have lower values of total carbon (TC) (<200 µg/g) than the other five samples from this hole, for which TC ranges from 221 to 344 µg/g. Total sulfur concentrations are below 220 µg/g and are consistent with total sulfur abundances previously reported from Brothers volcano. Total nitrogen (TN) and total inorganic carbon (TIC) are below the limit of detection for all Site U1529 samples.

Structural geology

At Site U1529, no meaningful structural measurements could be made because no recovered pieces of core were oriented. Some pieces of dacite have a network of microfractures, but no faults or alteration veins are present. In both Holes U1529A and U1529B, the main structure observed is a shape-preferred orientation defined macroscopically by vesicles and microscopically by vesicles, phenocrysts, and microlites.

Physical properties

The low recovery and the fragmented nature of the clasts and volcaniclastic sediments made the cores mostly unsuitable for continuous physical property measurements on whole-round cores and section halves. However, natural gamma radiation (NGR) measurements for Hole U1529A recorded values around ~12 counts/s (1.9 mbsf), and Section Half Multisensor Logger (SHMSL) point magnetic susceptibility (MSP) data indicate values as high as ~2250 × 10^{-5} IU (15.14 mbsf).

Five discrete samples from Hole U1529A and three samples from Hole U1529B, including cut clasts and volcaniclastics, were analyzed for moisture and density (MAD). Bulk density values range from 1.92 g/cm^3 to 2.37 g/cm^3, and grain density values range from 2.43 to 2.50 g/cm^3. Porosity ranges from 6 to 38 vol% and is inversely correlated with bulk density. Three measurements of P-wave velocity made in the x-direction on coherent clasts in Hole U1529A section halves vary from ~3500 to 4500 m/s. No thermal conductivity measurements were made because of the limited recovery and fragmented nature of the material.

Paleomagnetism

No paleomagnetic measurements were performed on Site U1529 samples because of the absence of any oriented core pieces.

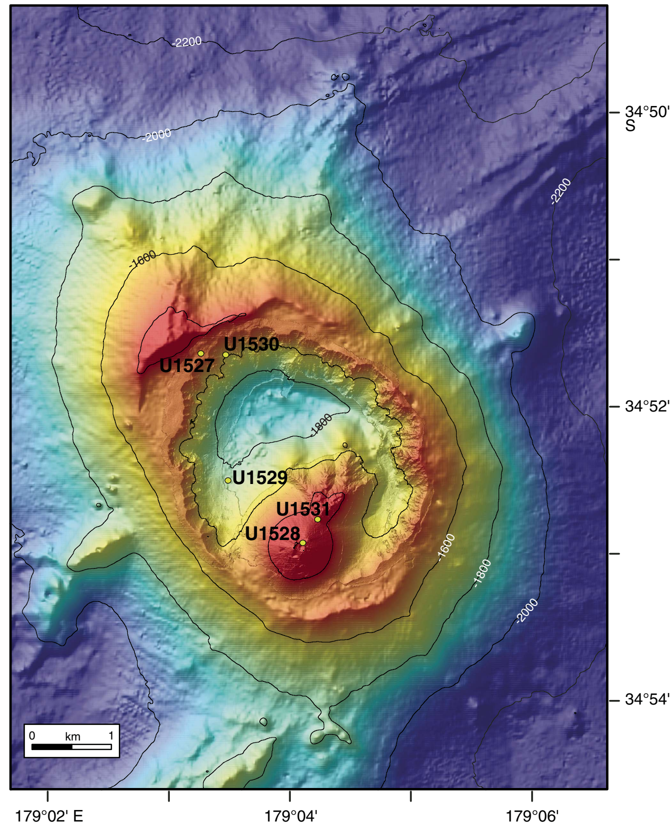
Microbiology

No samples were collected from Site U1529 for microbiological analyses because of the nature of the material recovered.

Background and objectives

Site U1529 is located on the western side of the caldera floor of Brothers volcano at 34°52.5162′S, 179°3.51402′E at a water depth of 1765 m (Figure **F1**). The primary objective for this site was to drill a second hole into the margin of the upflow zone of a Type I hydrothermal system dominated by modified seawater-derived fluids that would penetrate deeper into the system.

Figure F1. Detailed bathymetry of Brothers volcano and surrounding area showing the location of sites drilled during Expedition 376. Contour interval = 200 m. Modified from Embley et al., 2012.



Site U1529 lies 300 m southwest of seismic Line Bro-3 on a seafloor sloping as much as 10° (see Figure **F2** in the Site U1527 chapter [de Ronde et al., 2019c]). It is situated in a zone of low crustal magnetization, or "burn hole" (see Figure **F5** in the Expedition 376 summary chapter [de Ronde et al., 2019b]), modeled to be at least 300 m deep (Caratori Tontini et al., 2012) that delineates the W Caldera upflow zone but lacks obvious seafloor manifestations or any evidence for present-day hydrothermal activity from water column measurements made during a detailed autonomous underwater vehicle survey.

The plan for drilling, coring, and logging at Site U1529 was to penetrate ~565 m through the low-magnetic anomaly zone and into the footwall of the original caldera floor, thereby transecting the deepest parts of the hydrothermal system and obtaining an eruptive history within the caldera. Three general types of lithology were anticipated: sediments on the caldera floor, volcaniclastic material infilling the caldera, and lava forming the base of the caldera.

Operations

The original plan for Site U1529 was to drill two holes. The pilot hole was intended to core to ~50 mbsf with the RCB system (see Figure **F3** in the Site U1527 chapter [de Ronde et al., 2019c]). The second hole was dedicated to drilling in a reentry system to a depth determined by lithologies revealed in the pilot hole to facilitate 565 m of penetration at Site U1529. The actual operations consisted of

RCB coring two pilot holes, Hole U1529A to 12.0 mbsf and Hole U1529B to 34.4 mbsf, both of which had to be abandoned due to poor hole conditions.

Hole U1529A

After clearing the seafloor in Hole U1528C, the vessel moved slowly in dynamic positioning (DP) mode from Site U1528 to Site U1529 while continuing to recover the drill string. The 0.7 nmi transit was completed in between two periods of operations at Site U1528 (see **Operations** in the Site U1528 chapter [de Ronde et al., 2019d]). Once the bit cleared the rig floor at 0430 h on 27 May 2018, we made up the RCB bottom-hole assembly (BHA) (see Figure **F4** in the Site U1527 chapter [de Ronde et al., 2019c]) with a new CC-7 RCB coring bit. A perforated brass insert containing fractured quartz crystals wrapped in gold foil supplied by the science party was installed in the bit prior to assembly into the BHA (Figure **F2**). It was hoped that these crystals would trap borehole fluids (as fluid inclusions) while coring. The bit was then lowered to just above the seafloor, and the subsea camera system was run down to conduct a survey at Site U1529. Prospective hole positions were located, and the seafloor was tagged to confirm the water depth. The survey also verified the absence of vent-related animals. Upon recovery of the subsea camera system, Hole U1529A was spudded at 1610 h on 27 May at a water depth of 1735.0 m. RCB coring began with a 12 m core to allow us to make the first connection without clearing the seafloor. After Core 376-U1529A-1R penetrated the seafloor to 12 mbsf and recovered 1.86 m of core (15.5%), we measured high torque and had to work a tight hole from 12 mbsf back to the seafloor. We were unable to retrieve the core barrel, and the drill string had to be pulled out of the hole because of poor hole conditions related to unconsolidated volcanic material. Hole U1529A ended when the bit cleared the seafloor at 1925 h on 27 May. The core barrel was retrieved, and another core barrel was dropped. All cores, penetration depths, core recovery, and times recovered on deck are displayed in Table **T1**. The time spent in Hole U1529A was 15 h, or 0.6 days.

Figure F2. RCB coring bit used during Expedition 376. Bit has inserted perforated brass holder containing fractured quartz crystals designed to trap borehole fluids while implementing coring. (Credit: Tobias W. Höfig and IODP.)

Hole U1529B

The vessel was offset 20 m east from Hole U1529A, and RCB coring in Hole U1529B started at a water depth of 1733.0 m at 2030 h on 27 May 2018. Cores 376-U1529B-1R through 3R penetrated

Table T1. Site U1529 core summary. DRF = drilling depth below rig floor, DSF = drilling depth below seafloor, R = drilled interval, G = ghost core, DS = drill string. **Download table in CSV format.**

Hole U1529A
Latitude: 34°52.5161′S
Longitude: 179°3.5139′E
Seafloor (drill pipe measurement below rig floor, m DRF): 1746.0
Time on hole (days): 0.6
Total depth (drill pipe measurement from rig floor, m DRF): 1758.0
Distance between rig floor and sea level (m): 11.01
Total penetration (drilling depth below seafloor, m DSF): 12.0
Total length of cored section (m): 12.0
Total core recovered (m): 1.86
Core recovery (%): 15.5
Drilled interval (m): 0
Total cores (no.): 1

Hole U1529B
Latitude: 34°52.5217′S
Longitude: 179°3.5207′E
Seafloor (drill pipe measurement below rig floor, m DRF): 1744.0
Time on hole (days): 1.2
Total depth (drill pipe measurement from rig floor, m DRF): 1778.4
Distance between rig floor and sea level (m): 11.01
Total penetration (drilling depth below seafloor, m DSF): 34.4
Total length of cored section (m): 34.4
Total core recovered (m): 0.6
Core recovery (%): 1.7
Drilled interval (m): 0
Total cores (no.): 3

Core	Top of interval DSF (m)	Bottom of interval DSF (m)	Interval advanced (m)	Recovered length (m)	Curated length (m)	Recovery (%)	Date on deck (2018)	Time on deck UTC (h)	Time to cut core (min)	Core barrel	Mud pumped (bbl)	Driller's notes
376-U1529A-												
1R	0.0	12.0	12.0	1.86	3.00		27 May	0810	90	N-Mag	30	Approx 5 mbsf amp increase rocks and boulders probably more!! Work DS!!
		Hole U1529A totals:	12.0	1.86	3.00	15.50						
376-U1529B-												
1R	0.0	15.0	15.0	0.30	0.32	2.0	27 May	1150	95	N-Mag	60	
2R	15.0	24.7	9.7	0.20	0.22	2.1	27 May	1400	60	N-Mag	30	
3R	24.7	34.4	9.7	0.10	0.12	1.0	27 May	2040	135	N-Mag	60	
4G	34.4	34.4	0.0	8.17	8.17	0	27 May	2300		N-Mag		Lost circulation. Plugged jets. Depth 12.58 mbsf.
		Hole U1529B totals:	34.4	0.60	0.70	1.74						

from the seafloor to 34.4 mbsf with poor total recovery of 0.6 m (2%). All cores, penetration depths, core recovery, and times recovered on deck are displayed in Table **T1**. We again experienced a tight hole at the bottom depth and attempted to work the drill string back to ~15 mbsf. A core barrel was dropped to improve circulation; however, circulation was lost when the bit was at 15 mbsf. We then decided to abandon Hole U1529B because the drill bit and jets were plugged with debris and the hole conditions were extremely unstable. The drill string was pulled out of the hole, and the bit cleared the seafloor at 1015 h on 28 May. The core barrel that was in place during the attempt to get back to the bottom of the hole was then retrieved (i.e., Ghost Core 4G; 8.17 m of lapilli-sized tephra). After two unsuccessful attempts to establish an adequate pilot hole, coring operations at Site U1529 were abandoned. The drill string was pulled back to a water depth of 1116.5 m, and the vessel moved in DP mode back to Site U1528, where we arrived at 1530 h on 28 May to make a second attempt to reenter Hole U1528B. This attempt was not successful, so we recovered the drill string at 0025 h on 29 May, officially ending Hole U1529B. In total, 76.25 h, or 3.2 days, was spent in Hole U1529B.

Igneous petrology and volcanology

At Site U1529, one igneous unit was recovered (Figure **F3**) in intervals 376-U1529A-1R-1, 0 cm, to 1R-2, 102 cm (0–2.52 m), and 376-U1529B-1R-1, 0 cm, to 3R-1, 12 cm (0–24.82 m). Igneous Unit 1 consists of alternating intervals of unaltered, black, plagioclase-pyroxene-phyric dacite lava and unconsolidated, black, monomict, dacitic lapilli tephra (Figure **F4**). The contacts between the lava and the lapilli tephra were neither observed nor recovered. Furthermore, an 8.17 m long ghost core of unconsolidated, unaltered, black lapilli-ash was recovered at 0–34.4 mbsf and curated as Core 376-U1529B-4G.

Igneous Unit 1

Intervals: 376-U1529A-1R-1, 0 cm, to 1R-2, 102 cm; 376-U1529B-1R-1, 0 cm, to 3R-1, 12 cm
Depths: Hole U1529A = 0–2.52 mbsf; Hole U1529B = 0–24.82 mbsf
Lithology: plagioclase-pyroxene-phyric dacite lava alternating with black, monomict, dacitic lapilli tephra

Igneous Unit 1 consists of alternating intervals of unaltered, black, plagioclase-pyroxene-phyric dacite lava (7–16 cm thick intervals) and unconsolidated, monomict, dacitic lapilli tephra layers (16 to >32.7 cm thick). The dacite lava was recovered as fragments that range from 0.5 to 6 cm long. The fragments are unaltered plagioclase-pyroxene-phyric dacites with a glomeroporphyritic, hypohyaline texture. Macroscopically, the glassy and plagioclase-microphyric groundmass (~60–70 vol%) contains equigranular phenocrysts of plagioclase and pyroxene. The plagioclase phenocrysts (≤10 vol%) appear unaltered, are euhedral to subhedral, and have a maximum length of 5 mm. Pyroxene also appears unaltered, is less abundant than plagioclase (1 vol%), and occurs primarily in small (1 mm) subhedral to anhedral grains intergrown with the plagioclase glomerocrysts. The lava is moderately vesicular, with ~2 mm wide vesicles that are angular to subangular and elongate with low sphericity. The elongate axis of vesicles extends ≤20 mm.

Thin section observations (interval 376-U1529B-1R-1, 25–27 cm) (Figure **F5**) show a primary mineral assemblage of plagioclase (5 vol%), clinopyroxene (3 vol%), and Fe-Ti oxide (mainly magnetite, 2 vol%) (see **Paleomagnetism**) phenocrysts in a groundmass of pla-

Figure F3. Lithostratigraphic summary, Holes U1529A and U1529B.

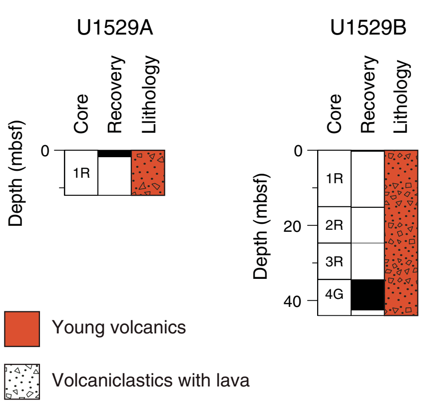


Figure F4. Representative macroscopic samples, Holes U1529A and U1529B. A. Volcaniclastic xenocryst included in dacite lava. B, C. Dacite with fractures accentuated by white halite. D. Lapilli-sized fragments of dacite lava.

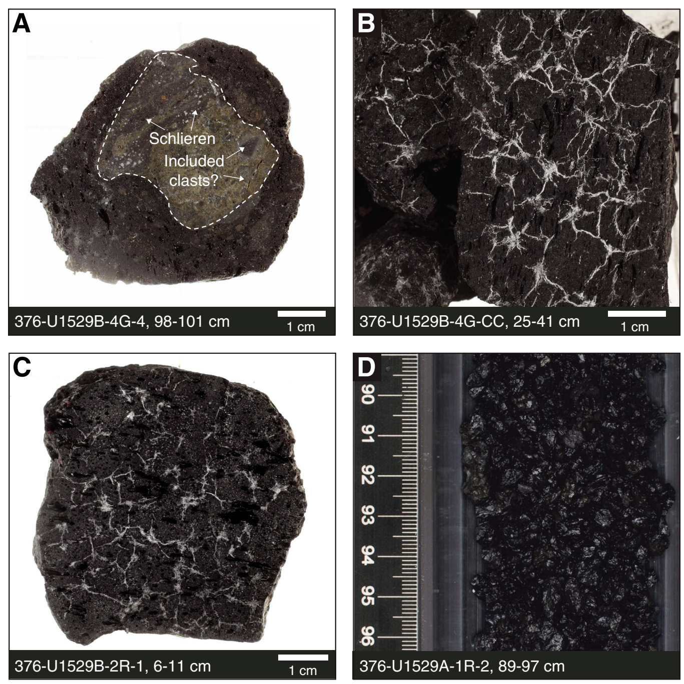


Figure F5. Representative thin section, Hole U1529B. A. Plane-polarized light (PPL). B. Cross-polarized light (XPL). Note both the elongated orientation of the vesicles that indicate flow texture and the abundant glomerocrysts in this rock.

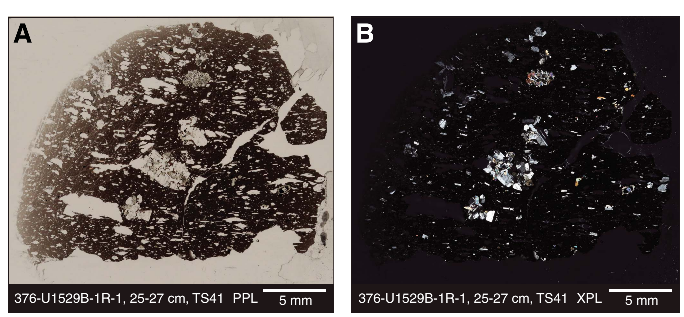


Figure F6. Representative microscopic images, Hole U1529B. A–C. Glomerocryst of plagioclase (Plag), clinopyroxene (Cpx), Fe-Ti oxides, and aphyric glass. MI = melt inclusion, Mss = monosulfide solid solution, Mt = magnetite. A. Transmitted, PPL. B. Transmitted, XPL. C. Reflected, PPL. Note the melt and sulfide inclusions hosted in plagioclase. D–F. Orthopyroxene–Fe-Ti oxide symplectite entrained in dacite lava. V = vesicle, Ol = olivine, Opx = orthopyroxene. D. Transmitted, PPL. E. Transmitted, XPL. F. Reflected, PPL.

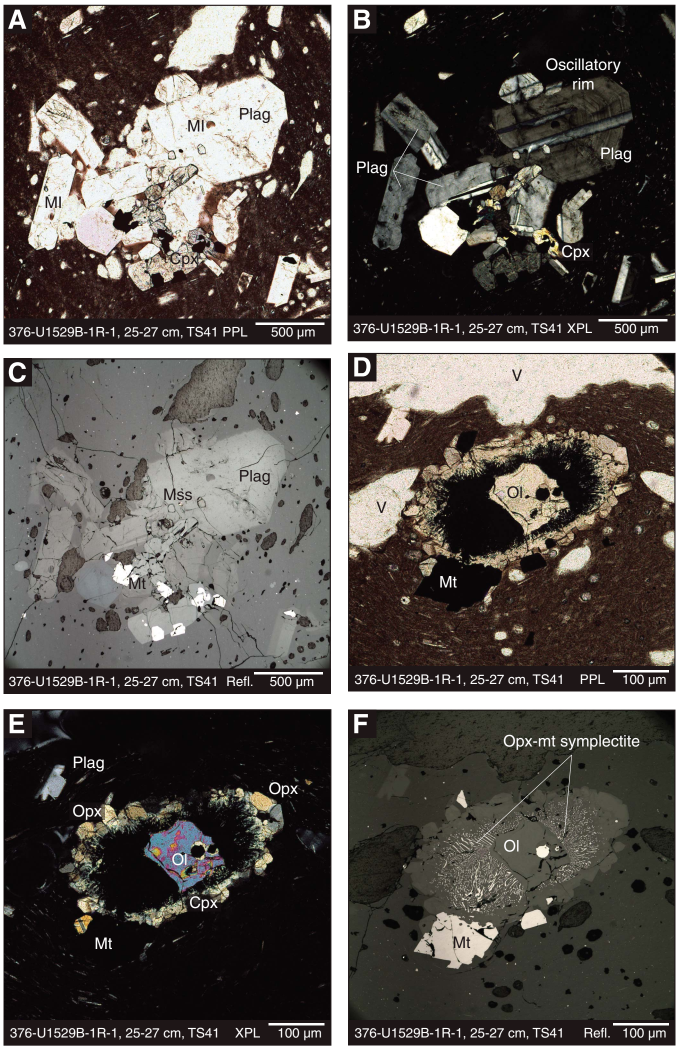


Table T2. Results from portable X-ray fluorescence (pXRF) analyses on rock powders, Site U1529. **Download table in CSV format.**

gioclase-microphyric, unaltered glass. The phenocrysts (~10 vol% in total) have an equigranular texture exhibited as scattered tabular and euhedral plagioclase (<1.5 mm); blocky, subhedral clinopyroxene (<0.6 mm); and cubic, euhedral Fe-Ti oxides (<0.3 mm) crystals. The groundmass makes up ~70 vol% of the thin section, with a further ~10 vol% each of glomerocrysts, vesicles, and phenocrysts (plagioclase, clinopyroxene, and Fe-Ti oxides). Glomeroporphyritic clots (~10 vol% of the rock) are composed of plagioclase (70 vol%; as large as 1.5 mm), clinopyroxene (20 vol%; as large as 1.5 mm), Fe-Ti oxides (3 vol%; as large as 0.2 mm), and interstitial glass (~7 vol%) but lack microlites (Figure **F6A, F6C**). Plagioclase crystals show rare oscillatory zonation and may contain melt and/or sulfide inclusions (Figure **F6A, F6C**). The groundmass (70 vol%) consists of 30 vol% unaltered dark brown glass with an intersertal trachytic texture of 40 vol% plagioclase microlites (<0.2 mm long). Vesicles make up ~10 vol%, range in size from 0.2 to 5 mm, are subrounded, and exhibit low (elongated) sphericity. Another notable feature is an orthopyroxene–Fe-Ti oxide symplectite resulting from the breakdown of olivine (Figure **F6D, F6F**). The 0.4 mm large olivine is overgrown by a symplectite of orthopyroxene and Fe-Ti oxide and surrounded by small (<0.1 mm) orthopyroxene crystals. The symplectite is unique and occurs only once in this thin section, but it has important implications for the petrogenesis of these rocks.

The black, monomict lapilli tephra is mostly well sorted and ranges in size from fine ash to medium lapilli with an average size of coarse ash to fine lapilli. The clasts are angular to subangular fragments of dacite lava. A smear slide from the finest grain size fraction of Core 376-U1529A-1R (Sample 1R-1, 69–70 cm) contains 85 vol% angular, vitric ash that resembles the larger lapilli clasts and fragments of dacite lava. The clasts are blocky, have no traces of vesicle walls, and contain plagioclase microlites in fresh glass. Crystals make up the remaining 15 vol%, including angular fragments of plagioclase (8 vol%) with visible melt inclusions, angular fragments of green and brown pyroxene crystals (5 vol%), and subangular fragments of Fe-Ti oxides (2 vol%).

Portable X-ray fluorescence analyses of powdered dacite lava in Igneous Unit 1 at Site U1529 are very similar in major and trace element composition to one another, as well as to dacite lava recovered at Sites U1527 and U1528 (Table **T2**).

Ghost Core 376-U1529B-4G

Interval: 376-U1529B-4G-1, 0 cm, to 4G-CC, 42 cm
Depth: Hole U1529B = 0–34.4 mbsf
Lithology: monomict, dacitic lapilli-ash

Unaltered, black dacitic lapilli-ash was recovered in a ghost core (core type G), which is a core filled with material derived from previously cored intervals that entered the core barrel during substantial hole cleaning operations. The hole terminated at 34.4 mbsf, and the ghost core may consist of material deposited anywhere from 0 to 34.4 mbsf that entered the core barrel as it was retrieved. Therefore, the stratigraphic context of the lapilli-ash and the original sorting and grading are unknown. The clasts of lapilli-ash range in size from ash to medium lapilli on average. Maximum clast sizes are very large pebbles.

Ash- and lapilli-sized clasts are subangular and angular with a vesicularity and mineral assemblage similar to that of Igneous Unit 1 (plagioclase and clinopyroxene phenocrysts and glomerocrysts; compare with the dacite of Unit 1). The lithologic similarity is consistent with the lapilli tephra and represents a mechanical mixture of Unit 1 dacitic rocks.

There are two notable features in the Site U1529 dacitic clasts. First, larger clasts from Ghost Core 376-U1529B-4G enclose other clasts of volcaniclastic origin at 33 and 100 cm in Section 4G-4 (Figure **F4A**). The volcaniclastic xenoliths, conspicuous by their brownish beige colors, range in size from 1 to 2.5 cm and are angular to subangular. The volcanic clast recovered in interval 4G-4, 98–101 cm, includes differently altered clasts, some darker and less altered than others, with areas of darker schlieren (Figure **F4A**).

Secondly, all larger dacite clasts of lava and tephra intervals in Igneous Unit 1 exhibit networks of very thin (<0.5 mm) fractures that sometimes take concentric forms. These fractures become visible on the drying rock surface (both cut and uncut), where they are accentuated by halite crystals precipitating from seawater (Figure **F4B, F4C**). Such fractures are observed to cut through the dacite, a volcanic clast in the dacite, and vesicles at interval 376-U1529B-4G-4, 98–101 cm.

Interpretation

Compositionally, the dacite lava from Site U1529 resembles that dredged from Brothers volcano during previous expeditions (e.g., Wright and Gamble, 1999; Haase et al., 2006; Timm et al., 2012) and material recovered at other sites during Expedition 376. These observations further confirm the hypothesis that Brothers volcano produces primarily dacite lava and tephras with limited compositional range and lacks the more mafic basaltic-andesite series rocks that are erupted from many other volcanoes of the Kermadec arc (e.g., Graham et al., 2008).

The presence of an orthopyroxene–Fe-Ti oxide symplectite, however, is possible evidence for olivine-bearing mafic materials residing deeper within the Brothers volcanic system. Olivine breaks down at subsolidus conditions at about 800°C (consistent with temperatures recorded from dacite magma chambers) (e.g., Millet et al., 2014) when primary magmatic Fe-Ti oxides are present and in chemical disequilibrium (Barton and Van Gaans, 1988). We thus suggest that a mafic, olivine–Fe-Ti oxide–bearing cumulate was entrained by the dacite magma during eruption.

Although larger dacite fragments suggest emplacement during effusive eruptions, the abundant lapilli tephra experienced significant fragmentation prior to deposition. Fragmentation can stem from explosions due to magmatic gas expansion and/or interaction with seawater or collapse of lava formations (gravitational or due to internal gas pressure). Dacite lava and dacitic lapilli tephra alternate with each other in intervals of decimeter thickness. Because of pronounced disturbance by drilling, it is unclear to what extent the alternate layering and the measured thicknesses represent an original, in situ sequence. We suggest that the recovered lithologies are part of poorly sorted, fractured rock debris that typically accumulates within volcanic calderas in the near vicinity of an active volcanic edifice.

The fine-fracture networks observed in many Site U1529 dacite clasts suggest that the lava began to break up after solidification. A preliminary interpretation is that rapid cooling caused incipient cracking of the glassy dacite magma by thermal contraction during emplacement in a subaqueous eruption. Such fracturing may facilitate further disintegration of the dacite lava and be the first stage of the process that produces the highly abundant lapilli clasts found at Site U1529 (Figure **F4B, F4D**).

The volcaniclastic xenoliths resemble pick-up clasts that are integrated into the cooling, viscous lava. This integration may happen as the ascending magma passes the wall of the conduit or, after eruption, as the flowing magma advances across a pre-existing seafloor either composed of volcaniclastic rock or covered by volcaniclastics accumulated by erosion (or collapse) of the surrounding caldera walls.

Alteration

The volcanic rocks of Igneous Unit 1 at Site U1529 appear fresh to slightly altered. Alteration Type I is the only alteration type recognized at this site, and it is defined by the presence of smectite and Fe oxyhydroxide, the two primary alteration phases identified in these rocks. However, some individual clasts (xenoliths) in Unit 1 are highly altered and contain microcrystalline silica and Fe oxyhydroxide.

Alteration Type I

Distinguishing alteration minerals: smectite + Fe oxyhydroxide
Degree of alteration: slightly altered
Intervals: 376-U1529A-1R-1, 0 cm, to 1R-2, 150 cm; 376-U1529B-1R-1, 0 cm, to 4G-CC, 42 cm
Depths: Hole U1529A = 0 –12.0 mbsf; Hole U1529B = 0–34.4 mbsf

Alteration Type I occurs within the lapilli tephra and coarser fragments of dacitic lava. It is characterized by minor replacement of phenocrysts and groundmass by smectite and by Fe oxyhydroxide coating vesicle walls (Figure **F4A**). X-ray diffraction analysis of eight samples from Holes U1529A and U1529B indicate that no other detectable alteration mineral phases are present. The xenoliths in the fresh to slightly altered dacitic lava in the ghost core, however, are highly altered to microcrystalline silica, Fe oxyhydroxide, and an unidentified green clay mineral (Figure **F4A**). Contacts between the xenoliths and dacitic lava are sharp.

Synthesis and interpretation

The alteration mineral assemblage and low degree of alteration that characterize Alteration Type I are consistent with low-temperature alteration by seawater. The altered xenoliths preserve a more extensive alteration overprint of silica and clay minerals that occurred prior to final deposition of the tephra.

Structural geology

Holes U1529A and U1529B: Igneous Unit 1

In Holes U1529A and U1529B, the main structure is a shape-preferred orientation defined macroscopically by vesicles and microscopically by vesicles, phenocrysts, and microlites. Some vesicles have a high aspect ratio and define a lineation. Sample 376-U1529B-1R-1, 25–27 cm (thin section [TS] 41; 0.25 mbsf), exhibits vesicles with a high aspect ratio defining a fabric, along with microlites of plagioclase and phenocrysts of plagioclase and clinopyroxene. Glomerocrysts are also aligned with the fabric, but phases within the glomerocrysts are not, suggesting the glomerocrysts were formed prior to eruption and fabric formation. Unfortunately, no pieces of core were oriented, so no meaningful structural measurements could be made. Some pieces of dacite show microfractures highlighted by the preferential growth of secondary halite (see **Igneous petrology and volcanology**). No faults or alteration veins are present in the cores recovered from Holes U1529A and U1529B.

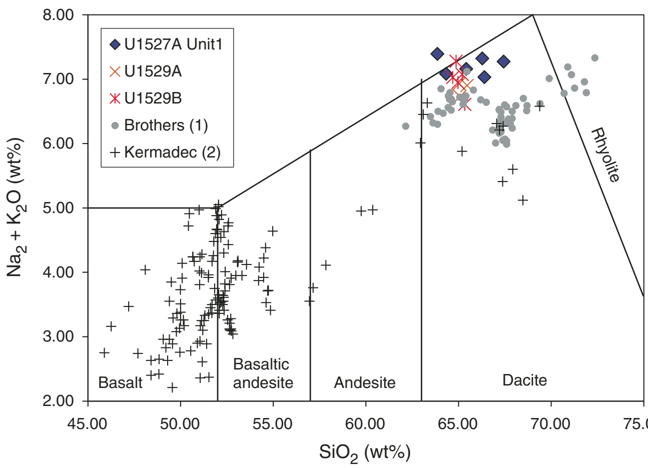
Geochemistry

Hard rock geochemistry

Eight volcanic samples were selected for shipboard geochemical analysis of major and trace element compositions (Tables **T2**, **T3**). All samples are from Igneous Unit 1 and are characterized as fresh to slightly altered, black, plagioclase-pyroxene phyric dacite lava or unconsolidated, black, monomict lapilli tephra (see **Igneous petrology and volcanology** and **Alteration**). Samples span the depth range of Holes U1529A and U1529B (i.e., from 0.06 mbsf [Sample 376-U1529A-1R-1, 6–7 cm] to ~34.5 mbsf [Samples 376-U1529B-

Table T3. Major and trace element abundances determined by inductively coupled plasma–atomic emission spectroscopy (ICP-AES), Site U1529. **Download table in CSV format.**

Figure F7. Total alkali ($Na_2O + K_2O$) vs. silica (SiO_2). Data are reported for unaltered dacites from Hole U1527A (Igneous Unit 1) and unaltered to slightly altered dacitic clasts and lapilli from Holes U1529A and U1529B. Major element oxide concentrations reported in Table T3 were recalculated to 100% on a volatile-free basis. Additional data include (1) dacitic to rhyolitic glasses and whole rock from Brothers volcano reported in previous studies (Haase et al., 2006; Wright and Gamble, 1999; Timm et al., 2012) and (2) subaerial lava recovered along the Kermadec arc (25°–37°S) (data compiled from the GEOROC geochemical database, **http://georoc.mpch-mainz.gwdg.de/georoc**; downloaded on 5 June 2018) are also reported for comparison.



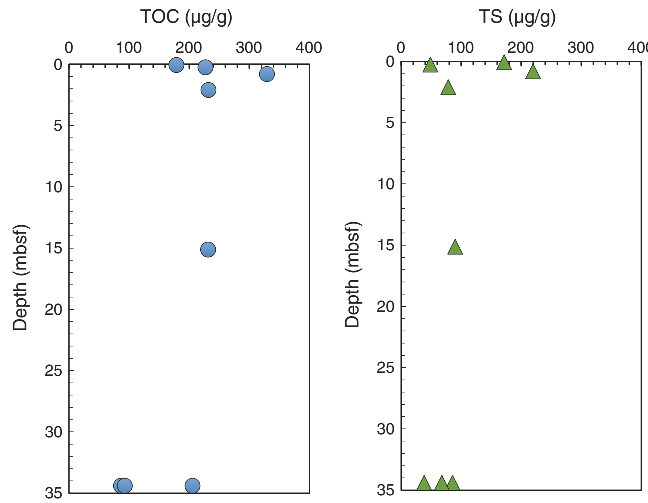
4G-3, 114–115 cm; 4G-5, 33–34 cm; and 4G-CC, 37–38 cm]). Hole U1529B terminated at 34.4 mbsf, and Ghost Core 376-U1529B-4G may consist of any material deposited between 0 and 34.4 mbsf. Therefore, the stratigraphic context of the lapilli-ash and downhole geochemical variations are unknown. Three samples were chosen from Hole U1529A, and five samples were chosen from Hole U1529B. Three of the Hole U1529B samples were collected from the ghost core and have therefore been ascribed a single depth for interpretation purposes (34.4 mbsf).

Unaltered to slightly altered dacitic clasts and lapilli from Holes U1529A and U1529B (Igneous Unit 1) are typical dacites with SiO_2 concentrations ranging from 62.3 to 65.4 wt% and $Na_2O + K_2O$ contents ranging from 6.61 to 7.07 wt% (Table **T3**; Figure **F7**). The similarity of major elements in fresh dacites from Sites U1529 and U1527 is consistent with the limited compositional range previously observed in dacites at Brothers volcano (Wright and Gamble, 1999; Haase et al., 2006; Timm et al., 2012; Graham et al., 2008). Average compositions of dacitic clasts are also reported in Table **T3** and are compared with average compositions of unaltered dacites from Unit 1, Hole U1527A. For all major elements and most trace elements, geochemical compositions of unaltered dacites from Holes U1529A, U1529B, and U1527A are indistinguishable from each other.

The eight powdered samples of dacitic clasts and lapilli collected for inductively coupled plasma–atomic emission spectroscopy (ICP-AES) analysis from Holes U1529A and U1529B were also analyzed for TC, TN, and total sulfur contents using the elemental analyzer. TIC abundance was also determined for all powdered samples by coulometry (see **Geochemistry** in the Expedition 376 methods chapter [de Ronde et al., 2019a]). The shallowest sample (0.06 mbsf) from Hole U1529A and two samples from the ghost core have lower values of TC (<200 µg/g) relative to the other five samples, in which TC ranges from 221 to 344 µg/g (Table **T4**). Total sulfur concentrations are below 220 µg/g and are consistent with low total sulfur abundances determined in previously analyzed samples from Brothers volcano (Haase et al., 2006). TN and TIC are below the limit of detection for all Site U1529 samples (<30 µg/g for both methods) (Table **T4**).

Table T4. Total carbon (TC), total sulfur (TS), and total nitrogen (TN), measured by elemental analyzer; total inorganic carbon (TIC) measured by coulometry; and total volatiles measured by loss on ignition (LOI), Holes U1529A and U1529B. **Download table in CSV format.**

Figure F8. Downhole variations of total sulfur (TS) and TOC of dacitic clasts and lapilli, Holes U1529A and U1529B.



Calculated total organic carbon (TOC) contents range between 90 and 330 µg/g. Representative results are shown in Figure **F8**, and the data are reported in Table **T4**. Overall, all samples from Site U1529 contain low total volatile abundance as confirmed by correspondingly low loss on ignition (LOI) values (0.4–1.4 wt%).

Headspace analysis of H_2, CO, CH_4, and C_2H_6

Pore space dissolved gas abundances including H_2, CO, CH_4, and C_2H_6 were determined via headspace analysis of a single sample from 2.02 mbsf in Hole U1529A. Dissolved C_2H_6 concentration was below the detection limit (<0.03 µmol/L), whereas H_2, CH_4, and CO concentrations were 0.85, 2.76, and 2.49 µmol/L, respectively. These concentrations are consistent with ambient air concentrations and are probably not related to any hydrothermal fluid input.

Interstitial water

One interstitial water (IW) sample was collected from the ghost core at Site U1529 (Sample 376-U1529B-4G-3, 130–150 cm). Water was extracted from 20 cm of unconsolidated dacitic lapilli by ramping to 30,000 lb (13,608 kg) of applied force on the Manheim squeezer. The volume of fluid extracted was less than 4 mL. Because of the loose nature of the material and its large grain size, the outer core surface was not removed prior to IW extraction. The suite of analyses conducted on the ship was limited by sample volume (see **Geochemistry** in the Expedition 376 methods chapter [de Ronde et al., 2019a]). Geochemical data for the IW sample are given in Table **T5**. Major and minor cation and anion concentrations, pH, and alkalinity values for the sample match the composition of drilling fluid (surface seawater; see **Geochemistry** in the Expedition 376 methods chapter [de Ronde et al., 2019a] for sampling details), within analytical error. Thus, it is likely that the IW is primarily derived from ambient seawater mixed into the ghost core. Further-

Table T5. Geochemistry of interstitial water sample, Hole U1529B. **Download table in CSV format.**

more, a comparison of the chemical composition of drilling fluid and the IW extracted from Sample 4G-3, 130–150 cm, provides an assessment of possible contamination of trace metals that can be contributed by drilling activities at moderate temperature and near-neutral pH conditions in the shallow seafloor. For example, abundances of Al, Co, Cr, Cu, Mn, Ni, V, and Zn were all elevated in the IW sample relative to drilling fluid (Table **T5**).

Paleomagnetism

No paleomagnetic measurements were performed on the samples from Site U1529 because of the absence of any oriented pieces of core in any of the sections.

Physical properties

Physical property data for Site U1529 were obtained for cores from Holes U1529A and U1529B. Core temperatures were ~10°–17°C upon arrival on the rig floor. Cores were left to equilibrate to room temperature (~20°C) prior to further analyses. Core recovery was low and limited to fragmented clasts and unconsolidated volcaniclastic deposits that were mostly unsuitable for continuous measurements along whole-round cores and section halves. Discussion of these data is therefore restricted to qualitative assessment of whole-round NGR and section-half MSP data. Additional measurements were made on discrete samples. In total, five samples from Hole U1529A and three samples from Hole U1529B, including cut clasts and coarse-grained tephra, were analyzed for MAD. Three measurements of *P*-wave velocity were also made on coherent clasts in section halves from Hole U1529A. No thermal conductivity measurements were made because of the limited recovery and the fragmented nature of the material.

Density and porosity

Individual MAD porosity and bulk, dry, and grain density values are given in Table **T6**. Bulk density values range from 1.92 to 2.37 g/cm^3 with an average of 2.21 g/cm^3 across Holes U1529A and U1529B. Grain density values range between 2.43 to 2.50 g/cm^3 and have a mean value of 2.46 g/cm^3. Porosity ranges from 6 to 38 vol% with a mean value of 17 vol% and is inversely correlated with bulk density.

P-wave velocity

P-wave velocities were measured in the *x*-direction on three rock fragments in section halves from Hole U1529A (Table **T7**). Measured *P*-wave velocities were ~3500, ~4000, and ~4400 m/s at 0.65, 2.60, and 2.83 mbsf, respectively.

Magnetic susceptibility

SHMSL MSP data are generally higher for volcanic rock fragments than for volcaniclastics, which likely reflects the smaller amount of material in direct contact with the sensor in the unconsolidated volcaniclastics. For volcanic rock fragments, the highest recorded magnetic susceptibility is 2252 × 10^{-5} SI (Core 376-U1529B-2R-1; 15.14 mbsf).

Natural gamma radiation

NGR data for Hole U1529A were between 5 and 13 counts/s, and the maximum value was recorded at 1.2 mbsf in Section 376-U1529A-1R-1. All cores recovered from Hole U1529B were shorter than 50 cm and could not be measured with the Natural Gamma Radiation Logger.

Table T6. Moisture and density (MAD), Holes U1529A and U1529B. **Download table in CSV format.**

Table T7. *P*-wave velocity, Hole U1529A. **Download table in CSV format.**

Reflectance colorimetry

Reflectance colorimetry values show no significant variations, which is consistent with the homogeneous black to dark gray color of the recovered material from both holes.

Integration of observations

Physical property measurements made on limited, fragmented core recovered from Holes U1529A and U1529B are consistent with unaltered dacite lava and tephras and similar to values found for Igneous Unit 1 at Sites U1527, U1528, and U1531. The limited recovery, fragmented nature of the core, and lack of oriented pieces limit further interpretation of the physical properties of Holes U1529A and U1529B.

Microbiology

Sampling efforts for microbiology during Expedition 376 were focused on cores with softer materials (i.e., clays) resulting from hydrothermal alteration and on rocks with fractures and veins filled with alteration minerals. Because the recovered material at Site U1529 was mainly unconsolidated, fresh, homogeneous, hard volcanics, no samples were collected for microbiological analyses. Tephra deposits could not be utilized for microbiological studies because there was no way to sample uncontaminated parts of the material due to their high porosity.

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