International Ocean Discovery Program
Expedition 376 Scientific Prospectus

Brothers Arc Flux

Gateway to the subarc mantle: volatile flux, metal transport, and conditions for early life

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Abstract

Almost two-thirds of Earth's submarine volcanism is expressed in the ocean basins along the ~65,000 km long mid-ocean-ridge (MOR) system, but the remaining third takes place along intraoceanic arcs and seamounts. The 22,000 km long intraoceanic arc system appears to surpass the MOR system in terms of both the frequency of hydrothermal activity, with several sites per 100 km of arc, and the range in chemical composition of the fluids being discharged.

Hydrothermal systems hosted by submarine arc volcanoes differ substantially from those in spreading environments in that they commonly contain a large component of magmatic fluid. Our primary scientific goal is to discover the fundamental underlying processes that develop as a consequence of this difference. A magmatic-hydrothermal signature, coupled with the shallow depths of arc volcanoes and their high-volatile contents, strongly influences the chemistry of fluids and the resulting mineralization and likely has important consequences for the biota associated with these systems. Because of the high metal contents and very acidic fluids, these hydrothermal systems are also thought to be important analogs of many porphyry copper and epithermal gold deposits mined today on land.

Drilling at Brothers volcano on the Kermadec arc will provide the missing link (i.e., the third dimension) in our understanding of mineral deposit formation along arcs, the subseafloor architecture of these volcanoes and their related permeability, as well as the relationship between the discharge of magmatic fluids and the deep biosphere. Expedition 376 will drill and log two caldera sites, one on the rim of the caldera and a second inside the caldera, and a third site at the summit of a volcanic cone, located inside the caldera at Brothers. These sites represent discharge zones of geochemically distinct fluids that are variably affected by magmatic volatile input, allowing us to directly address the consequences of magma degassing for metal transport to the seafloor and its effect on the functioning of microbial communities. Drilling will provide access to critical zones dominated by magma degassing and high-temperature hydrothermal circulation over depth intervals regarded as crucial, not only in the development of multiphase mineralizing systems but also in identifying subsurface microbially habitable environments. The specific objectives of Expedition 376 are

- To characterize the subvolcano, magma chamber–derived volatile phase to test model-based predictions that this is either a single-phase gas or two-phase brine-vapor;
- To determine the subseafloor distribution of base and precious metals and metalloids and the reactions that have taken place along pathways to the seafloor;
- To quantify the mechanisms and extent of fluid-rock interaction and consequences for mass transfer of metals and metalloids into the ocean and the role of magmatically derived carbon and sulfur species in mediating these fluxes; and
- To assess the diversity, extent, and metabolic pathways of microbial life in an extreme, metal-toxic, and acidic volcanic environment.

Expedition schedule

Expedition 376 is based on International Ocean Discovery Program (IODP) drilling Proposal 818-Full2 (available at **http://iodp.tamu.edu/scienceops/expeditions/brothers_arc_flux.html**). Following ranking by the IODP scientific advisory structure, the expedition was scheduled for R/V *JOIDES Resolution,* operating under contract with the *JOIDES Resolution* Science Operator (JRSO). At the time of publication of this *Scientific Prospectus,* the expedition is scheduled to start in Auckland, New Zealand, on 5 May 2018 and to end in Auckland on 5 July. Accounting for 5 days of port call and 2 days of transit, a total of 54 days will be available for drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see **http://iodp.tamu.edu/scienceops/**). Further details about the facilities on board the *JOIDES Resolution* can be found at **http://www.iodp.tamu.edu/publicinfo/drillship.html.**

Introduction

Volcanic arcs are the surface expression of magmatic systems that result from the subduction of mostly oceanic lithosphere at convergent plate boundaries. Arcs with a submarine component include intraoceanic arcs and island arcs that span almost 22,000 km on Earth's surface, with the vast majority located in the Pacific region (de Ronde et al., 2003). It is estimated that all intraoceanic arcs combined may contribute hydrothermal emissions equal to ~10% of that from mid-ocean ridges (MORs) (Baker et al., 2008).

Hydrothermal activity associated with these submarine arc volcanoes is commonly dominated by the discharge of magmatic volatiles, in contrast to MOR systems, which are governed by seawater circulation through basaltic oceanic crust. Submarine arc magmatic-hydrothermal systems are driven by crystallization of magmas produced through partial melting of mantle that is fluxed by volatiles released from the subducting slab. These magmas are an order-of-magnitude enriched in volatiles compared with MOR basalts (e.g., Wallace, 2005; Plank et al., 2013). The degassing of these arc magmas gives rise to extraordinary phenomena, such as the discharge of liquid CO_2 (Lupton et al., 2006) and the formation of liquid "lakes" of sulfur on the seafloor (de Ronde et al., 2015). Although intraoceanic arcs are some of the most hostile environments for life because of the exceptionally high concentrations of toxic metals and metalloids in very acidic (and gas rich) fluids, diverse animal and microbial communities are commonly observed (e.g., Clark and O'Shea, 2001; Takai et al., 2009).

The Kermadec segment of the Kermadec-Tonga intraoceanic volcanic arc (Figure **F1A**) is host to ~30 large volcanoes of which 80% are hydrothermally active, making it the most active arc in the world. Magmatic-hydrothermal signatures, including high concentrations of sulfur and carbon species gases and high iron contents, coupled with the shallow depths of venting (~1800–120 m below sea level [mbsl]) of these volcanoes, heavily influence the chemistry of the discharging fluids and the minerals that precipitate from these fluids, and have important consequences for the biota associated with these systems. Given the high metal contents and very acidic fluids, these hydrothermal systems are also thought to be important analogs for many of the porphyry copper and epithermal gold deposits exploited on land today.

Brothers volcano of the Kermadec arc is an excellent example of a submarine arc hydrothermal system and has been the focus of a continuing series of studies. Indeed, an IODP workshop (Lisbon, November 2012; **http://www.ecord.org/science/magellanplus/**) identified Brothers volcano as the top candidate worldwide for arc volcano drilling to provide the missing link (i.e., the third dimension) in our understanding of mineral deposit formation along arcs and the subseafloor architecture of these volcanoes and their related permeability, as well as the relationship between the discharge of magmatic fluids and the deep biosphere.

During Expedition 376, we plan to core and log three primary (with four alternate) sites located in the caldera, on its rim, and at the summit of a volcanic cone inside the caldera of Brothers volcano. They represent discharge zones of geochemically distinct fluids that are variably impacted by magmatic volatile input, enabling us to directly study the implications of magma degassing for metal transport to the seafloor and its influence on the functioning of microbial communities.

Scientific background and geological setting

The Kermadec-Tonga arc northeast of New Zealand (Figure **F1A**) is one of the longest continuous intraoceanic arcs in the world. Approximately 80 volcanoes of varying size—the vast majority of which are submarine—occur along the arc, with more than half occurring within the Kermadec sector (de Ronde et al., 2003, 2007). Volcanic rocks along the Kermadec arc range in composition from basalt to rhyodacite. Trace element and isotopic data indicate significant magma source heterogeneity both along and across the arc as a result of variable subduction of continent-derived sediments, pelagic sediments, and oceanic crust and/or interaction with continental crust (e.g., Gamble and Wright, 1995; Gamble et al., 1996; Haase et al., 2002; Timm et al., 2012, 2013, 2014).

Brothers volcano (Figure **F1B**) is one of three caldera volcanoes included in 13 major volcanic edifices that form the active Kermadec volcanic arc front between 37° and 34°50′S (Wright, 1997; Wright and Gamble, 1999). Brothers is part of a ~35 km long and 15 km wide predominantly silicic volcanic complex that is dissected by basement fractures and associated dike-controlled ridges that are 1–1.5 km wide and rise 400–500 m above the seafloor. These structures strike predominantly northeast (55°–65°), although a conjugate set of faults is oriented subparallel to the elongated Brothers edifice and caldera (Figure **F1B**). These bearings are consistent with rifting of the Havre Trough (e.g., Wright et al., 1996; Delteil et al., 2002; Ruellen et al., 2003) and indicate first-order extensional tectonic control on Brothers volcano. The base of Brothers volcano rises from ~2200 mbsl to a continuous caldera rim at 1540 mbsl, with an outer, northwestern rim shoaling to 1320 mbsl (Figure **F2**). The caldera floor has a basal diameter of 3–3.5 km, averages 1850 m deep, and is surrounded by 290–530 m high walls. An elongate northeast–southwest, 1.5–2 km wide and 350 m high postcollapse cone (Upper Cone) occurs within the caldera, with a satellite cone (Lower Cone) conjoined with its northeast flank. The Upper Cone in part coalesces with the southern caldera wall and shoals to 1220 mbsl (de Ronde et al., 2005).

Brothers volcano represents a window into the complicated hydrothermal systems that are found at submarine arc volcanoes, with a range of geological and structural settings, and vent fluid chemistry, as well as animals and microbes, as yet undiscovered at any other site on the seafloor. Four hydrothermal fields have been identified on the caldera walls at Brothers volcano with three of them active (i.e., Upper Caldera, NW Caldera, and W Caldera) and a fourth that appears to be inactive, or at least it does not contribute to vent plumes measured above the seafloor (Baker et al., 2012). Two other active vent fields sit atop the Upper and Lower cones, respectively. Extensive autonomous underwater vehicle (AUV) mapping of the caldera (de Ronde et al., 2012; Embley et al., 2012) shows that these hydrothermal fields are closely correlated to areas defined by magnetic "lows," consistent with zones of hydrothermal upflow where numerous manifestations of seafloor venting are seen on the seafloor (Figure **F3**) (Caratori Tontini et al., 2012a, 2012b; Gruen et al., 2012).

Two different types of hydrothermal activity represent the active fields. Type I is characterized by high-temperature (up to 312°C) venting of relatively gas-poor, moderately acidic fluids at the W, NW, and Upper Caldera sites, where Cu-Au-rich sulfide chimneys are commonplace. By contrast, Type II is characterized by lower temperature (≤120°C) venting of gassy, very low pH fluids (to 1.9) at the summits of the two cone sites where native sulfur chimneys and extensive Fe oxyhydroxide crusts occur (de Ronde et al., 2005, 2011). Time-series studies, carried out between 1999 and 2011, of hydrothermal plumes above the two most active sites (i.e., NW Caldera and both Cone sites) have shown that the Upper Cone site in particular has expelled fluids of widely differing composition over that time period, with large variations in dissolved H_2S, particulate Cu, dissolved Fe, and Fe/Mn values (de Ronde et al., 2011). In contrast, chemically distinct chronic plumes above the NW Caldera site have not changed in composition over the same interval (de Ronde et al., 2005).

Microbial community development patterns associated with the two different types of hydrothermal activity at Brothers volcano have been explored using a limited number of samples collected from the seafloor (Stott et al., 2008; Takai et al., 2009). Microbial community compositions obtained from chimneys at the NW Caldera site are characterized by an abundance of slightly thermophilic and hyperthermophilic chemolithoautotrophs (Takai et al., 2009), as observed in typical high-temperature hydrothermal vent environments of MORs and backarc basin systems (Nakamura and Takai, 2014). On the contrary, microbial communities from the Cone site exhibit a diversity of bacterial lineages, with potential psychrophilic and thermophilic sulfur- and iron-oxidizing chemolithotrophs (Stott et al., 2008) found in the magmatic volatiles-rich hydrothermal environments of submarine arc volcanoes (Nakamura and Takai, 2014). These intrafield differences in microbial community composition and function are thought to be associated with the different hydrothermal fluid compositions distinguishing the two types of hydrothermal activity. In particular, the highly variable volatile species concentrations induced by phase separation, the variable mixing ratios of hydrothermal and seawater inputs, and the concomitant precipitation of mineral phases are considered crucial factors in the control of chemosynthetic microbial community development (Takai and Nakamura, 2011; Nakamura and Takai, 2014). The existence of two distinct hydrothermal microbial ecosystems occurring together within a single caldera—showing a clear niche segregation in response to both physical and chemical differences in the hydrothermal fluids—is currently globally unique (Flores et al., 2012; Nakamura and Takai, 2014).

Modeling of the subseafloor hydrology at Brothers volcano has suggested that phase separation, inferred from measured temperatures and calculated end-member vent fluid chemical and isotopic compositions, can be achieved only by the input of saline magmatic fluids at depth (de Ronde et al., 2011; Gruen et al., 2012, 2014). In addition, the venting appears to evolve over a short period of time, with the expulsion of magmatic heat and volatiles occurring within the first few hundred years of magma emplacement in the form of low-salinity, vapor-rich fluid while magmatically derived salt is temporarily trapped in the crust. This retained salt is then periodically expelled from the system by later convection of seawater (Gruen et al., 2014). This model has important implications for the distribution of metals during hydrothermal mineralization. For example, sulfide-complexed metals such as Au will be preferentially transported during early, vapor-dominated fluid discharge, whereas chloride-complexed metals such as Cu, Pb, and Zn will be retained in the dense magmatic brine, thus potentially forming layers of metal sulfides with distinct zonation (Gruen et al., 2014). These models will be tested during Expedition 376.

Previous drilling

There has been no previous scientific drilling at Brothers volcano. However, in 2005 Neptune Minerals Inc. drilled a number of shallow holes at Brothers volcano using the *DP Hunter* in a bid to constrain the third dimension of massive sulfide mineralization outcropping at the NW Caldera site. Twenty-three holes were cored for a total of 107.3 m drilled. Six of these holes were drilled on the NW Caldera rim, 16 were drilled on the slopes of the NW Caldera wall, and a single hole was drilled inside the crater atop the Upper Cone. Approximately 47.2 m of material were obtained, representing 44% recovery. Hole depths ranged from 0.6 to 14.8 m (averaging ~4.7 m). The longest single core recovered was 11.07 m in length from Hole B-002 (Figure **F5A**), drilled to 14.8 m below seafloor (mbsf) on the NW Caldera wall. Drill tools used to drill these shallow holes ranged from an alien corer (2 holes) over an extended nose corer (15) to a hydraulic piston corer (5) and noncoring (1); the holes that used the hydraulic piston corer recovered no material. The extended nose corer consistently recovered the highest percentage of core.

The tops of many of these holes revealed a dark brown ooze locally containing glass sand and grit. This ooze is commonly underlain by a ~1 m thick zone containing pieces of sulfide chimney, glass grit, Fe-Si-Mn oxyhydroxides, and mixtures thereof. Then typically underlying this zone are variably hydrothermally altered volcanic rocks, ranging from volcanic silt and sand to volcanic glass, gravel, breccia, and more massive volcanic rock (dacite). Alteration colors vary from pale gray to pale green; locally, stockwork veins cut the rocks. Pyrite is common throughout the cores. The one core drilled inside the pit crater at the summit of the Upper Cone intersected volcanic breccias, gravels, and rocks together with native sulfur down to 10 mbsf (information by courtesy of Neptune Minerals Inc.; data accessible via IODP Site Survey Data Bank query at https://ssddb.iodp.org).

Seismic studies and site survey data

The supporting site survey data for Expedition 376 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org**). Available data sets include systematic, detailed, ship- and AUV-borne geophysical data, including high-resolution (AUV-derived) bathymetric and magnetic data; backscatter data; and sidescan sonar data together with seismic sections and gravity maps, as well as thousands of seafloor photographs; >40 hours of submersible video tape; and AUV-derived water column data delineating all present-day hydrothermal venting in the caldera and atop the cone (de Ronde et al., 2012, and references therein). Additionally, high-resolution video and still photographs are available from the recent R/V *Sonne* Expedition 253 (December 2016 to January 2017) to Brothers volcano that utilized the remotely operated vehicle (ROV) *Quest 4000.* A large rock sample collection with associated geochemical and isotopic analyses is also available at GNS Science, New Zealand. Detailed descriptions of shallow (<14 m) drill holes, percentage of core recovered, drill tools used, and photographs of the core are in an unpublished in-house report from Nautilus Minerals Inc. (contact Nautilus Minerals Inc. to request data access).

Regional multichannel seismic lines were collected by the National Institute for Water and Atmospheric Research (NIWA) as part of the 2012 NIRVANA cruise aboard the R/V *Tangaroa* (Figure **F4**). Seismic data acquisition included a "pseudo-3D" box over the caldera of Brothers volcano and four regional lines of which only two (Lines Bro-1 and Bro-3) are applicable to Expedition 376. These regional seismic lines are considered representative of those shot inside the pseudo-3D box, which did not provide quality data due to difficulties in acquisition (weather and technical problems), accuracy of line location on the seafloor, and problems with reflections off the caldera walls.

The multichannel seismic regional lines were acquired with a source array comprising a dual generator-injector (GI) gun (2 × 45/105) system in order to provide a high-energy record with a crisp return. The calculated source signature has a fairly flat amplitude spectrum across the range of ~5–240 Hz. Shot intervals were 25 m and record lengths were 7000 ms. The streamer was a 600 m long active section comprising 48 channels (12.5 m channel spacing). Seismic data were merged with navigation information using Hydropro navigation software and incorporated into the SEG-D header. Seismic velocity data for the subseafloor region were not available due to the streamer length/water depth combination. As a result of the limited streamer length, velocity estimates below the seafloor were tied to the seafloor two-way traveltime. Data were processed using Globe Claritas software at GNS Science, edited to remove noisy data, gain balanced, and corrected for system delays. The data were filtered to eliminate wave propagation along the streamer, to correct for wave-induced vertical hydrophone motion, and to remove source signature effects. Using the estimated velocity model, the stacked data were migrated. Velocity data from the regional multichannel seismic lines were not obtained due to the streamer length being too short. Thus, velocities of 2.5 km/s—similar to those used by Kim et al. (2013) for welded and consolidated volcaniclastics (but greater than the 1.5 km/s used by these authors for relatively homogeneous but unconsolidated volcanic ash and flows near the seafloor) infilling a submarine caldera volcano of the Tonga arc—were used to estimate thicknesses of volcanic units at Brothers.

Scientific objectives

Our primary scientific goal is to discover the fundamental, underlying processes that distinguish hydrothermal systems in arc volcanoes from those in spreading environments, such as backarc basins and MORs. Through the recovery of cores and downhole logging at Brothers volcano, we will strive for this goal by pursuing the following objectives:

- To characterize the subvolcano, magma chamber–derived volatile phase in order to test model-based predictions that this is either a single-phase gas, or a two-phase brine-vapor. This will be achieved through petrographic examination together with detailed study of mineralogical, chemical, and isotopic characteristics of trapped volatiles and precipitates in veins and wall-rock reaction products;
- To explore the subseafloor distribution of base and precious metals and metalloids as well as the reactions that have taken place along pathways to the seafloor;

- To quantify the mechanisms and extent of fluid-rock interaction, the consequences for mass transfer of metals and metalloids into the ocean, and the role of magmatically derived carbon and sulfur species in mediating these fluxes; and
- To assess the diversity, extent, and metabolic pathways of microbial life in an extreme, metal-toxic, and acidic volcanic environment.

The effects of magma degassing on the metal flux to the seafloor and how this impacts microbial life will be investigated through accessing discharge zones of fluids, which are geochemically distinct and reflect variable contributions of magmatic volatiles.

Recognizing the major differences between the gas- and water-dominated Cone and Caldera wall sites, respectively, we will test models for hydrothermal activity within the Brothers volcano caldera and examine the evolution from juvenile (magmatic) to more evolved (seawater dominated) fluids.

Drilling and coring strategy

In order to address the scientific objectives, a strategy involving two independent drilling efforts has been developed to allow recovery of cores from both shallow (<200 mbsf) and deep (~200–800 mbsf) intervals. Cores with good recovery are required from the shallowest intervals (tens of meters below seafloor) to explore aspects of hydrogeology, including the flux of metals to the seafloor, the permeability of the volcanic rock, fluid flow and seawater entrainment, and their effects on microbial community development and habitability. This will be accomplished by deploying the MeBo seafloor drill rig (Freudenthal and Wefer, 2007) from the *Sonne* at a time yet to be scheduled (Bach, Haase, Wefer, and de Ronde, Co-Principal Investigators). Strategically, this will allow IODP to bypass coring in the shallowest parts of the holes if necessary and set up the holes for casing required for deep coring.

Expedition 376 will drill and log three primary sites; one site is situated on the rim of the caldera at Brothers, another on the floor of the caldera, and a third is located at the summit of the Upper Cone (Figure **F5**). These three sites will provide access to critical zones dominated by magma degassing and high-temperature hydrothermal circulation over depth ranges considered crucial in the development of multiphase mineralizing systems. The proposed primary drill sites, alternate sites, and drilling and coring strategy for each are described below (Tables **T1, T2**). At all sites, wireline logging will be performed following coring if borehole conditions permit (see **Logging/Downhole measurements strategy**).

The drilling strategy to be employed is the same at each site. That is, an initial pilot hole (Hole A) will be drilled and cored to ~50 mbsf with the rotary core barrel (RCB) after a camera survey of the seafloor. This will be followed by drilling in a reentry system with 13⅜ inch casing to ~14 mbsf in a second hole (Hole B), which will then be cored with the RCB to 150 mbsf. The reentry system will stabilize the upper sections of the hole and allow multiple bits to be run into the hole. Several different types of reentry systems and bits will be available to find the most effective way of drilling into the hydrothermally altered volcanic rocks. Following installation of the reentry system, the hole may be widened to 12.5 inches, and 10¾ inch casing will be run to ~140 mbsf. RCB coring will then continue to the target depth. If necessary, half-coring may be utilized to increase recovery. The hole will then be logged if borehole conditions permit.

The final detailed operations plan will depend on drilling conditions encountered during operations at the primary sites, including time constraints and weather conditions (Tables **T1, T2;** see **Risks and contingency**).

Proposed drill sites

Two of the three proposed primary drill sites (and three of the four alternate sites) are located within, or on the rim of, the caldera of Brothers volcano (Figure **F5**). The third site is located on the summit of the Upper Cone with its alternate site situated on the saddle between the Upper and Lower Cones.

The proposed primary sites range in penetration from ~400 to 800 mbsf and include drilling into both types of hydrothermal systems (i.e., the NW Caldera and Cone). The two primary NW Caldera sites, NWC-1A and WC-1A, are located on the periphery of a large inferred upflow zone, as determined by the presence of magnetic low anomalies, or so-called "burnholes" (Figures **F3**, **F5**); the primary Cone site, UC-1A, is located directly above a zone of magmatic gas discharge. Thus, proposed Sites NWC-1A and WC-1A focus on a seawater-dominated Type I hydrothermal system, whereas proposed Site UC-1A focuses on a Type II system that is dominated by magmatic components dissolved in seawater; fluids from Type II systems discharge near the summits of both the Upper Cone and Lower Cone. We can intersect our main target depths with a ~400 mbsf hole on the caldera rim (proposed Site NWC-1A), an ~800 mbsf hole at the Cone site (proposed Site UC-1A), and an ~600 mbsf hole beneath the caldera floor (proposed Site WC-1A), as shown in Figure **F6**. However, note that proposed Site WC-1A has been projected onto the seismic line displayed in Figure **F6**; it should be shallower than 600 mbsf at the target depth because it is located closer to the inward-dipping caldera walls than is the seismic section.

Modeling of the magnetic low anomalies suggests that the NW Caldera and W Caldera upflow zones likely merge at depth (Caratori Tontini et al., 2012b). Thus, the combination of proposed Sites NWC-1A and WC-1A will result in a continuous section through the margins of a seawater-dominated Type I hydrothermal system, with the former penetrating the top section of the NW Caldera upflow zone and the latter a deeper section of the W Caldera upflow zone.

NW Caldera site

Proposed Site NWC-1A is situated atop the caldera rim at a water depth of 1464 m in the northwest sector of the volcano (Figure **F7**; Table **T1**), 240 m northeast of seismic Line Bro-3 (Figure **F7B**). The site is located in an area of flat seafloor with evidence for only sparse, probable diffuse hydrothermal activity (Baker et al., 2012), although an extensive magnetic low anomaly covering the area is testament to more intense activity in the past (Caratori Tontini et al., 2012a, 2012b). Given that the caldera-bounding faults are vertical to slightly outward dipping (Embley et al., 2012) and knowing that the mineralization generally decreases in age from caldera rim to caldera floor (de Ronde et al., 2011), drilling here will target the upper portions of an older hydrothermal upflow zone of Type I seawater-dominated hydrothermal activity. The hole is expected to penetrate 405 mbsf through the margin of the inferred upflow zone and down through the footwall of the original caldera (Figure **F8**). Anticipated lithologies are dacite lava and volcaniclastic material.

Holes drilled by Neptune Minerals Inc., located 250 m northeast of proposed Site NWC-1A, recovered brown platy Fe oxyhydroxides with varying amounts of volcanic glass in the uppermost 3 m. The area around the proposed site was surveyed during the *Sonne* Expedition 253, which placed a marker (#46) with the ROV *Quest 4000* at the preferred site for drilling. No evidence for venting was seen at the time.

Proposed alternate Site NWC-2A has been identified to achieve similar scientific objectives in the event that operations at proposed primary Site NWC-1A are unsuccessful or not possible. Site NWC-2A is located ~900 m southeast of proposed Site NWC-1A on the floor of the caldera at a water depth of 1892 m, being 85 m northwest of seismic Line Bro-1 (Figure **F9**). The drill site is located within the same general, distinct magnetic low anomaly covering this sector of the caldera, which is believed to infer an area of high-temperature hydrothermal upflow. This site is ~750 m downslope and to the south of the active high-temperature black smoker vents of the NW Caldera vent field, near the margin of the inferred upflow zone. In order to achieve a similar result for drilling as planned for proposed primary Site NWC-1A, operations at this alternate site would drill through a thicker stratigraphic section as a result of caldera infill. The hole is expected to penetrate ~550 mbsf into the inferred upflow zone and down to the base of the original caldera (Figure **F10**). Three general types of lithology are expected: sediments on the caldera floor, dacitic volcaniclastic material infilling the caldera, and lavas forming the base of the caldera. Pelagic ooze sediments will likely be present within the uppermost 5–10 m of the caldera floor.

Upper Cone site

Proposed primary Site UC-1A is the second priority site and is located at the summit of the Upper Cone at Brothers volcano, in a water depth of 1232 m (Figure **F11**). The primary objective at this site is to drill an upflow zone of a Type II hydrothermal system and to transect several volcanic cycles that are thought to comprise Upper Cone volcanic stratigraphy (Figure **F6**). The site is located on ground sloping up to 15° inside a small, ~40 m diameter pit crater on the summit of the Upper Cone, ~30 m northeast of seismic Line Bro-3. Site UC-1A is located in an area exhibiting advanced argillic alteration where relatively gas-rich, very acidic fluids are being discharged. This site has the highest potential for sampling rocks influenced by magma degassing. Tremor data recovered from hydrophones deployed on the caldera floor at Brothers indicate a two-phase zone beneath the general cone area ~800 m below the cone summit (Dziak et al., 2008), making this an important target for deep drilling and intersection of single-phase magmatic gas. The projected 800 m long hole is expected to penetrate inferred zones of magmatic fluid flow, including areas of magmatically derived salt (Gruen et al., 2014). Furthermore, it will intersect the boundaries of at least three prominent stratigraphic units, thereby ensuring coring of several volcanic cycles demarcating cone growth in the seismic section through the cone (Figure **F12**). Two main types of lithology are expected: dacitic lavas and volcaniclastic material. Both types will likely be affected to varying degrees by advanced argillic alteration; the latter is expressed on the seafloor both inside the pit crater on the summit of the Upper Cone and at the crest of the Lower Cone, as well as on the flanks of both cones. Advanced argillic alteration includes alteration of primary rocks to native sulfur, silica, sulfates, and pyrite, typically resulting in material that is structurally weaker than the original rock.

Proposed Site UC-1A was surveyed using the ROV *Quest 4000* during the *Sonne* Expedition 253. A marker (heat flow Blanket F) was deployed in the center of the crater where the seafloor was flattest. No hydrothermal venting was noted within the crater itself, although an extensive field was discovered ~75 m northeast of the crater, perched on a small plateau.

Two alternate sites for proposed Site UC-1A have been identified in the event of difficulties at the primary site. Proposed alternate Site UC-2A is located on the south-southeast margin of the Upper Cone of Brothers volcano in a water depth of 1476 m (Figure **F13**). It has similar objectives to proposed Site UC-1A: drilling the margin of an upflow zone within a Type II hydrothermal system and transecting several volcanic cycles that make up the cone. The site is located on relatively flat ground where the flank of the Upper Cone coalesces with the caldera wall on seismic Line Bro-3. Its potential for successful penetration is considered high, enabling sampling of rocks influenced by magma degassing. This site would likely still intersect some of the volcanic units that comprise the main Upper Cone, although it is off-center from the inferred main upflow zone. Drilling would take place on the periphery of a diffuse vent field, on the margin of a weak magnetic low. Drilling and coring, using a strategy similar to that for proposed Site UC-1A, are planned to 530 mbsf in order to penetrate the periphery of the volcanic units of the Upper Cone and reach the caldera footwall (Figure **F14**). Lithologies akin to those encountered at proposed Site UC-1A are expected.

The second alternate site is proposed Site LC-1A located on the saddle between the Lower and Upper Cones of Brothers volcano, 380 m northeast of seismic Line Bro-3, in a water depth of 1359 m (Figure **F15**). The site is located on relatively flat ground but is surrounded by slopes over 15° because the nearby cone flanks shoal to their respective cone summits. This area marks the boundary of the Lower Cone vent field and includes vents discharging the most Fe-rich fluids sampled at Brothers volcano to date. This site is ~130 m deeper than proposed Site UC-1A and likely straddles the margins of upflow zones of both the Upper and Lower Cones considering there is no detectable magnetic low in this area. However, proposed alternate Site LC-1A would still intersect the inferred volcanic units that mark the growth of the Upper Cone and/or the transition between the two cones and the upflow zone of metal-rich fluids. Drilling and coring are planned to 300 mbsf in order to penetrate the volcanic units and intersect single-phase magmatic volatiles. Similar lithologies to those encountered at proposed primary Site UC-1A are expected. A marker (#31) was placed at this site in early 2017 after surveying the general area with the ROV *Quest 4000*. No evidence for venting was seen at the saddle between the Upper and Lower Cones, although there is noticeable venting identified ~200 m east of the saddle, on the crest of the Lower Cone.

W Caldera site

Proposed Site WC-1A is the third priority site and is located on the west side of the caldera floor of Brothers volcano, in a water depth of 1765 m (Figure **F16**). The primary objective for this site is to drill a second hole into the margin of the upflow zone of a Type I seawater-dominated hydrothermal system. Proposed Site WC-1A is located 300 m southwest of seismic Line Bro-3 on seafloor sloping as much as 10°. It is situated within a significant magnetic low that delineates the W Caldera upflow zone, but lacks obvious seafloor manifestations or indeed evidence from water column measurements for present-day hydrothermal activity. Here, the magnetic low has been modeled to be at least 300 m thick. A 565 m drill hole is planned to penetrate the low–magnetic anomaly zone and into the footwall of the original caldera floor, thereby transecting the deepest parts of this Type I hydrothermal system (Figure **F17**). Three general types of lithology are expected: sediments on the caldera floor, volcaniclastic material infilling the caldera, and lavas forming the base of the caldera. Pelagic ooze will be present on the caldera floor and several meters below. Dacitic volcaniclastic material and intercalated lavas are the main lithologies expected between the caldera floor and underlying basement.

The alternate drill site for proposed Site WC-1A is proposed Site SEC-1A on the eastern side of the caldera floor, located 1.4 km northeast of seismic Line Bro-3 (Figure **F18**). This drill hole targets the extinct SE Caldera upflow zone that does not have any surface manifestation of present-day hydrothermal activity. Hence, the upflow zone in the subseafloor at this site is less likely to be affected by magmatic volatiles. The upflow zone is demarcated by a <300 m thick magnetic low. Drilling is expected to penetrate to 300 mbsf and encounter mineralized and hydrothermally altered dacite and altered volcaniclastic material.

Logging/Downhole measurements strategy

Downhole logging will be essential for characterizing the subseafloor lithologies and their structures, particularly regarding extrapolation to complete sections. We intend to use the available standard suite of downhole logging tools (**http://iodp.tamu.edu/tools/logging**) at all three primary sites. However, their actual deployment will depend on the in-hole temperatures at depth, which will be measured prior to each planned logging run by using an ultrahigh-temperature probe as a memory tool on the coring line. This measurement will determine whether additional logging tools can be deployed. Priority will be given to minimizing the risk to the logging tools (see **Risks and contingency**), given that all the published temperature ratings for the in-house downhole logging tools (Figure **F19**) are less than the maximum fluid temperatures measured for hydrothermal venting on the seafloor at Brothers.

Recovering borehole hydrothermal fluid would considerably enhance the success of Expedition 376. Thus, we are going to attempt to sample hydrothermal fluid that might be entering the borehole at depth. A device that will be capable of sampling fluid from anywhere in the hole is currently being investigated. The utilization of a high-temperature resistive water-sampling tool is presently under consideration. Through the chemical characterization of borehole fluids we will be able to differentiate seawater signatures from those derived from magmatic-hydrothermal fluids.

Postcruise monitoring of the long-term temperature profile over the entire depth of the drilled boreholes is desired for Brothers volcano. Thus, we are investigating the possibility of installing an observatory focused on measuring temperature, consisting of a thermistor string to be placed down one or more of the boreholes. The installed reentry system at each drill site will serve as a platform for the installation of the observatory.

Risks and contingency

Drilling and logging operations focused on the caldera of a hydrothermally active submarine volcano bear several risks and present challenges with respect to achieving the expedition objectives. For example, drill hole stability in a fractured system consisting of a heterogeneous succession of volcanic and volcaniclastic units subjected to alteration by hydrothermal fluids may lead to a stuck bottom-hole assembly (BHA), resulting in lost time and possible loss of equipment. Additional hardware will be made available to mitigate any losses. Extra time may be required for hole remediation (i.e., cleaning and stabilization of the hole). Two casing strings of two different diameters will be available to stabilize the hole for coring. Loss of a mud motor and/or underreamer while drilling in the planned short casing string is always possible. A second mud motor and spare underreamers will also be made available. Given the minimal (or nonexistent) pelagic sediment coverage at Brothers volcano, the establishment of a reentry system forms an additional operational challenge. Ultimately, multiple holes may be required to find an area with stable (sub)seafloor conditions (cf. Ocean Drilling Program Leg 193; Binns, Barriga, Miller, et al., 2002). Unpredictable drill hole conditions and concomitant efforts on remediation of the hole may take a considerable amount of time, which is difficult to plan for in the operations schedule (Tables **T1, T2**). Similar formation characteristics have yielded low recovery (≤20%) on previous expeditions, which may hamper sampling objectives.

Although unstable downhole conditions can also significantly impede wireline logging, the greatest risk to the successful running of logging tools is their exposure to high-temperature fluids subseafloor at Brothers volcano. Fluid and/or formation temperatures may be too high to permit logging at all if temperatures exceed limits pertinent to the deployed logging tool. As circulation of drilling fluid is stopped during logging operations, there will be no significant cooling of the hole at this time. Where possible, the logging tools will be equipped with sealing elements (O-rings) and flasks in order to insulate the electronics from the external heat as long as possible. This will ensure that the tools can be used at their full temperature rating. The acidic nature of formation fluids to be encountered may represent an additional issue because the logging wireline cable may become corroded. Thus, the availability of acid-resistant wireline cables is being investigated.

Weather conditions always represent potential problems, as rough seas and the resulting heave may exert unfavorable influence on drilling operations, particularly while establishing a casing and reentry system. In addition, quality and recovery of core can be negatively affected. The weather window for Expedition 376 is not ideal considering drilling operations will begin near the onset of the Southern Hemisphere winter. Therefore, delays caused by weather are possible. The currently scheduled contingency time for compensating delays caused by weather or operational issues is 4.3 days (Table **T1**).

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted at **http://www.iodp.org/policies-and-guidelines/.** This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that scientists incur if they receive samples and data. The Sample Allocation Committee (SAC; composed of the Co-Chief Scientists, Expedition Project Manager/Staff Scientist, and IODP Curator onshore and curatorial representative aboard the ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postexpedition sampling.

Every member of the science party is obligated to carry out scientific research for the expedition and to publish the results. All shipboard scientists and any potential shore-based scientists are required to submit a research plan and associated samples and data using the IODP Sample and Data Request Database (**http://www.iodp.tamu.edu/sdrm**). Based on the research plans submitted, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and expedition objectives. That is, the sampling plan will be subject to modification depending on the actual material recovered and collaborations that may evolve between scientists during the expedition. The SAC must approve modifications to the sampling strategy during the expedition.

Shipboard sampling will include samples taken for shipboard analyses and samples needed for personal, postexpedition research. The minimum permanent archive will be the standard archive half of each core. All sample sizes and sampling frequencies must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests. We expect a large number of shipboard and personal whole-round samples to be taken for geochemical, petrophysical, and possibly microbiological measurements. If some critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling or reduced sample size and sampling rate. The SAC may require an additional formal sampling plan to be developed for critical intervals.

The cores from Expedition 376 will be delivered to the IODP Kochi Core Center in Kochi, Japan, for permanent storage. All Expedition 376 data and samples will be protected by a 1 y moratorium period that will start at the end the expedition. During this moratorium, all data and samples will be available only to the expedition shipboard scientists and approved shore-based participants.

Expedition scientific participants

The current list of scientific participants for Expedition 376 can be found at **http://iodp.tamu.edu/scienceops/expeditions/brothers_arc_flux.html.**

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Table T1. Operations plan and time estimates for primary sites, Expedition 376. mbrf = meters below rig floor, mbsf = meters below seafloor; EPSP = Environmental Protection and Safety Panel; nmi = nautical mile; RCB = rotary core barrel; WL = wireline, FMS = Formation MicroScanner.

Site No.	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Transit (days)	Drilling Coring (days)	WL Log (days)
Auckland, New Zealand			Begin Expedition 5.0 Port Call Days			
			Transit 241 nmi from Auckland to Site NWC-1A @ 10.5 knots	1.0		
NWC-1A	34° 51.6516' S	1475	Hole A: Pilot Hole: Coring with RCB system to ~50 mbsf		1.4	
EPSP	179° 3.2410' E		Hole B: Drill in re-entry cone with ~14 m of 13 3/8" 54.5 lb/ft conductor casing			
approved to			and cement reentry system in place.		1.4	
405 mbsf			RCB core to ~150 mbsf		2.9	
			Open hole to 12.5" diameter and run 10 3/4" casing string to ~140 mbsf		2.3	
			RCB core from ~140 mbsf to ~405 mbsf		3.9	
			Take Open Hole temperature measurements and wireline log with			
			Triple Combo, FMS-Sonic			1.1
			Sub-Total Days On-Site: 13.0			
			Transit 1 nmi from NWC-1A to Site UC-1A @ 1.0 knots	0.04		
UC-1A	34° 52.9282' S	1243	Hole A: Pilot Hole: Coring with RCB system to ~50 mbsf		1.3	
EPSP	179° 4.10034' E		Hole B: Drill in re-entry cone with ~14 m of 13 3/8" 54.5 lb/ft conductor casing			
approved to			and cement reentry system in place.		1.4	
800 mbsf			RCB core to ~150 mbsf		3.1	
			Open hole to 12.5" diameter and run 10 3/4" casing string to ~140 mbsf		2.2	
			RCB core from ~140 mbsf to ~800 mbsf		10.2	
			Take Open Hole temperature measurements and wireline log with			
			Triple Combo, FMS-Sonic			1.6
			Sub-Total Days On-Site: 19.8			
			Transit 1 nmi from UC-1A to Site WC-1A @ 1.0 knots	0.04		
WC-1A	34° 52.5162' S	1776	Hole A: Pilot Hole: Coring with RCB system to ~50 mbsf		1.4	
EPSP	179° 3.51402' E		Hole B: Drill in re-entry cone with ~14 m of 13 3/8" 54.5 lb/ft conductor casing			
approved to			and cement reentry system in place.		1.4	
565 mbsf			RCB core to ~150 mbsf		3.3	
			Open hole to 12.5" diameter and run 10 3/4" casing string to ~140 mbsf		2.4	
			RCB core from ~140 mbsf to ~565 mbsf		6.9	
			Take Open Hole temperature measurements and wireline log with			
			Triple Combo, FMS-Sonic			1.4
			Sub-Total Days On-Site: 16.8			
			Contingency Time - weather and operations		4.3	
			Transit 241 nmi from Site UC-1A to Auckland @ 10.5 knots	1.0		
Auckland, New Zealand			End Expedition	2.1	49.8	4.1

Port Call:	5.0	Total Operating Days:	56.0
Sub-Total On-Site:	53.9	Total Expedition:	61.0

Table T2. Operations and time estimates for alternate sites, Expedition 376. mbrf = meters below rig floor, mbsf = meters below seafloor; EPSP = Environmental Protection and Safety Panel; nmi = nautical mile; RCB = rotary core barrel; WL = wireline, FMS = Formation MicroScanner.

Site No.	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Drilling Coring (days)	WL Log (days)
NWC-2A	34° 51.99174' S	1903	**Hole A**: Pilot Hole: Coring with RCB system to ~50 mbsf	1.4	
EPSP	179° 3.6594' E		**Hole B**: Drill in re-entry cone with ~14 m of 13 3/8" 54.5 lb/ft conductor casing		
approved to			and cement re-entry system in place.	1.5	
555 mbsf			RCB core to ~150 mbsf	3.4	
			Open hole to 12.5" diameter and run 10 3/4" casing string to ~140 mbsf	2.4	
			RCB core from ~140 mbsf to ~555 mbsf	6.9	
			Take Open Hole temperature measurements and wireline log with		
			Triple Combo, FMS-Sonic		1.3
			Sub-Total Days On-Site: 16.9		
UC-2A	34° 53.2582' S	1487	**Hole A**: Pilot Hole: Coring with RCB system to ~50 mbsf	1.3	
EPSP	179° 4.34484' E		**Hole B**: Drill in re-entry cone with ~14 m of 13 3/8" 54.5 lb/ft conductor casing		
approved to			and cement re-entry system in place.	1.4	
530 mbsf			RCB core to ~150 mbsf	3.2	
			Open hole to 12.5" diameter and run 10 3/4" casing string to ~140 mbsf	2.3	
			RCB core from ~140 mbsf to ~530 mbsf	6.3	
			Take Open Hole temperature measurements and wireline log with		
			Triple Combo, FMS-Sonic		1.3
			Sub-Total Days On-Site: 15.8		
LC-1A	34° 52.7758' S	1370	**Hole A**: Pilot Hole: Coring with RCB system to ~50 mbsf	1.3	
EPSP	179° 4.2186' E		**Hole B**: Drill in re-entry cone with ~45 m of 10 3/4" 40.5 lb/ft casing		
approved to			and cement re-entry system in place.	1.8	
300 mbsf			RCB core to ~300 mbsf	4.1	
			Take Open Hole temperature measurements and wireline log with		
			Triple Combo, FMS-Sonic		1.1
			Sub-Total Days On-Site: 8.3		
SEC-1A	34° 52.5663' S	1687	**Hole A**: Pilot Hole: Coring with RCB system to ~50 mbsf	1.4	
EPSP	179° 4.86414' E		**Hole B**: Drill in re-entry cone with ~45 m of 10 3/4" 40.5 lb/ft casing		
approved to			and cement re-entry system in place.	1.9	
300 mbsf			RCB core to ~300 mbsf	4.3	
			Take Open Hole temperature measurements and wireline log with		
			Triple Combo, FMS-Sonic		1.1
			Sub-Total Days On-Site: 8.7		

Figure F1. A. Bathymetric map of the Kermadec arc and trench with major tectonic elements labeled; Brothers volcano is located on the active volcanic front in the southern half of the arc (from de Ronde et al., 2012). B. Detailed bathymetry of Brothers volcano and surrounds. Dashed lines are structural ridges. Letters designate North fault (NF), South fault (SF), North rift zone (NRZ), Upper Cone (UC), and Lower Cone (LC), NW Caldera (NWC), W Caldera (WC), and regional tectonic ridge (RTR). Letters A-B and C-D are endpoints for the bathymetric cross sections shown in the top panels. The topographic cross section 'A-B' is coincident with the seismic section Line Bro-3. Red dots mark the locations of the ocean bottom hydrophones referred to in the text. Contour interval is 200 m (modified from Embley et al., 2012).

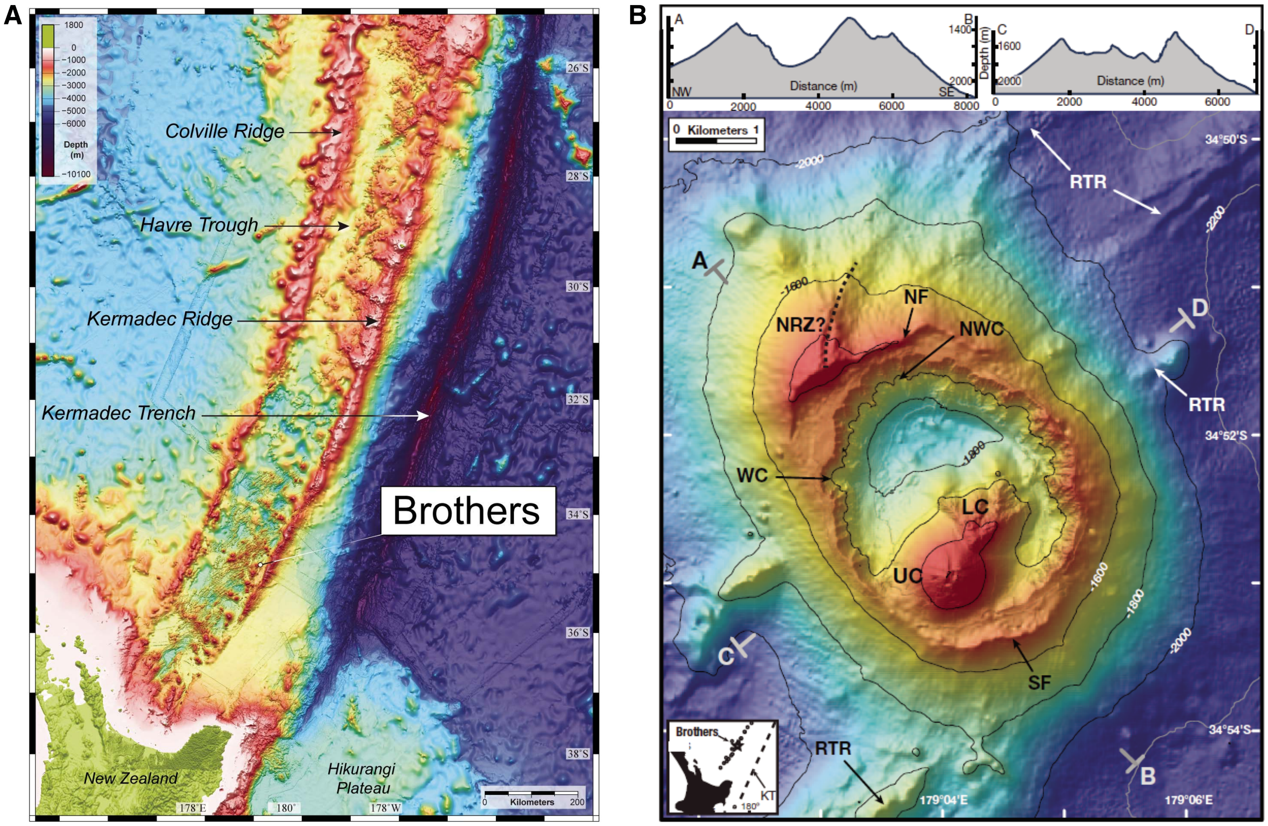


Figure F2. A. Autonomous underwater vehicle (AUV) tracks of the 2007 *ABE* dives (colored tracks) and the 2011 AUV *Sentry* dive (white tracks). Figure from Baker et al. (2012). B. Results of the high-resolution (~2 m) mapping of the caldera walls and cones from the *ABE* survey combined with EM300 bathymetric survey (~25 m resolution) data for the caldera floor and upper (outside) flanks of the caldera. Figure from Embley et al. (2012).

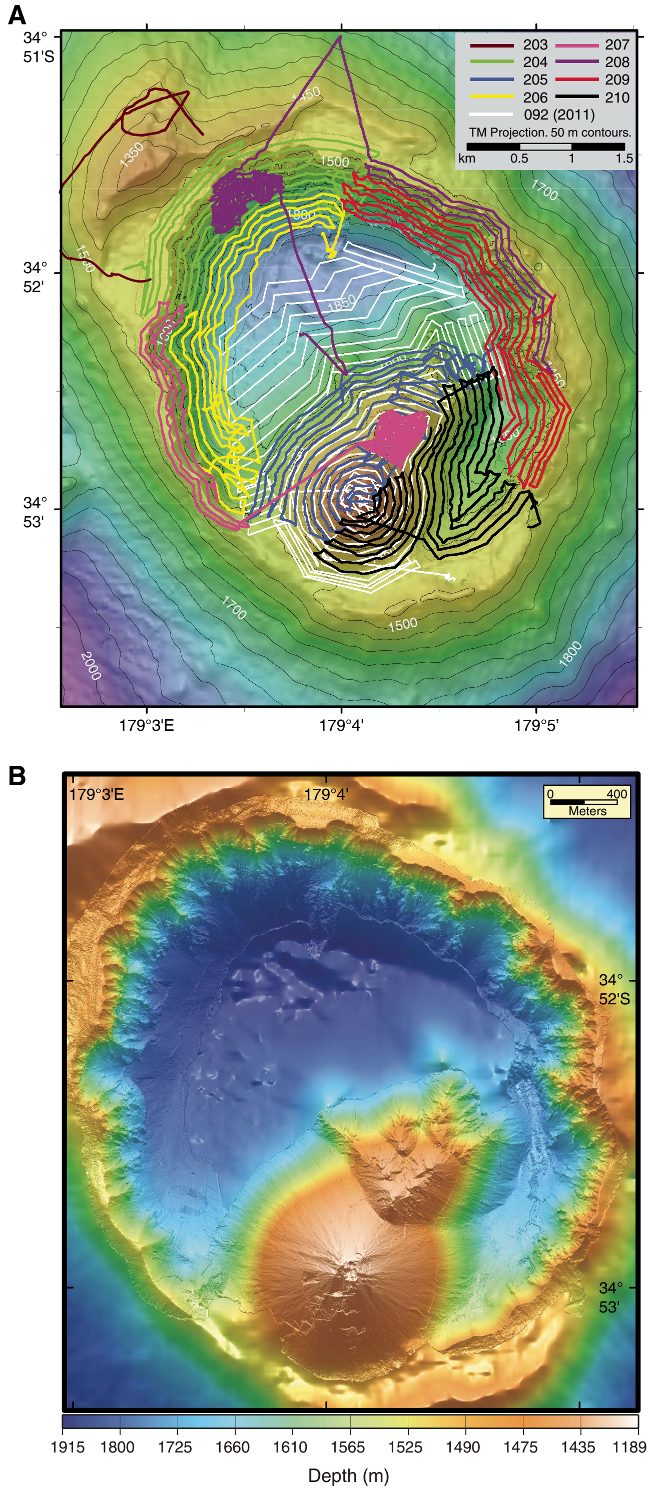


Figure F3. Apparent magnetization map of Brothers volcano showing reduced crustal magnetization over five hydrothermal vent sites. Outlined areas have either very low (<2.5 A/m; Zones A and D) or moderate (<3.5 A/m; Zones B and C) magnetization (Caratori Tontini et al., 2012a), which is in general agreement with the location of the various vent fields. Structural lineaments (white lines) and ring faults (white lines with hash marks) are shown for reference. Figure from Caratori Tontini et al. (2012a). Zones: A = Upper Caldera and NW Caldera, B = Cone, C = SE Caldera, D = W Caldera.

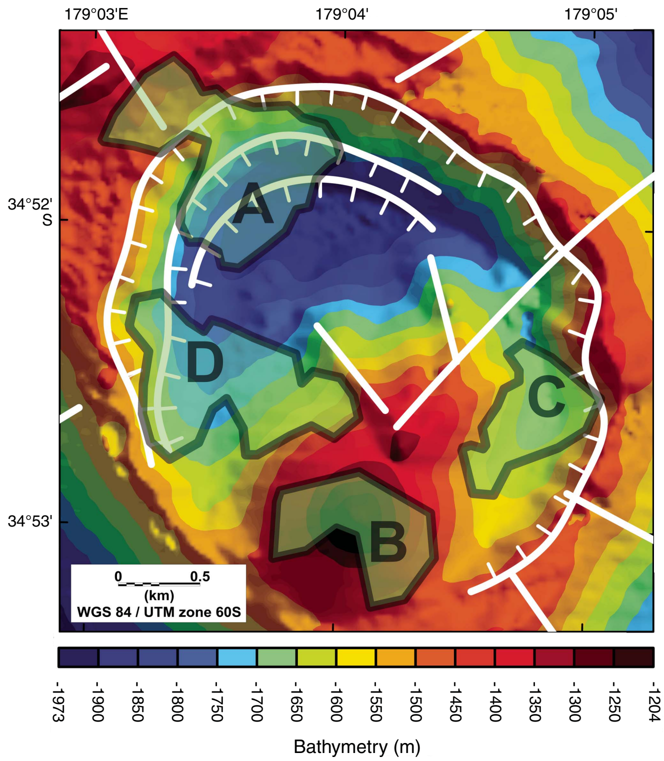


Figure F4. Regional multichannel seismic lines and “pseudo-3D” box over Brothers volcano. Seismic data were acquired during the 2012 NIRVANA cruise. Figure from Wysoczanski et al. (2012).

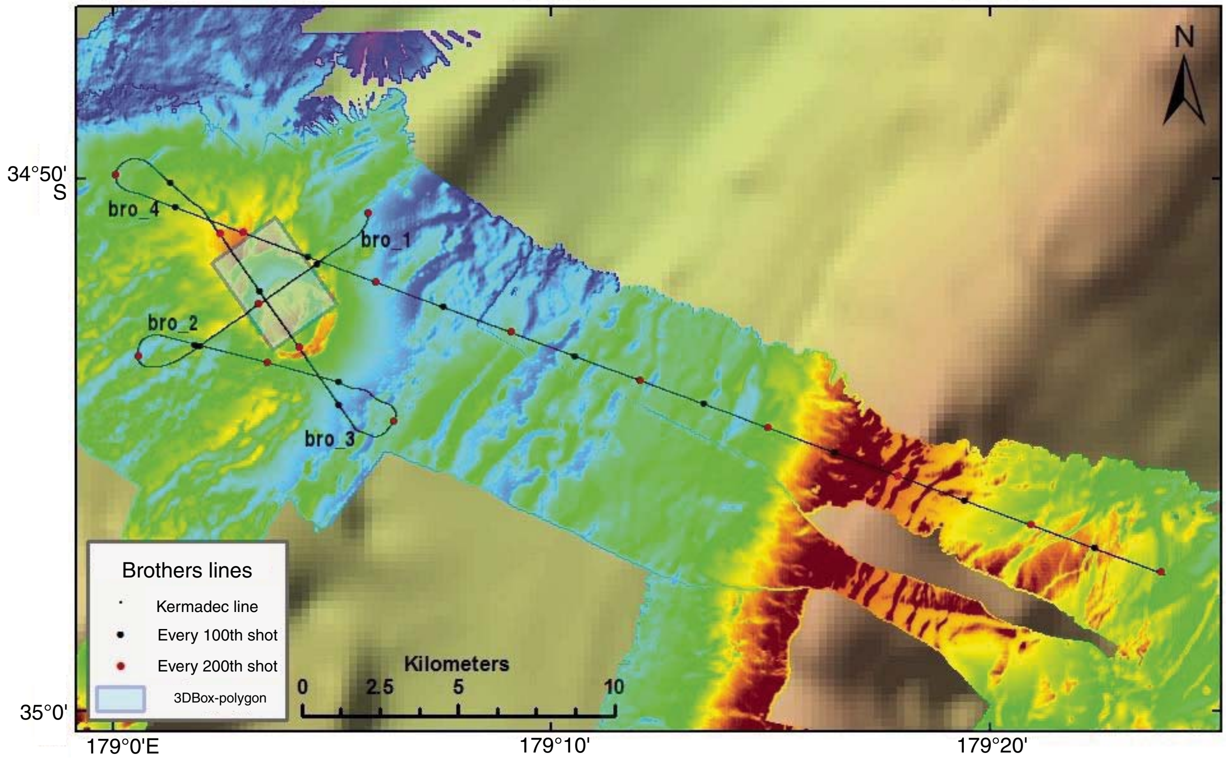


Figure F5. A. Location of proposed Expedition 376 drill sites at Brothers volcano. Transparent areas mark magnetic "lows" (redrawn from Caratori Tontini et al., 2012a) inferred to be upflow zones within the volcano's hydrothermal system. B. Slope map of Brothers volcano. Proposed Sites NWC-1A, NWC-2A, SEC-1A, and UC-2A are on slopes of <5°; proposed Site WC-1A on <10°; proposed Sites UC-1A and LC-1A <15° within minimum circle areas of 15–150 m. NWC = NW Caldera, UC = Upper Cone, LC = Lower Cone, SEC = SE Caldera, WC = W Caldera. Red lines mark seismic Line Bro-3 shown in Figure F4. Neptune Minerals Inc. drill Hole B-002 is the deepest hole drilled to date, at 14.8 mbsf.

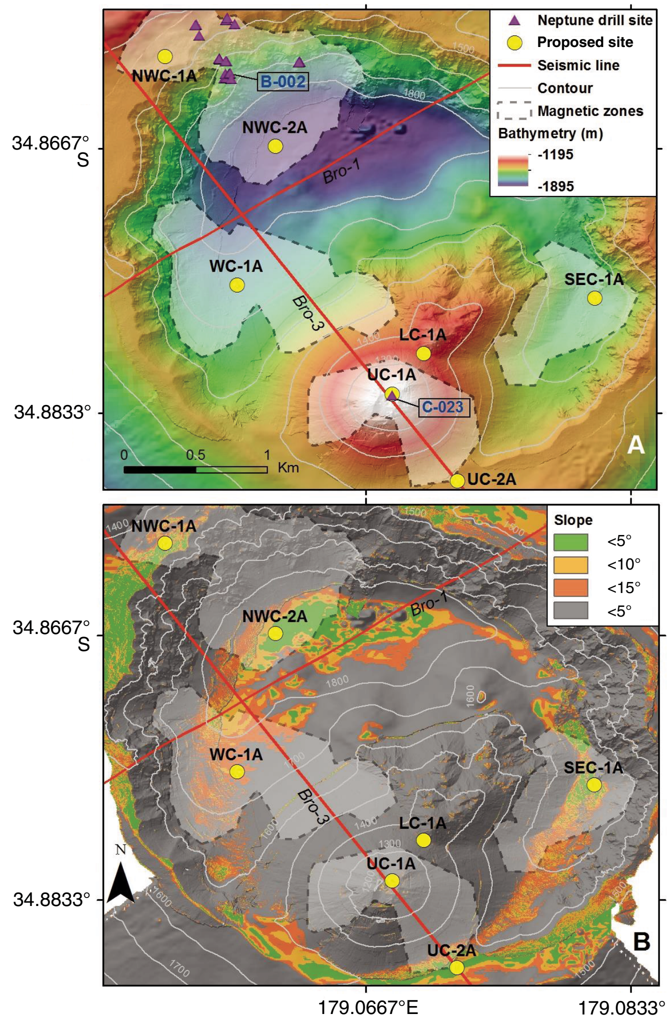


Figure F6. Seismic section along Line Bro-3 for the three proposed primary sites (NWC-1A, UC-1A, and WC-1A) and one proposed alternate site (UC-2A). Legend shows the length of a ~400 m hole based on a seismic velocity of 2.5 km/s; higher velocities will mean "deeper" and lower velocities will mean "shallower" holes on the same section. Blue line is the seafloor derived from bathymetric data. Proposed Site WC-1A is slightly out of the plane of the section. The two-phase zone is derived from the ocean-bottom seismometer survey of Dziak et al. (2008).

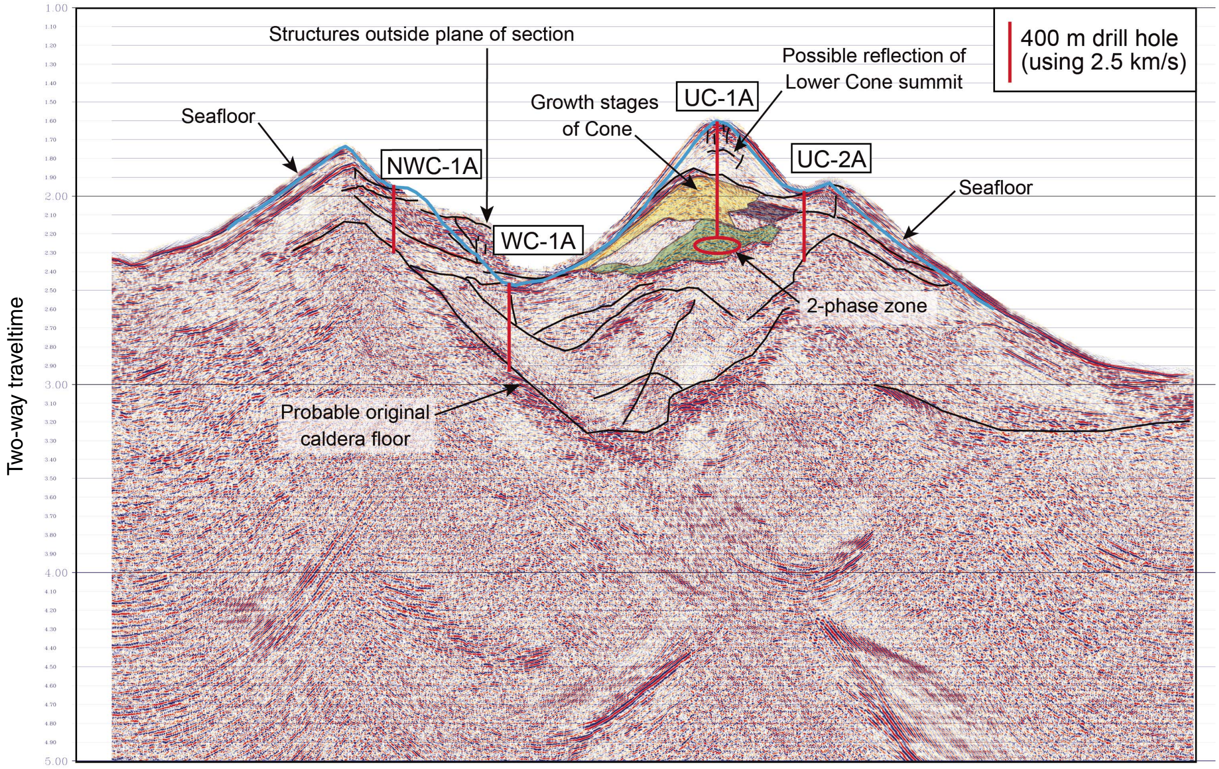


Figure F7. A. Location of proposed primary Site NWC-1A. B. Detail of site location with a portion of seismic Line Bro-3 shown. Bathymetry at this site is at 2 m resolution.

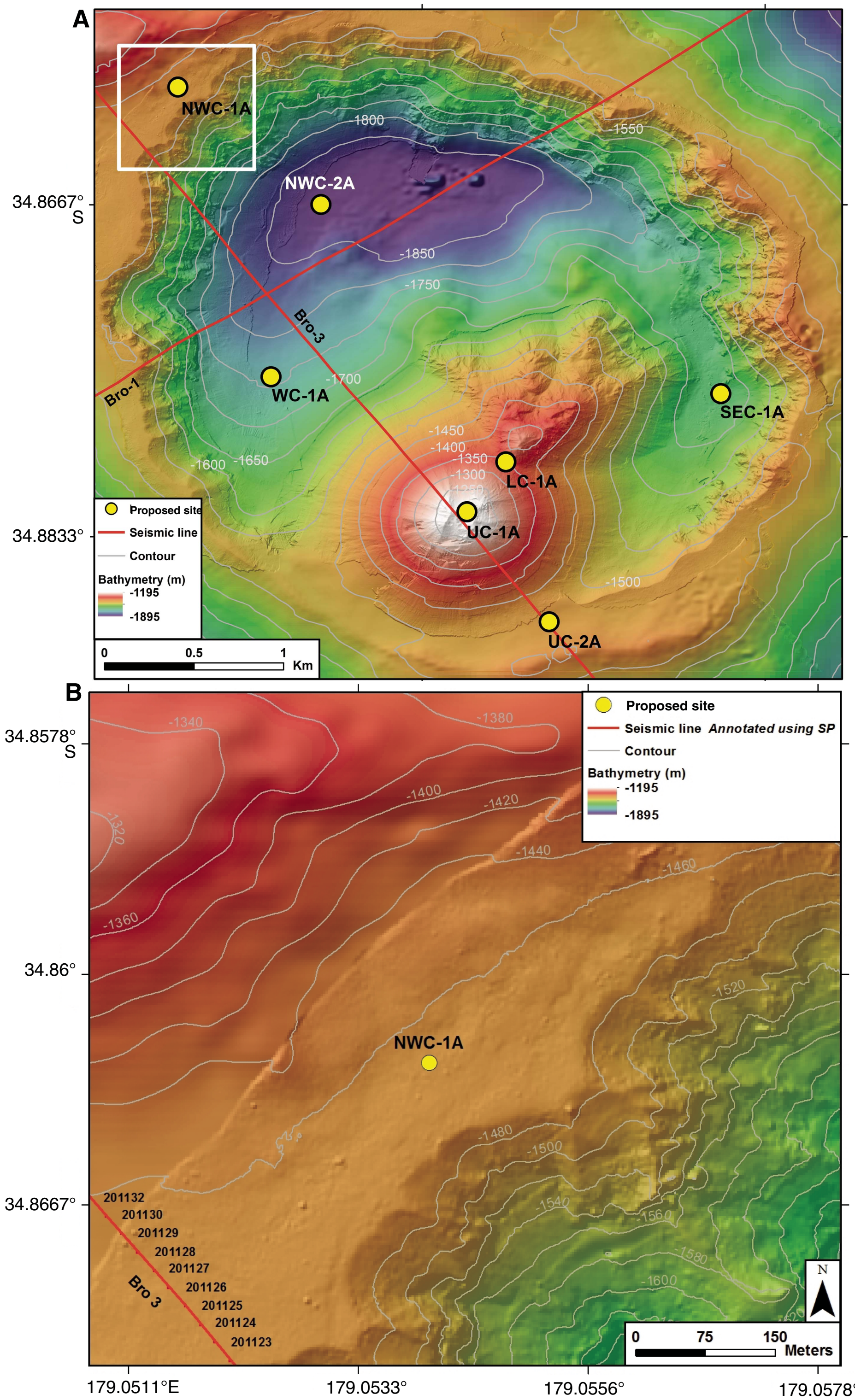


Figure F8. (A) Uninterpreted and (B) interpreted seismic section of Line Bro-3 showing the location of proposed primary Site NWC-1A.

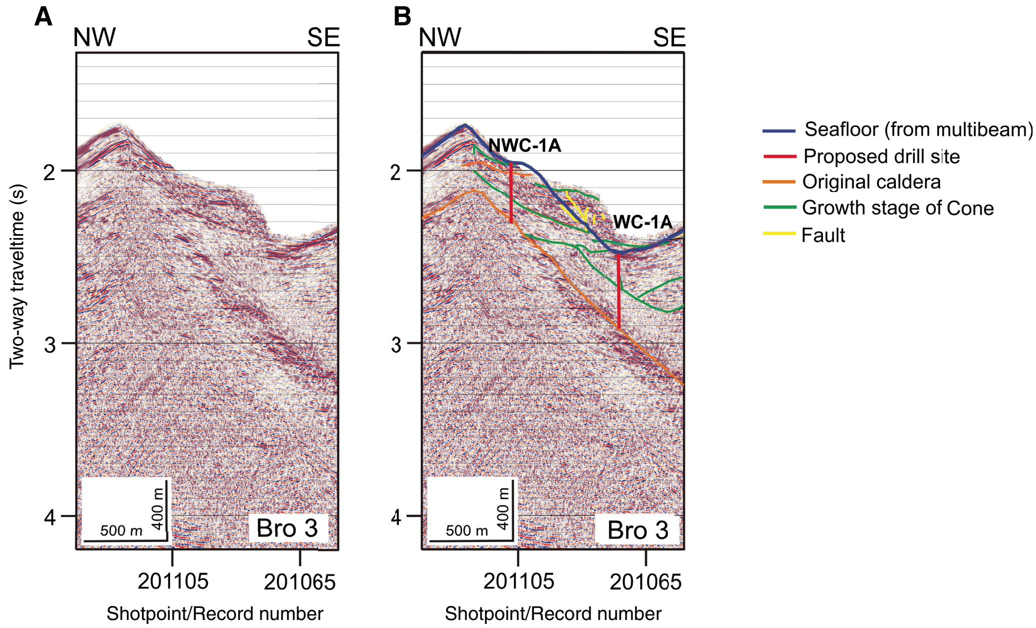


Figure F9. A. Location of proposed alternate Site NWC-2A. B. Detail of site location with a part of seismic Line Bro-1 shown. Bathymetry at this site is at 25 m resolution.

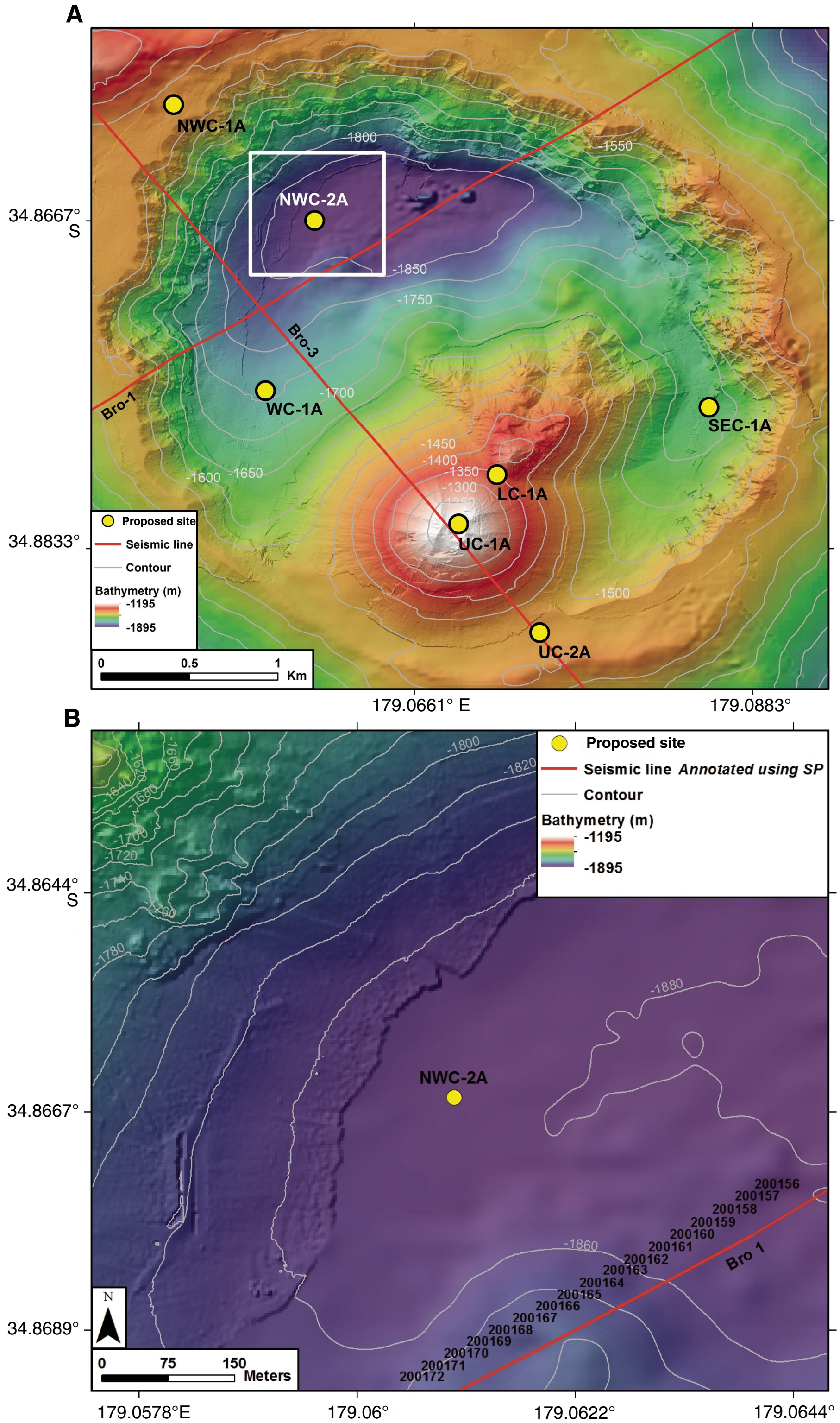


Figure F10. (A) Uninterpreted and (B) interpreted seismic section of Line Bro-1 showing the location of proposed alternate Site NWC-2A. The target depth will be shallower than shown because the drill site is located closer to the caldera margins than is the seismic line.

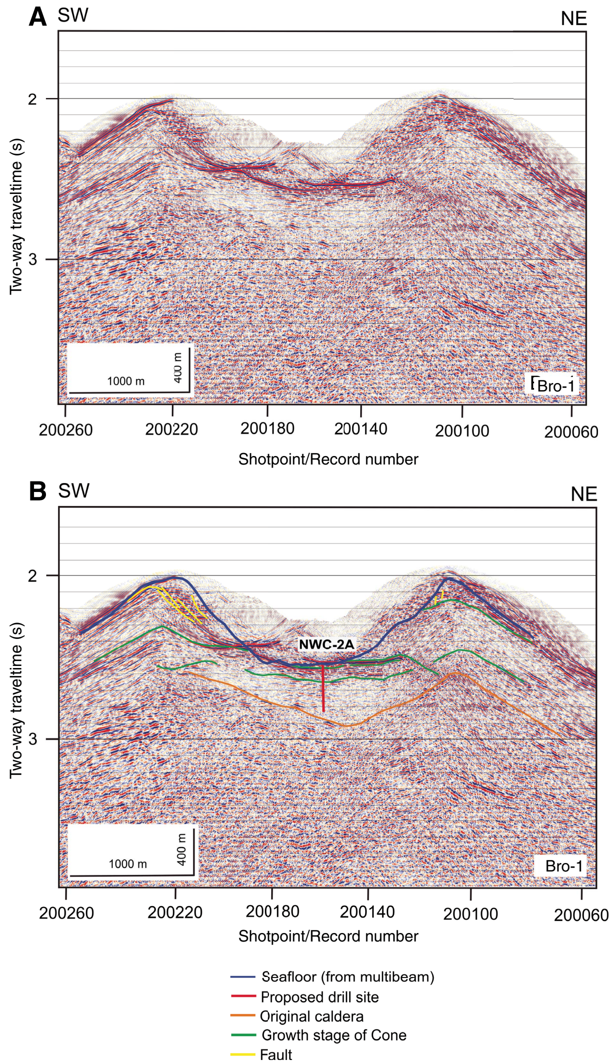


Figure F11. A. Location of proposed primary Site UC-1A. B. Detail of site location with a portion of seismic Line Bro-3 shown. Bathymetry at this site is at 2 m resolution.

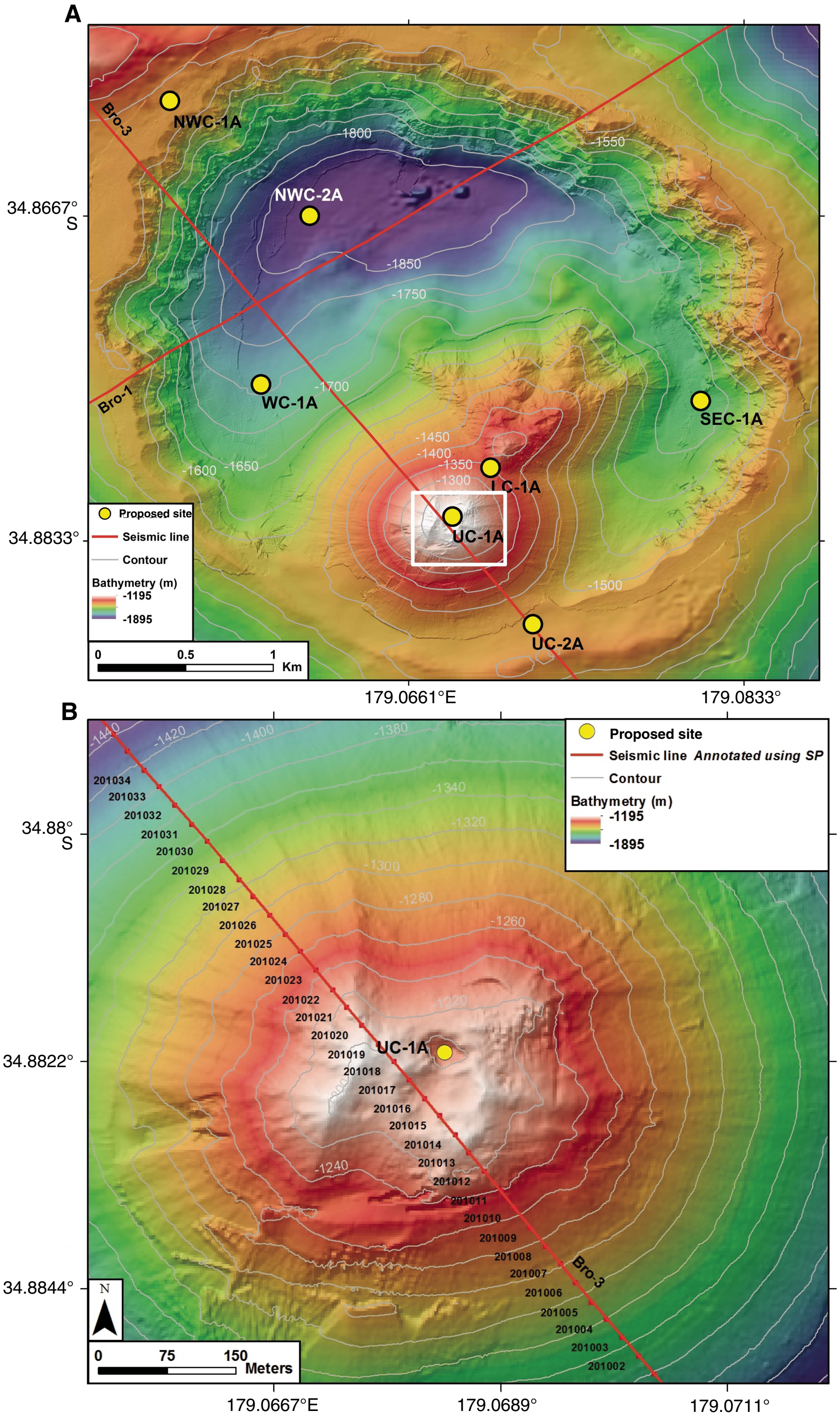


Figure F12. (A) Uninterpreted and (B) interpreted seismic section of Line Bro-3 showing the location of proposed primary Site UC-1A.

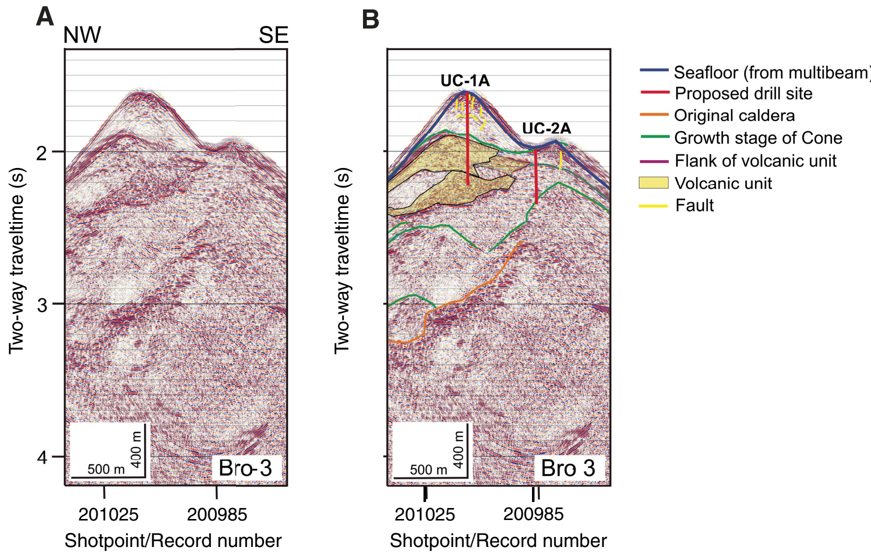
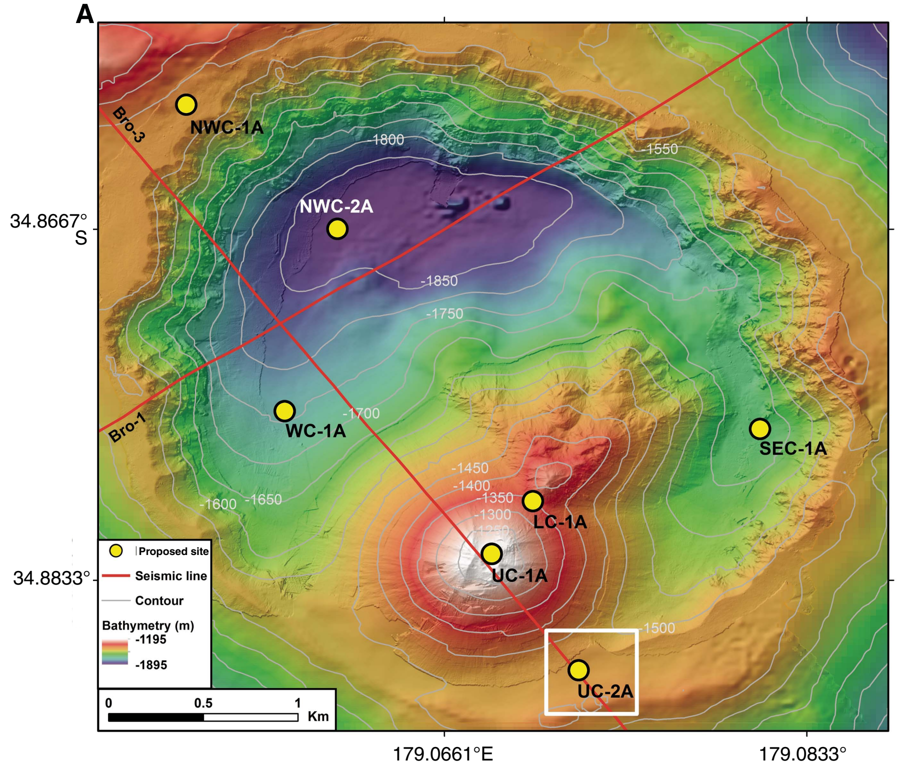


Figure F13. A. Location of proposed alternate Site UC-2A. B. Detail of site location with a portion of seismic Line Bro-3 shown. Bathymetry at this site is at 25 m resolution.



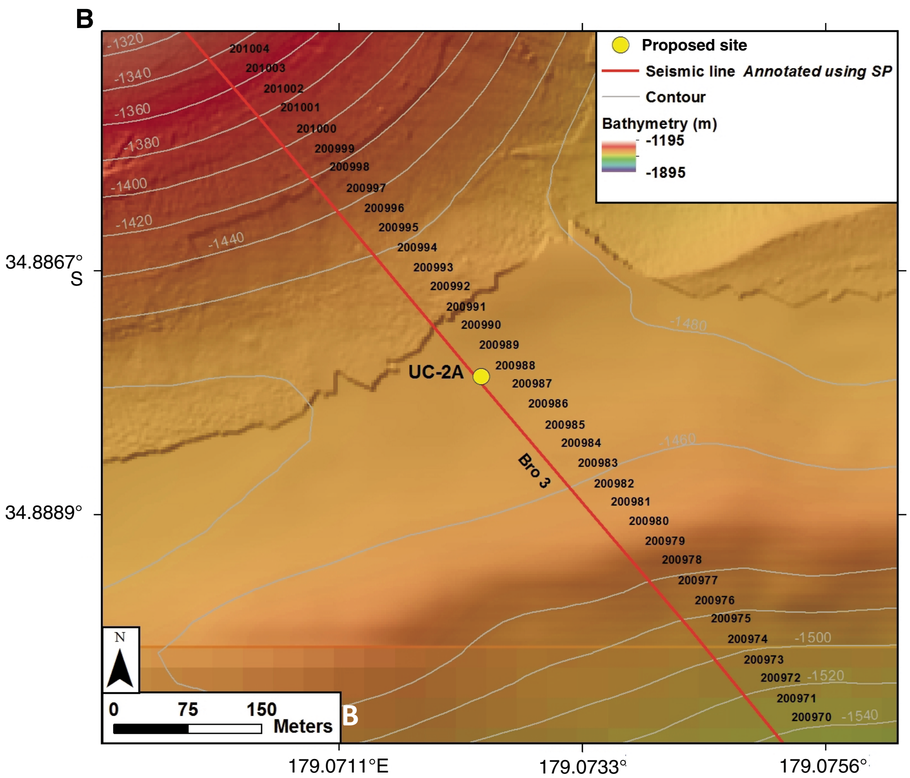


Figure F14. (A) Uninterpreted and (B) interpreted seismic section of Line Bro-3 showing the location of proposed alternate Site UC-2A..

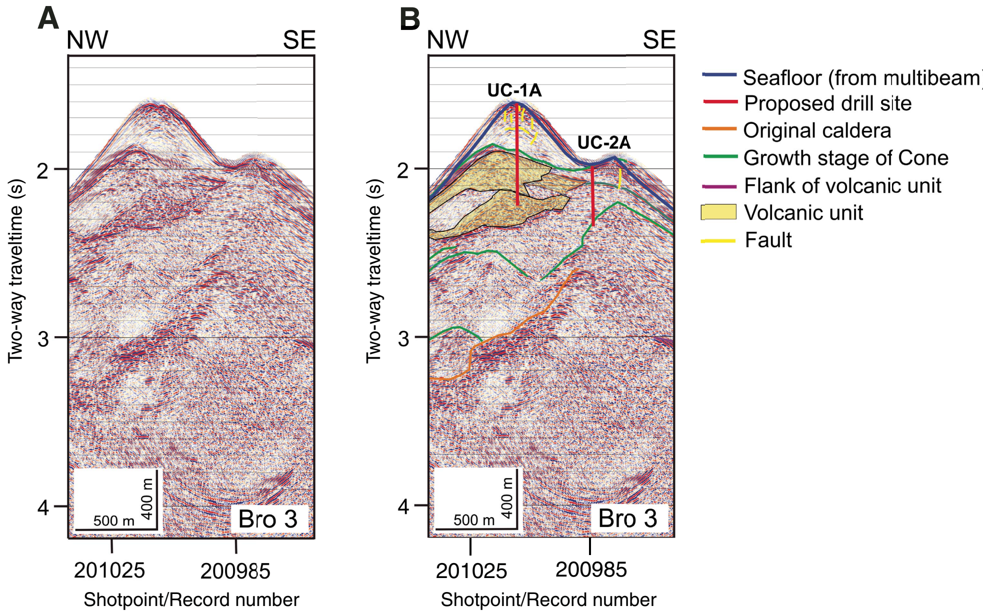


Figure F15. A. Location of proposed alternate Site LC-1A. B. Detail of site location. Bathymetry at this site is at 2 m resolution.

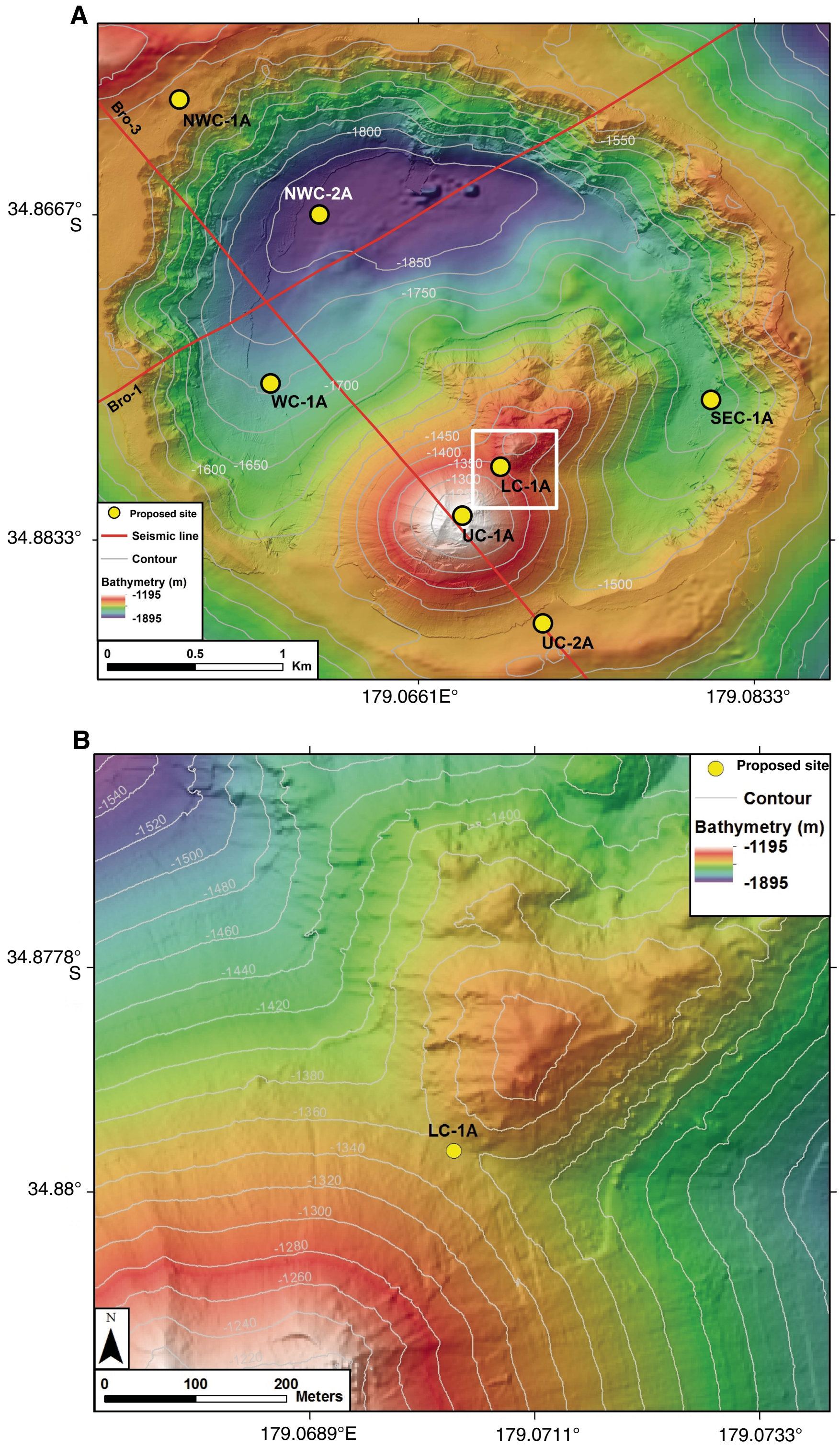


Figure F16. A. Location of proposed primary Site WC-1A. B. Detailed Site WC-1A location map with parts of seismic lines Bro-1 and Bro-3 shown. Bathymetry of this site is at a resolution of 25 m.

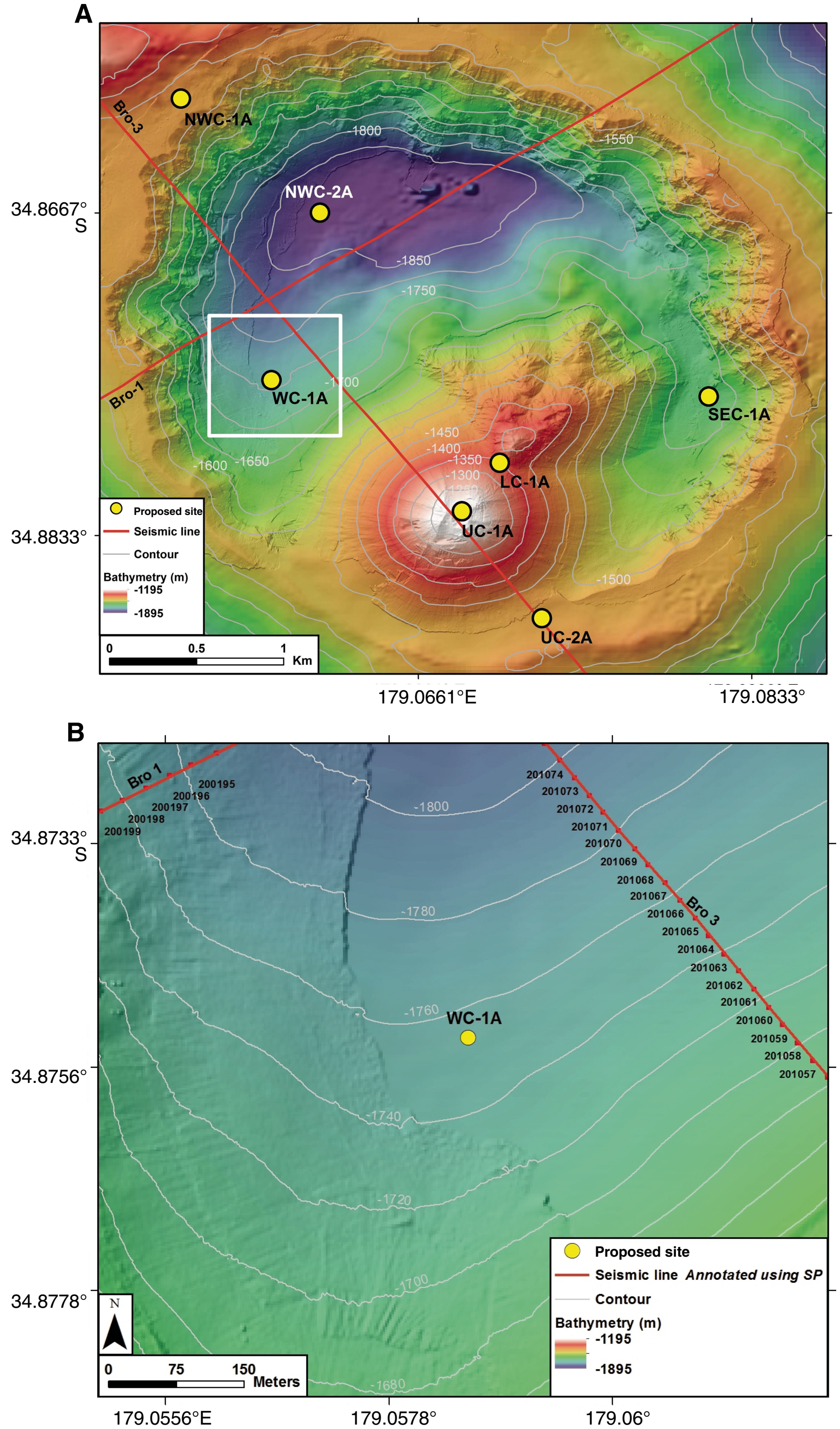


Figure F17. (A) Uninterpreted and (B) interpreted section of Line Bro-3 showing the location of proposed primary Site WC-1A. Drill sites have been projected on the seismic line; therefore, the projected depth will be less than that shown because proposed Site WC-1A is closer to the margin of the caldera than is the seismic line.

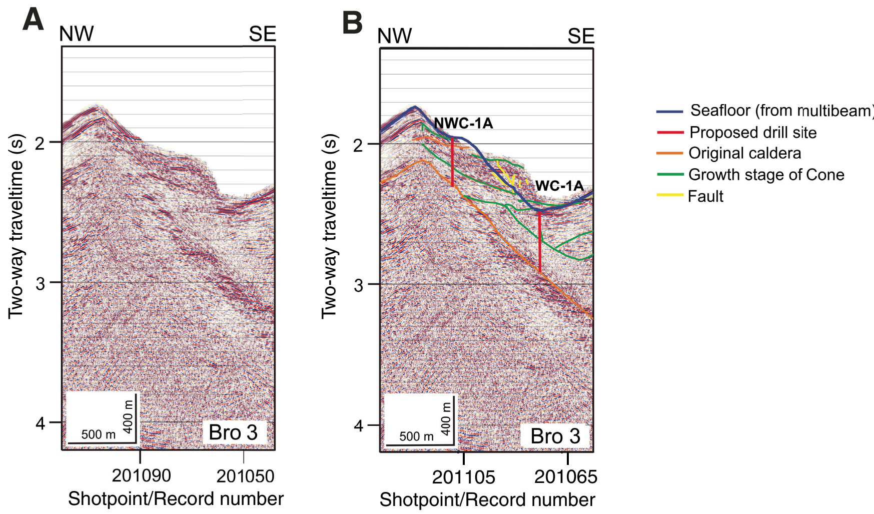


Figure F18. A. Location of proposed alternate Site SEC-1A. B. Detail of site location. Bathymetry at this site is at 2 m resolution.

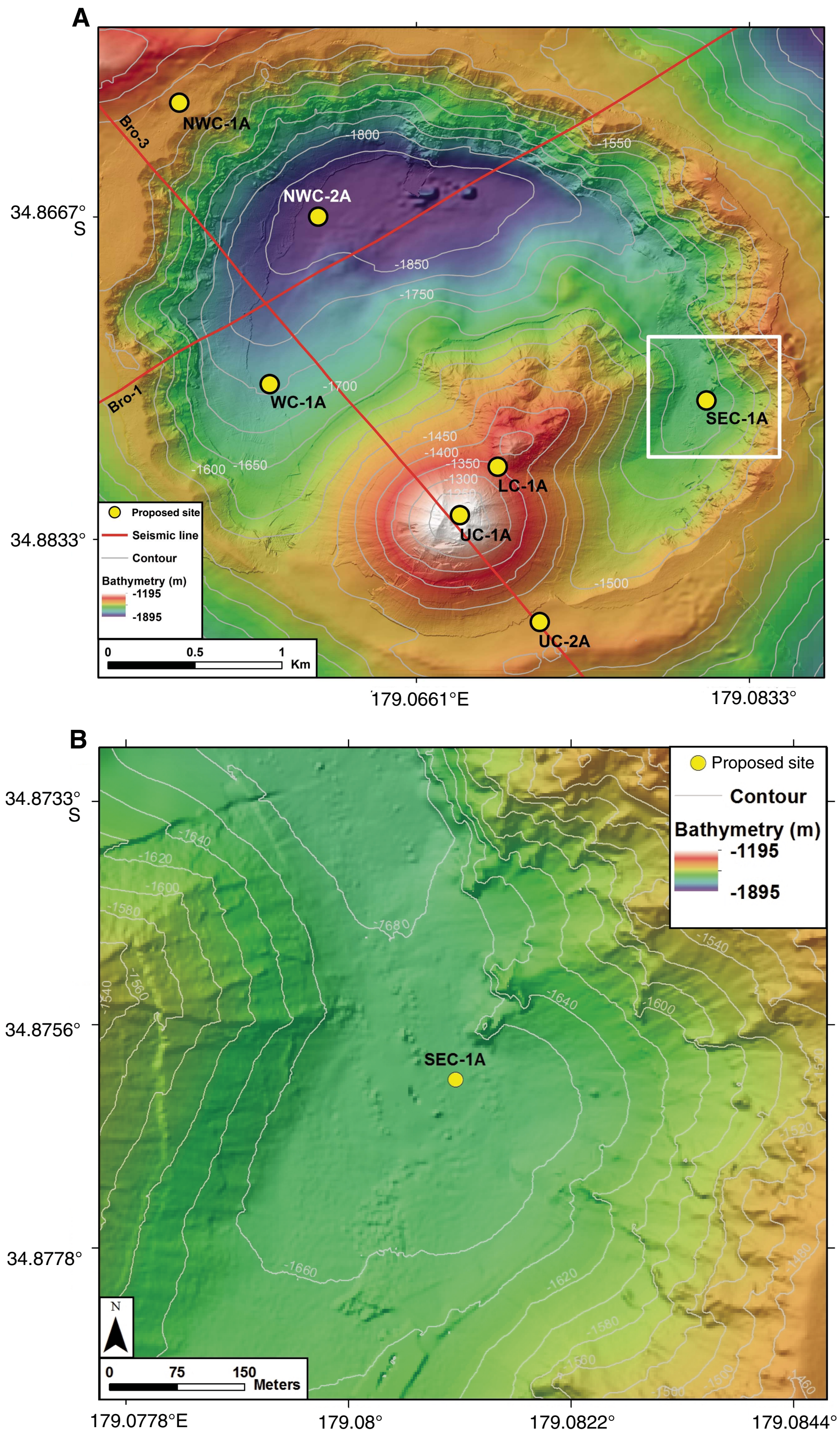
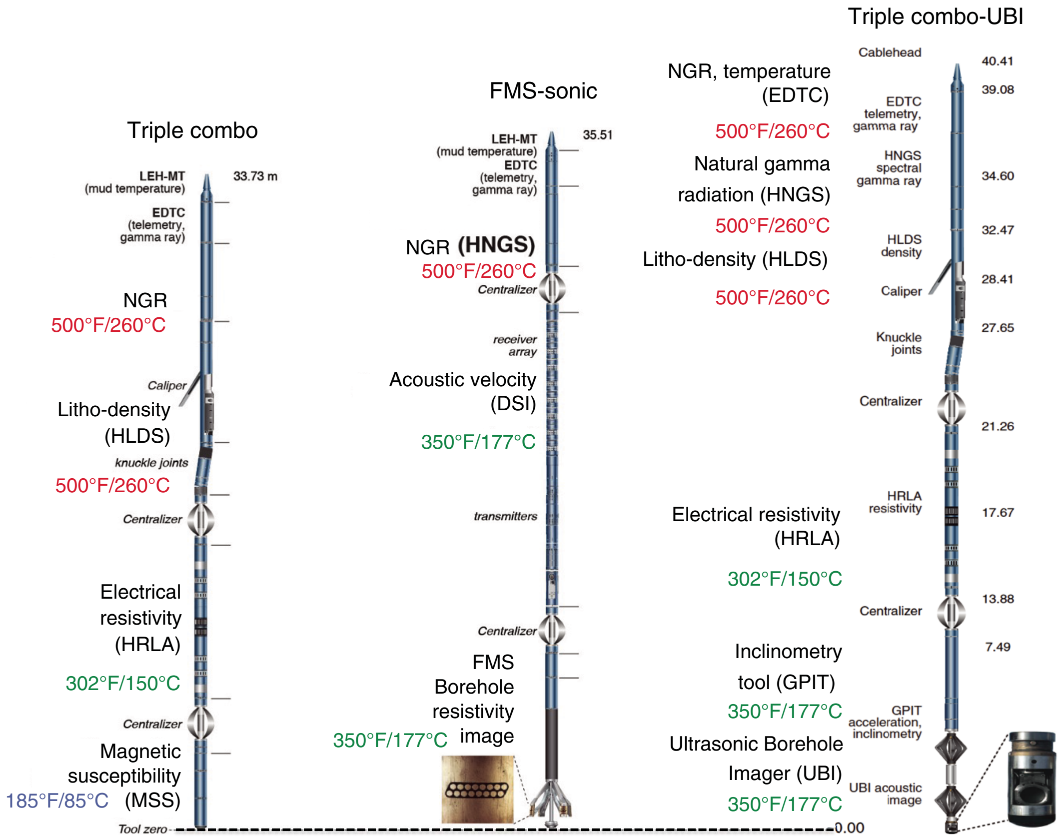


Figure F19. Triple combination (triple combo), FMS-sonic, and triple combo-Ultrasonic Borehole Imager (UBI) downhole logging tool strings (see **http://iodp.tamu.edu/tools/logging**) intended for use during Expedition 376 wireline logging (if formation temperature permits), including published tool temperature ratings (in both °F and °C). The temperatures are displayed in three different colors referring to the maximum temperature level of the corresponding tool. LEH-MT = Logging Equipment Head-Mud Temperature, EDTC = Enhanced Digital Telemetry Cartridge, NGR = Natural Gamma Radiation, HNGS = Hostile Environment Natural Gamma Ray Sonde, HLDS = Hostile Environment Litho-Density Sonde, HRLA = High-Resolution Laterolog Array Tool, MSS = Magnetic Susceptibility Sonde, DSI = Dipole Sonic Imager, FMS = Formation MicroScanner (borehole microresistivity imager), GPIT = General Purpose Inclinometry Tool.



Site summaries

Site NWC-1A

Priority:	Primary
Position:	34.86086°S, 179.054017°E (34°51.6516′S, 179°3.2410′E)
Water depth (m):	1464
Target drilling depth (mbsf):	405
Approved maximum penetration (mbsf):	405
Survey coverage (track map; seismic profile):	MCS Line Bro-3, CDP between 201105 and 201065 • Track map (Figure F7) • Seismic profile (Figures F6, F8)
Objective(s):	Drilling an older part of the upflow zone of Type I hydrothermal activity; retrieving samples of hydrothermally altered and mineralized rock
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry installation, double casing string to ~140 mbsf • RCB coring from ~140 to ~405 mbsf
Logging/Downhole measurements program:	Hole B: • Open-hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Dacite lavas and volcaniclastics

Site UC-1A

Priority:	Primary
Position:	34.882137°S, 179.068339°E (34°52.9282′S, 179°4.10034′S)
Water depth (m):	1232
Target drilling depth (mbsf):	800
Approved maximum penetration (mbsf):	800
Survey coverage (track map; seismic profile):	MCS Line Bro-3, CDP between 201025 and 200985 • Track map (Figure F11) • Seismic profile (Figures F6, F12).
Objective(s):	Drilling a Type II hydrothermal upflow zone and transecting several Upper Cone volcanic cycles; sampling rocks influenced by magmatic volatiles
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry installation, double casing string to ~140 mbsf • RCB coring from ~140 to ~800 mbsf
Logging/Downhole measurements program:	Hole B: • Open hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Dacitic lava and volcaniclastics (with advanced argillic alteration)

Site WC-1A

Priority:	Primary
Position:	34.87527°S, 179.058567°E (34°52.5162′S, 179°3.51402′E)
Water depth (m):	1765
Target drilling depth (mbsf):	565
Approved maximum penetration (mbsf):	565
Survey coverage (track map; seismic profile):	MCS Line Bro-3, CDP between 201105 and 201065 • Track map (Figure F16) • Seismic profile (Figures F6, F17).
Objective(s):	Penetrating the footwall of the original caldera floor and thereby transecting the deepest parts of the Type I hydrothermal system; retrieving core material complementary to proposed Site NWC-1A
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry installation, double casing string to ~140 mbsf • RCB coring from ~140 to ~565 mbsf
Logging/Downhole measurements program:	Hole B: • Open hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Pelagic ooze, dacite, and volcaniclastics

Site NWC-2A

Priority:	Alternate to NWC-1A
Position:	34.866529°S, 179.060990°E (34°51.99174′S, 179°3.6594′E)
Water depth (m):	1892
Target drilling depth (mbsf):	555
Approved maximum penetration (mbsf):	555
Survey coverage (track map; seismic profile):	MCS Line Bro-1, CDP between 200180 and 200140 • Track map (Figure F9) • Seismic profile (Figure F10)
Objective(s):	Drilling a Type I hydrothermal upflow zone; retrieving samples of hydrothermally altered and mineralized rock
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry installation, double casing string to ~140 mbsf • RCB coring from ~140 to ~555 mbsf
Logging/Downhole measurements program:	Hole B: • Open-hole temperature measurements Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Pelagic ooze, dacite, and volcaniclastics

Site UC-2A

Priority:	Alternate to UC-1A
Position:	34.887636°S, 179.072414°E (34°53.2582′S, 179°4.34484′E)
Water depth (m):	1476
Target drilling depth (mbsf):	530
Approved maximum penetration (mbsf):	530
Survey coverage (track map; seismic profile):	MCS Line Bro-3, CDP between 201025 and 200985 • Track map (Figure F13) • Seismic profile (Figures F6, F14).
Objective(s):	Drilling the margin of an upflow zone within a Type II hydrothermal system and transecting several volcanic cycles of the Cone; sampling rocks influenced by magmatic volatiles
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry installation, double casing string to ~140 mbsf • RCB coring from ~140 to ~530 mbsf
Logging/Downhole measurements program:	Hole B: • Open hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Dacitic lava and volcaniclastics (with advanced argillic alteration)

Site LC-1A

Priority:	Alternate to UC-1A
Position:	34.879597°S, 179.07031°E (34°52.7758′S, 179°4.2186′E)
Water depth (m):	1359
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage (track map; seismic profile):	No seismic data available • Track map (Figure F15)
Objective(s):	Drilling a Type II hydrothermal upflow zone, intersecting Upper Cone volcanic units and single-phase magmatic volatiles
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B: • Reentry system with ~45 m of 10¾ inch casing • RCB coring to ~300 mbsf
Logging/Downhole measurements program:	Hole B: • Open hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Degraded dacitic volcaniclastics and lavas

Site SEC-1A

Priority:	Alternate to WC-1A
Position:	34.876105°S, 179.081069°E (34°52.5663′S, 179°4.86414′E)
Water depth (m):	1676
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	300
Survey coverage (track map; seismic profile):	No seismic data available • Track map (Figure **F18**)
Objective(s):	Drilling extinct Type I hydrothermal upflow zone (SE Caldera system)
Drilling program:	Hole A: RCB coring to ~50 mbsf Hole B • Reentry system with ~45 m of 10¾ inch casing • RCB coring to ~300 mbsf
Logging/Downhole measurements program:	Hole B: • Open hole temperature measurements • Wireline log with triple combo and FMS-sonic
Nature of rock anticipated:	Hydrothermally mineralized and altered dacite and volcaniclastics