**IODP Expedition 397T: Transit and Return to Walvis Ridge Hotspot**

**Site U1585 Summary**

## Background and Objectives

Site U1585 was the second of two planned sites to sample the northern Walvis Ridge Guyot Province seamounts at locations slightly younger than that of the morphologic split, where the single ridge becomes 2–3 chains with different isotopic signatures. The site cores a Tristan track seamount that is part of a quasilinear chain of seamounts and ridges that stretch to the volcanically active Tristan da Cunha island group and have the same isotopic signature. The principal goal was to core basalt lava flows for major and trace element geochemistry and isotope geochemistry, obtain fresh basalt samples for geochronology, and recover multiple lava units for paleomagnetic inclination studies. Other important science objectives were to learn more about the volcanologic formation and evolution of Walvis Ridge seamounts and to obtain sediments that complement prior studies of sedimentation in the region.

## Operations

We completed the 111 nmi transit from Site U1584 to Site U1585 (proposed Site TT-04A) at a speed of 11.4 kt and arrived on 17 September 2022 at 1615 h (UTC + 1 h). Dynamic positioning (DP) mode was established and we were ready for operations at 1650 h. A bit and bit sub were made up to the rotary core barrel (RCB) bottom-hole assembly (BHA), which was deployed to just above the seafloor based on the precision depth recorder (PDR) signal. We picked up the top drive, pumped the “pig” to clear the newly installed pipe from potential rust and other obstructions, dropped the RCB, and began to spud Hole U1585A. The mudline was established by advancing the BHA until the driller noted a tag and the core barrel was recovered with a muddy coating. At 0340 h on 18 September, we declared the seafloor depth at 3468.5 m below rig floor (mbrf) (3457.3 m below sea level [mbsl]). At 0430 h a wash barrel was dropped, followed by a center bit, and we drilled ahead to 144.1 mbsf. The wash barrel and center bit were retrieved at 1815 h, the core barrel was dropped, and coring began with Core U1585A-3R. The driller noted a hard tag at 250 mbsf, followed by a drilling break at 262 mbsf. This corresponded to the penetration of a massive basalt breccia layer. Hard rock drilling rates were encountered from Core 31R on downwards, corresponding to the penetration of massive basalt. The last core, 39R, was retrieved in the morning of 23 September, reaching a total penetration of 498.8 mbsf. In Hole U1585A, we recovered a total of 217.7 m of sediment and rock for a 354.7 m interval cored, with recovery ranging from 11% to 103% (average 61%).

At 0615 h on 23 September, having used the available drilling time, we began retrieving the drill string and the bit cleared the rig floor at 1555 h, ending Hole U1585A. The drill floor was secured, the thrusters were raised, and the voyage to Lisbon, Portugal began at 1715 h. The

4,333 nmi transit ended at 0950 h on 11 October when the pilot boarded the vessel. Expedition 397T ended at 1115 h when all lines were secured at the Rocha cruise terminal, Port of Lisbon, Portugal.

COVID-19 mitigation protocols were followed with mask wearing, social distancing, and antigen testing of all personnel for the six days that started after the last recorded positive case on board was quarantined, as mandated by the COPE protocol. As of midnight on 21 September, daily COVID testing ended and wearing of masks was no longer mandatory. On 24 September the last of four infected personnel was released from quarantine.

## Principal Results

*Lithostratigraphy*

A 274 m thick succession consisting of a mixture of pelagic and detrital sediment and mixed fine (argillaceous) to coarse (blocky) volcaniclastic materials lying on top of 81 m of igneous basement was drilled at Site U1585. Igneous basement was encountered at 417.65 mbsf and the hole was ended at 498.8 mbsf. Five main lithostratigraphic units were recognized, four in the sediment section and one in the igneous section.

Unit I (144.10–157.02 mbsf) is a ~13 m succession of bioturbated nannofossil chalk with foraminifers, faintly alternating in color from whitish to pale green, with chert horizons and containing occasional thin ash intercalations.

Unit II (157.02–249.20 mbsf) is a thick (~92 m) succession of massive and bedded pumice and scoria lapillistone units, showing a downhole increasing abundance of basaltic clasts, reworking and compaction. It is divided into two subunits, IIA and IIB, based on increasing reworking, clast alteration, and tuffaceous chalk intercalations.

- Subunit IIA (157.02–194.80 mbsf) is a massive, unsorted basaltic lapillistone of dominantly pale-green pumice, scoria and basaltic clasts.
- Subunit IIB (157.02–194.80 mbsf) is a continuation of Subunit IIA but displays an increasing degree of reworking and clast oxidation and chalk intercalations.

Unit III (249.20-397.76 mbsf) is a thick (~149 m) complex succession of alternating pink to greenish-grey tuffaceous chalk-rich to silty and sandy sediments containing multiple thin, graded ash turbidites and tuffaceous ash, intercalated thick tuffaceous chalk intervals, occasionally slumped, and several thick, coarse lapilli and block dominated volcaniclastic layers. It is divided into eight subunits, IIIA–IIIH. Three of these, IIIA, IIID, and IIIG are mainly basalt breccias.

- Subunit IIIA (249.02–259.29 mbsf) is a >10 m thick unsorted, partially cemented basalt-dominated volcanic lapillistone breccia, with basaltic ash.

- Subunit IIIB (259.29–281.50 mbsf) is a uniform, >22 m thick, highly bioturbated gray-green to pinkish-gray tuffaceous chalk and silty clay with some graded pumice and ash layers.
- Subunit IIIC (281.5–294.48 mbsf) is a ~13 m thick bioturbated sequence of alternating dark gray to greenish-gray tuffaceous, chalky claystone displaying downhole disturbance including inclined bedding, rounded chalk clasts, and brittle fracturing.
- Subunit IIID (294.48–298.67 mbsf) is a ~4 m thick basalt-dominated volcanic lapillistone breccia consisting of densely packed scoria and basalt, with a mixture of tuffaceous chalk pebbles and isolated basaltic blocks toward its base.
- Subunit IIIE (298.6–331.76 mbsf) is a ~33 m thick complex succession of bioturbated tuffaceous chalk displaying pale gray to pinkish-brown color alternations, and infrequent tuff or ash layers, some preserving plagioclase crystals, and bioclasts. Its base contains chaotic intervals displaying soft sediment deformation with rip-up clasts, indicative of submarine slumping.
- Subunit IIIF (331.76–367.07 mbsf) is a >35 m succession of carbonate-rich silty clay with a downhole grain size to a highly bioturbated, dark reddish-brown to dark greenish-gray silty sand. The frequency of crystal-rich ash and shell debris layers increases downhole indicative of shallower water.
- Subunit IIIG (367.07–374.10 mbsf) is a >7 m thick polymict lapilli-sized volcanic breccia passing downward into blocky breccia with minor reworking. It contains “zoned” (accretionary?) lapilli and basalt fragments with glassy/palagonitized (tachylitic) rims. These juvenile pyroclasts indicate proximity to a volcanic source.
- Subunit IIIH (374.10–397.76 mbsf) is >24 m thick succession; the uppermost interval is a bioturbated dark greenish-gray to dark reddish-brown tuffaceous, carbonate-rich silty clay with numerous ~2–5 cm thick tuff or ash layers. The lower half of the unit contains thicker (~5–10 cm) polymict conglomeratic graded intervals containing tuffaceous chalk pebbles, fine shell debris, and lapillistone with some block-sized clasts. Lapillistone contains palagonitized quenched/glassy basaltic fragments—an admixture of juvenile pyroclastic fallout.

Unit IV (397.76–417.60 mbsf) is a thick (~20 m) deposit of volcanic breccia consisting of a stacked succession of basaltic block, bomb, and accretionary lapilli. An abundance of glassy shards and tachylitic rims on angular basaltic fragments, together with marine bioclasts and recrystallized foraminifers in the cement, indicates juvenile and reworked volcaniclastic components and a complex explosive eruptive–sedimentary environment. It is not divided into subunits.

In chronological order, the cored succession begins with an igneous basement consisting of unusually thick uniform basaltic units (Unit V). This is overlain by a varied succession combining initially juvenile volcaniclastic material (Unit IV), and subsequent sedimentary lithofacies involving reworked volcaniclastics eventually passing into deep marine chalk-dominated sedimentary units (Units I–III). The lowermost basalt “flow” and primary volcanic deposits represent the end stages of the constructive phase of the evolution of the volcanic edifice. Following this effusive-explosive phase is a period of deepening marine environment, and the onset of drowning of the site (Unit III). Repeated influxes of coarse volcanic debris indicate a nearby offshore, shallow source in which accumulated clastic detritus periodically slumped into deeper water. Long periods of deepwater pelagic accumulation are represented by the preservation of alternating redox conditions within tuffaceous and increasingly purer nannofossil chalk sediments (Subunits IIIB and IIIE). Tuffaceous carbonates eventually give way to more homogenous carbonate ooze (chalk). The thick pumice and scoria rich layers of Unit II represent a much later, and entirely separate, phase of volcanism. The length of hiatus between this later eruptive phase and the emplacement of the earlier lava units remains to be determined.

*Igneous Petrology and Volcanology*

Site U1585 penetrated 81.2 m of igneous basement (Interval 397T-U1585A-31R-5, 75 cm, through 397T-U1585A-39R-6, 43 cm), with 70.2 m recovered (86% recovery). The igneous basement at Site U1585 is designated Lithostratigraphic Unit V and Hole U1585A terminates within a massive lava flow with a minimum flow thickness of 43.3 m. Three igneous units were identified at Site U1585. Unit 1 and Unit 3 consist of massive lava flows, and each have two subunits distinguished by distinct textural and mineralogical changes. Unit 2 is an igneous unit that consists of a mineralogically and texturally distinct piece of quenched lava potentially related to a pillow sequence with very low recovery.

Igneous Unit 1 is a sparsely to highly olivine-clinopyroxene ± plagioclase phyric massive basalt (Interval 397T-U1585A-31R-5, 75 cm, through 397T-U1585A-34R-1, 0 cm; 417.60–441.2 mbsf). Textural and mineralogical changes suggest that this unit likely consists of, at minimum, two basalt flows each with distinctive mineralogy. The topmost flow (Subunit 1a) is a 4.47 m thick (417.60–422.07 mbsf) massive flow. Subunit 1b is a 19.1 m thick (422.07–441.20 mbsf) massive flow that is more fractionated (moderately clinopyroxene ± plagioclase phyric) basalt with noticeably coarser groundmass crystals than Subunit 1a.

Igneous Unit 2 consists of a 3 cm (441.20–441.23 mbsf) piece of quenched basalt with olivine phenocrysts in a microcrystalline groundmass. Because unrecovered intervals are defined by the end of a core, the thickness of Unit 2 is underrepresented and the thickness for Subunit 3A is overrepresented.

Igneous Unit 3 consists of two massive lava flows without any clear flow boundary features. However, changes in texture, mineralogy, and geochemistry suggest that two flows with separate fractionation histories may be present. The first flow is identified as Subunit 3a. It is 10.3 m thick (441.23–451.26 mbsf) and consists of a highly clinopyroxene-plagioclase phyric massive basalt flow with a fine-grained groundmass. Subunit 3b is a thick (>43.7 m; 451.26–495.0 mbsf), relatively featureless massive basalt flow that is moderately to highly pyroxene-plagioclase ± olivine phyric.

Broadly, two stages of alteration can be identified intermittently throughout the igneous units: (1) a higher temperature alteration chlorite-sericite-zeolite facies, and (2) a subsequent, lower-temperature Fe-oxyhydroxide alteration. The higher-temperature alteration was more pervasive, and resulted in pyrite, calcite, chlorite, and zeolite filling vesicles, veins, and fractures. The intensity of this alteration was moderate through Units 1 and Subunit 3a but decreased in intensity towards the bottom of Subunit 3b. The low-temperature, more oxidizing episode of alteration is patchy and often seen localized around fractures, which provided fluid pathways. The more oxidizing alteration episode happened secondarily and often removed vesicle and vein filling. It is observed mostly in Unit 1.

*Paleomagnetism*

Almost all core sections were measured with the superconducting rock magnetometer, producing 52,829 measurements. Additionally, 125 discrete samples were treated to detailed demagnetization. Magnetization intensity within the sedimentary section displayed an extreme range from $3.0 \times 10^{-5}$ to 7.3 A/m because of the variation from weakly magnetic carbonate sediments to basalt breccia. Magnetization intensity of basalt flow cores ranged from 0.45 to 15.26 A/m, which is normal for relatively unaltered basalt. Although a few of the upper breccia units (IIB, IIIA) gave scattered paleomagnetic inclination data, most cores produced consistent results. Cores U1585A-18R through the basalt section to the bottom of the hole yield positive inclinations, implying reversed magnetic polarity. The calcareous sediments at the top of the cored interval, Cores 3R and 4R (Unit I) are also reversed. In between there is at least one, but perhaps two, normal polarity zones, depending on confirmation of an intervening reversed interval. Cores 13R, 14R, and the top of 15R give scattered inclination data, but detailed demagnetization of two discrete samples indicates reversed polarity. This polarity zone requires confirmation with later study. If confirmed, it divides normal polarity zones observed in Cores 9R to 12R and 15R to the top of 18R. If not, there is probably only one normal polarity interval. The occurrence of a magnetic reversal in the latter core provides a potential opportunity for dating that can help calibrate the magnetic reversal timescale. Isothermal remanent magnetization (IRM) studies show that the magnetization carriers in the sediments are mostly titanomagnetite, but with varying amounts of high coercivity mineral, likely hematite. These experiments also show that the magnetizations of some massive flows are soft and may be carried by large, multidomain grains.

*Sedimentary Geochemistry*

A total of 119 sediment samples from lithologic Units I–III were analyzed to determine the weight percent of $CaCO_3$, total carbon (TC), total inorganic carbon, total organic carbon (TOC), and total nitrogen (TN). In Lithostratigraphic Unit I, $CaCO_3$ content is high, with a mean of 77 ± 9.7 wt%. The mean $CaCO_3$ content is more moderate in Subunits IIB, IIIA, IIIB, and IIIE, ranging from 40 ± 9.1 wt% to 62.9 wt% (Note: numbers with ± values are averages with standard deviation; those without are single measurements). Subunits IIA, IIIF, and IIIH all have low $CaCO_3$, ranging from 26 to 31 wt%. TOC content is low across all lithologic units

(<0.5 wt%) and shows no consistent trend between units. Therefore, TC contents are nearly identical (within error) to total inorganic carbon and do not show a clear pattern with depth. Likewise, given the complexity of each lithostratigraphic unit, it is difficult to draw clear connections between TC and lithostratigraphic units. Subunits IA and IIA have relatively higher TC (7.9 and 9.3 ± 1.3 wt%, respectively) than other units. TC is moderate in Subunits IIB, IIIB, IIIC, IIIE, and IIIH (4.0–6.6 wt%) and low in Subunits IIA, IIID, and IIIF (2.8–3.1 wt%). TN contents are below the instrumental detection limits for all samples.

*Igneous Geochemistry*

At Site U1585, 16 samples were analyzed for major and trace elements via inductively coupled plasma–atomic emission spectroscopy (ICP-AES) from the two igneous units comprised of massive flows. Additionally, 13 samples from large basalt clasts within various volcaniclastic lithostratigrapic units above the igneous basement were also analyzed. The majority of Site U1585 basalt clasts and lava flows lie within the basalt compositional field. However, five lava flows and three clasts are compositionally trachybasalts, and one basalt clast is a basaltic trachyandesite. Apart from three transitional basalt clasts, all Site U1585 samples are alkaline. Calculated Ti/V ratios demonstrate that the basalt lava flows have higher Ti/V ratios than most of the basalt clasts. The lower Ti/V ratios are consistent with lavas from Expedition 391 Sites U1575, U1576, and U1577, and overlap with values from mid-ocean-ridge basalt (MORB) and the transition to oceanic island basalt (OIB). The higher Ti/V ratios associated with the basalt lava flows fall between the values from Sites U1575–U1577 and Site U1578. They also lie completely in the OIB field.

The basalt clasts from Site U1585 show a wide range of Mg# (32.5–64.6), similar to basalt clasts from Site U1584. However, unlike clasts from Site U1584, the more numerous basalt clasts in Site U1585 also show a wider range of other elemental abundances (e.g., $SiO_2$ = 45–52 wt%, CaO = 5.0–16.6 wt%, $TiO_2$ = 0.9–2.8 wt%). The scatter in $K_2O$ may be due to seawater alteration. In contrast, the basalt lava flows show a range of compositions forming clear trends generated by fractional crystallization. The basalt lava flows show increasing $SiO_2$, $TiO_2$, CaO, $K_2O$, $Al_2O_3$, Zr, V, and Sr, with decreasing Mg#. The strong positive correlation between Mg# and Ni are indicative of modest olivine accumulation in the most MgO-rich samples (up to 18.3 wt% MgO and 565 ppm Ni). Overall, $TiO_2$ contents are modest for both basalt clasts and basalt lava flows; none are as $TiO_2$-rich as Site U1578 lavas. However, the $TiO_2$ content of the basalt clasts are lower than those of the basalt lava flows with similar Mg#. The relational offset is also observed in Zr and Sr. This compositional difference between the younger basalt clasts and the older basalt lava flows may be due to a change in magmatic source.

*Physical Properties*

Within Hole U1585A, three primary sedimentary units were identified and defined by changes in sedimentary successions and major shifts in physical property behavior. Three units were also identified within the igneous basement, but those units had minor changes in physical properties and were mainly distinguished using changes in petrography and geochemistry.

The physical properties data can be broken down into two categories: 1) properties that mark major lithostratigraphic boundaries by displaying distinct changes from the previous unit, and 2) properties that display intraunit variation and small-scale variations (e.g., within a single core). Bulk density measurements based on gamma ray attenuation (GRA) and moisture and density (MAD) analysis and *P*-wave velocity fall within the first category and were best suited to identify major lithostratigraphic boundaries. Bulk density and *P*-wave velocity are nearly homogeneous within the Units I through III, excluding the basalt breccia units in Unit III (Subunits IIIA, IIID, and IIIG) where *P*-wave velocity displays higher peaks. The two properties were more variable within Unit IV due to the amount of basaltic blocks within the ash cemented lapillistone, but stabilized and steadily increased into the igneous basement to the bottom of the hole. Magnetic susceptibility (MS, MSP), natural gamma ray (NGR), and porosity have more interunit variation when compared to density and *P*-wave velocity. They display systematic changes within a single core. Core-section (meter scale) variations are present, but careful processing of the data is needed to remove outliers introduced by gaps between sections and pieces. In general, both MS and NGR steadily increase from the top of the hole within the chalky Unit I to the base of breccia Unit IV, and both display intraunit variations on meter and core length scale that fluctuate between different sediment successions. NGR decreases a small amount in the highly pyroxene-olivine phyric basalt of Subunit 3b. Porosity was measured only in Units I through III and varies between 40–60 vol% across lithologic units and within single cores.