IODP Expedition 392: Agulhas Plateau Cretaceous Climate

Site U1582 Summary

Background and Objectives

The northern Agulhas Plateau is characterized by a rough topography and a number of basement highs separated by depressions with only a thin sedimentary cover. In between the interpreted basement highs, thicker sediment packages filling depressions or sediment drifts are observed. This distribution of sedimentary sequences attests to the strong erosional/nondepositional influence of the Agulhas Retroflection as well as Circumpolar Deep Water flowing over the northern Agulhas Plateau. The northern slope of the Agulhas Plateau furthermore lies under the influence of North Atlantic Deep Water and Antarctic Bottom Water, both of which shape sediment drifts. Site U1582 (proposed Site AP-07A) is located on the flank one of those basement highs (37°1.5002′S, 24°59.7168′E) in 3441 m water depth, where a small ledge is formed. The seismic data show basement below an ~100 m thick sedimentary sequence, which is characterized by reflectors M and LE. The uppermost part of basement further shows only few internal reflections, which differs from the seismic character of the basement at Sites U1579 and U1580. This has been interpreted to represent more homogeneous basalt at Site U1582.

Site U1582 was selected to recover both the thin Paleogene–Cretaceous sedimentary cover and basement samples. This site was especially dedicated to recover an extended record of basement material to unravel the nature of the basement and provide information on its age and geochemistry. Additional objectives include identifying potential late stage magmatism and its effect on sedimentary sequences. Integration of seismic profiles with the drilling results will allow direct dating the observed seismic unconformities M and LE and interpreting their causes, and recovery of the sediment/basement interface will provide information on the age of the oldest sediments on crust and paleodepth as well as paleoenvironment. At this site, a thin sediment sequence from the mid-Cretaceous to mid-Paleogene was expected to be drilled, spanning the long-term climate transition from the Cretaceous greenhouse potentially to the early Paleogene. Critical intervals of ocean/climate transitions such as the Cretaceous/Paleogene (K/Pg) boundary, Oceanic Anoxic Event (OAE) 2, and OAE 3 were expected to be documented in the sedimentary record. The recovery of basement rocks at this site on the northern Agulhas Plateau was expected to help address fundamental questions about the formation of this large igneous province.

Operations

The vessel arrived at Site U1582 at 1420 h on 27 March 2022. All times are local ship time (UTC + 2 h). The thrusters were lowered starting at 1424 h, the vessel was switched from cruise to dynamic positioning (DP) mode at 1440 h, and the rig floor was given the all clear. A new C-7

bit with a mechanical bit release was made up, and a four-stand rotary core barrel (RCB) bottom-hole assembly (BHA) was run into the hole starting at 1645 h. The drill pipe was lowered to 3378.3 meters below rig floor (mbrf), the sinker bars were installed, and the RCB core barrel was deployed.

The first attempt for core at 2340 h was a water core. Starting on 28 March, four more attempts were made to get the first core. On the sixth attempt, Hole U1582A was spudded at 0405 h, with Core U1582A-1R recovering 1.9 m. The seafloor was established at 3429.4 meters below sea level (mbsl). Coring continued and basement was reached at 42.7 m core depth below seafloor (CSF-A). Half-cores were taken on Cores 6R and 7R. The final core for Hole U1582A, Core 7R, was cored to 48.0 m CSF-A, but an excess of 100% was recovered (48.68 m CSF-A). Coring was terminated at 1915 h to trip out of the hole, as severe weather was expected over the site within 24 h. A total of seven cores were taken in Hole U1582A over a 48 m interval with 38.5% recovery. Total time on Hole U1581A was 38.4 h (1.6 d).

The pipe was tripped out of the hole, clearing the seafloor at 1945 h. On 29 March at 0215 h the pipe trip was completed with the BHA at the rig floor. The bit cleared the rig floor at 0455 h, ending Hole U1582A. The rig floor was secured at 0600 h, and the vessel was switched to cruise mode at 0604 h. The thrusters were raised and secure by 0618 h, and the sea passage for waiting on weather (WOW) began with the vessel transiting north at 10.6 kt. The vessel turned and took a westerly heading at 1818 h. Beginning on 31 March the vessel turned on a southerly and then easterly course to return to Site U1582.

On 1 April, the vessel arrived back on Site U1582. The thrusters were lowered starting at 1228 h, and the ship was switched to DP mode at 1245 h, ending the WOW. The vessel was positioned 10 m west of Hole U1582A. A new C-7 RCB bit was made up, and the BHA and pipe were tripped to the seafloor. A core barrel with a center bit was dropped, and Hole U1582B was spudded at 2315 h on 1 April. Seafloor was again set at 3440.7 mbsl (by offset). The driller then proceeded to drill down before reaching a hard contact at 36.3 m CSF-A. The center bit was retrieved and coring began at approximately 0530 h on 2 April, with Core U1582B-2R on deck at 1100 h. The rate of penetration (ROP) was very slow, averaging just over 1 m/h, due to the hard basalt formation and shallow depth of the hole limiting how much weight could be put on the bit. Coring continued into 3 April, through Core 5R at a final depth of 55.6 m CSF-A (recovery to 53.73 m CSF-A).

The weather over the site was expected to deteriorate over the next two days, thus forcing us off site and in transit to Cape Town, South Africa, early. Coring was terminated at 0230 h on 3 April, and the pipe was tripped back to the vessel. The bit cleared the rig floor at 1250 h, ending Hole U1582B and Site U1582. The vessel was switched to cruise mode at 1236 h, the thrusters were raised and secured by 1249 h, and we began our sea passage to Cape Town, South Africa, at 1250 h with the vessel making a wide turn to the northwest. A total of four cores were taken in Hole U1582B over a 19.3 m interval with 52.2% recovery. Total time on Hole U1582B was 48 h (2.0 d).

On 5 April the vessel came to anchorage in the Cape Town Harbor. The pilot boarded on 7 April at 1030 h and Expedition 392 officially ended with the first line ashore at 1154 h on 7 April.

Principal Results

Lithostratigraphy

Site U1582 consists of a 40.92 m thick sequence of sediments overlying a 16.9 m thick interval of basalt with intervening thin layers of sediment. The sequence recovered at Site U1582 is divided into two lithostratigraphic units, Unit I and Unit II. Unit I is entirely comprised of sediments and further subdivided into two subunits (Ia and Ib), and Unit II consists of pillow basalts with interspersed sediments.

Lithostratigraphic Unit I is an ~40 m thick sequence of nannofossil ooze, clayey silt, and clayey nannofossil ooze with sand in the upper sections and limestone at the base. The unit is further divided into two subunits, Subunits Ia and Ib, based on downcore increase in lithification. Both subunits contain variable amounts of sand, silt, clay, and manganese nodules. Subunit Ia consists of light brown clayey silt, nannofossil ooze, clayey nannofossil ooze with sand, and manganese nodules. From 2.0–2.11 m CSF-A, there is a dark brown, ~11 cm manganese nodule, and there are additional small nodules of manganese throughout the entire subunit. From 7.32 m CSF-A to the base of the subunit, medium to coarse sand-sized and occasionally pebble-sized manganese nodules are present. The contact between Subunits Ia and Ib is unclear, as it occurs in an interval of poor recovery between Cores U1582A-4R and U1582A-5R (~21.71–31.07 m CSF-A).

Subunit Ib consists of limestone, with one cobble-sized manganese nodule in interval U1582A-7R, 0–7 cm (45.5–45.57 m CSF-A). The limestone ranges from light gray to pale yellow in color and contains clasts of altered basalt and carbonate intraclasts, including pebble-sized angular calcite crystals. Manganese dendrites are also present in the light gray limestone. Carbonate content decreases from ~30% at 0.83 m CSF-A to <5% at 2.48 m CSF-A, and remains below 10% down to 21.57 m CSF-A. The contact between Units I and II was not recovered.

Lithostratigraphic Unit II is ~17 m in thickness and consists largely of pillow basalts with occasional layers/pockets of sediments between pillow basalts. The sediment includes limestones and volcaniclastic material, with the limestones ranging from pale yellow to light brown to light grayish-green in color. In the pale yellow and light brown limestones, limonite is present at contacts with the basalt. Dendritic manganese and calcite veining are also present in the limestones.

Igneous Petrology

Igneous rocks were first reached at 40.92 m CSF-A in Hole U1582A and at 36.83 m CSF-A in Hole U1582B, below sedimentary Lithostratigraphic Subunit Ib. In Hole U1582A, Lithostratigraphic Unit II is comprised of a 7.76 m thick sequence of pillow lava basalts with

thin, intercalated limestone pockets. Thirteen igneous units were identified and defined as individual inflationary pillow lava lobes in Hole U1582A. The sedimentary material in Lithostratigraphic Unit II consists of thin (<10 cm) limestones and is considered to be pockets of carbonate sediment that occupies interstices between individual pillow lobes.

The upper part of Lithostratigraphic Unit II in Hole U1583A (Igneous Units 1–3) is composed of predominantly plagioclase-phyric pillow basalts, which all show a yellow-brownish alteration pattern. There is abundant fresh glass along the chilled contact of the pillows, as well as an outer layer of palagonized (weathered) glass and possibly some sedimentary material. The basalt in the interior of the lobes is fine-grained and moderately to highly altered, sparsely plagioclase-phyric. Many intervals are also moderately vesicular with typical, radially arranged vesicle trains inward of the chilled margin, with all of the vesicles filled with calcite. The common yellow-brownish color of the basalts in the upper part of Lithostratigraphic Unit II indicates considerable weathering and oxidation. The lower part of Lithostratigraphic Unit II in Hole U1582A (Igneous Units 4–13) is also composed of predominantly plagioclase phyric pillow basalts. However, most of these basalt units possess a natural gray color and show no signs of oxyhydroxide staining, indicating a much lesser state of oxidative weathering than the uppermost basalts of the unit.

Hole U1582B was spudded 10 m west of Hole U1582A and delivered the same principle lithologies as in Hole U1582A, although igneous rocks were first encountered at ~4 m shallower depth (36.83 m CSF-A) below sedimentary Lithostratigraphic Subunit Ib. A 16.86 m thick sequence of pillow lava basalts was penetrated until the drilling ceased at 53.69 m CSF-A in Hole U1582B. The ~4 m shallower occurrence of the igneous basement in comparison to Hole U1582A attests the considerable lateral variability of pillow lava flow fields, which likely created an irregular sediment/basalt contact at this site. In total, 27 igneous units were identified in Hole U1582B, including 26 pillow lava units and one sequence of a hyaloclastite breccia. As in Hole U1582A, the pillow lava units were defined and interpreted as individual inflationary lava lobes.

The entire igneous succession cored in Holes U1582A and U1582B is interpreted as a stack of pillow lava lobes based on observed structures such as curved chilled margins, the presence of thick (fresh and altered) glass rinds along these margins, radially arranged vesicle trains, and concentric vesicle bands parallel to the curved margins. The basalts recovered in both holes are characterized by the presence of pockets or intervals of interpillow carbonate sediment often recovered in direct contact with the pillow rims. Calcareous nannofossils present within at least some of these carbonate pockets rule out a purely diagenetic origin of the carbonate. Instead, the evidence of mingling of plastic lava with unconsolidated sediments is tentatively interpreted as peperite, implying an interaction of lava and coexisting sediment during eruption.

Micropaleontology

The 53.73 m thick succession recovered at Site U1582 contains calcareous nannofossils and foraminifers in varying abundances. The sediments are barren of siliceous microfossils, and

samples from the site were not processed for palynomorphs due to the nature of the sediment and time constraints near the end of the expedition.

Calcareous nannofossils are abundant and moderately to poorly preserved in the nannofossil ooze of Lithostratigraphic Subunit Ia (0–21.76 m CSF-A). The clayey silt and clayey sand beds within this subunit, however, are barren or nearly barren of nannofossils. Nannofossils preservation generally decreases from the top of the hole down through Lithostratigraphic Subunit Ia. Nannofossils are very rare and poorly preserved in the limestone of Lithostratigraphic Subunit Ib. In contrast, nannofossils are present in rare to few numbers and moderately preserved in the greenish-gray sediment intercalated with basalt, whereas they are rarer and show poorer preservation in the yellowish-brown limestones associated with the basalt. Foraminifers are present within the upper four cores of Hole U1582A (0–21.73 m CSF-A; Lithostratigraphic Subunit Ia), with preservation ranging from good (Sample 2R-CC, 5–10 cm [7.66 m CSF-A]) to poor (Sample 4R-CC, 19–24 cm [21.71 m CSF-A]).

Chronostratigraphy

Calcareous nannofossils, foraminifers, and magnetostratigraphy provide age control for the Campanian(?) to upper Miocene sediments recovered at Site U1582 in Lithostratigraphic Unit I. The sedimentary cover is very thin (~40 m) at Site U1582, yet represents a long period of time (as much as 70 My), indicating very low sedimentation rates and/or significant erosion. The presence of abundant manganese nodules is consistent with this observation. The low sedimentation rates and other processes such as reworking of older sediment and burrowing, together with coring disturbance, make this a particularly challenging site for chronostratigraphy. Due to significant mixing, the youngest age diagnostic taxa within a given sample or set of samples was used for biostratigraphic age assessment, with outlier bioevents excluded that appear to result from drilling disturbance or contamination.

The nannofossil ooze, clayey silt, sand, and manganese nodules of Lithostratigraphic Subunit Ia (Hole U1581A: 0–21.76 m CSF-A) show predominantly reverse magnetic polarity with some intervals of normal polarity usually associated with manganese nodules. Nannofossil assemblages in this subunit often include a significant component of reworking and presence of multiple biostratigraphic marker taxa indicating broad age ranges. Foraminifers in the mudline sample (0 m CSF-A) indicate a very young (Pleistocene–Recent) age for the seafloor, while nannofossils indicates a late Miocene age between ~10.9 and 5.5 Ma for the interval between 0.43–1.35 m CSF-A. The interval between 1.85–1.98 m CSF-A is assigned an Eocene to mid-Oligocene age (~35–27 Ma), and the interval between 4.71–6.76 m CSF-A is assigned an early to early middle Eocene age (~54 to 47 Ma) based on nannofossil biostratigraphy. Samples between 7.63–11.90 m CSF-A contain assemblages of mixed ages with a significant component of older material reworked into younger sediment, together with likely contamination from younger material due to fall-in. However, although the nannofossil assemblage contains

Cretaceous taxa similar to those in the deeper samples, the presence of Paleogene nannofossils indicate an early Eocene or younger age for this interval.

The interval between 11.90–21.71 m CSF-A of Lithostratigraphic Subunit 1a contains a solely Cretaceous nannofossil assemblage with background taxa similar to those in the sediment intercalated with the basalt of Lithostratigraphic Unit II, indicating a Campanian to earliest Maastrichtian age, despite the dominance of older (Coniacian) species. The dominantly reverse polarity of this interval also precludes a Coniacian age. However, the possibility that the nannofossil assemblage is entirely reworked through this interval cannot be discounted. The lowermost sediments recovered above basalt at Site U1582 are limestones within Lithostratigraphic Subunit Ib (Hole U1582A: 40.92–31.00 m CSF-A; Hole U1582B: 36.83–36.30 m CSF-A), which contain only very rare and poorly preserved Cretaceous nannofossils that provide no additional age control. The limestone shows normal magnetic polarity, however, with no reversals between it and the basalt below. This may suggest that the limestone was deposited during the long Cretaceous Normal Superchron (C34n), indicating an age of Santonian or older; however, this age assessment is very tentative.

Nannofossils and magnetostratigraphy provide age constraints for the basalt and sediments of Lithostratigraphic Unit II (Hole U1582A: 48.68–40.92 m CSF-A; Hole U1582B: 53.73–36.83 m CSF-A). The limestones intercalated with basalt contain a sparse, moderately preserved Late Cretaceous nannofossil assemblage. Nannofossil marker taxa suggest an early Turonian to Santonian age (~93.7–84 Ma). The broad age interpretation of Turonian–Santonian is consistent with the persistent normal magnetic polarity of the basalt, which can therefore be assigned to Superchron C34n. Given the sparse nature of the assemblages, postcruise research may provide additional nannofossil age constraints for the sediments recovered within the basalts.

Paleomagnetism

Paleomagnetic measurements were undertaken on all archive section halves of Holes U1582A and U1582B and on four discrete samples from Hole U1582A. Demagnetization experiments were performed on both sedimentary and igneous units recovered from Site U1582. Results indicate that the sampled units at Site U1582 are reliable recorders of magnetic field directions. Magnetic polarity was constrained from all measured cores. Intervals of both positive and negative inclination were identified in Hole U1582A, indicative of reverse and normal geomagnetic polarity, respectively. All measured cores from Hole U1582B had negative inclination (normal polarity). Due to the condensed sediment interval collected in each hole, correlation to the geomagnetic polarity timescale (Gradstein et al., 2020; Ogg, 2020) was difficult, however preliminary chron assignments were made.

Geochemistry

The geochemistry program at Site U1582 was designed to characterize the composition of bulk sediment and interstitial water (IW) and report on the presence and abundance of volatile

hydrocarbons for routine safety monitoring. Six headspace samples were taken and analyzed for routine safety monitoring. Hydrocarbons in headspace samples were detected in Hole U1582A. Methane was above the detection limit in three samples, with concentrations of 0.68 and 0.51 ppmv in Samples U1582A-2R-4, 0–5 cm, at 6.41 m CSF-A and U1582A-3R-3, 0–5 cm, at 14.60 m CSF-A. Hydrocarbons with longer chain lengths up to n-hexane (C_6) were not detected in any of the headspace samples.

Samples for IW were collected from the upper 15 m CSF-A of Hole U1582A, where soft sediment was present. Alkalinity values range between 2.414 and 2.892 mM. The pH values range between 7.601 and 7.697. No further shipboard analyses were completed on IW samples from Site U1582 due to the small number of samples collected.

In total, five sediment samples were obtained for bulk carbon, nitrogen, and sulfur analyses at Site U1582. Total carbon and carbonate weight percentages (where carbonate is reported as calcium carbonate weight percentage) range from 0.2 to 3.41 wt% and 1.93 to 28.10 wt% at Site U1582, respectively. Carbonate is elevated (28.10 wt% as $CaCO_3$) in the uppermost sample (U1582A-1R-1, 82–83 cm, at 0.82 m CSF-A) that resides within Lithostratigraphic Unit Ia, which is a clayey nannofossil ooze that encompasses the upper 21.71 m CSF-A at this site, as compared to Lithostratigraphic Subunit Ib below 31 m CSF-A, which averages 5.16 wt% $CaCO_3$. Within Litholostraigraphic Subunit Ib, inorganic carbon averages 0.62 wt%. Total organic carbon is zero for all samples except Sample U1582A-1R-1, 82–83 cm, with a concentration of 0.05 wt%. Total nitrogen was measured but remained low, at or close to the detection limit, for the samples analyzed from Site U1582A. Concentrations remain below 0.05 wt%, with average concentrations at 0.04 wt%. Total sulfur concentrations range from below detection limit to 0.41 wt%.

Physical Properties

Standard measurements of physical properties were made on cores from Holes U1582A and U1582B using the Whole-Round Multisensor Logger (WRMSL), Section Half Multisensor Logger (SHMSL), and the Natural Gamma Radiation Logger (NGRL) track instruments. Discrete measurements were also made for moisture and density (MAD) analysis, thermal conductivity, and *P*-wave velocities on the *P*-wave caliper system (PWC). The physical property data from Site U1582 show a progression with depth that delineates the poorly consolidated clayey nannofossil ooze of Lithostratigraphic Subunit Ia (0–31.00 m CSF-A) from the underlying lithified limestone and manganese nodules of Lithostratigraphic Subunit Ib (31.00–40.92 m CSF-A in Hole U1582A), and from the deeper pillow basalts with interspersed pockets of limestone of Lithostratigraphic Unit II (36.83–53.73 m CSF-A in Hole U1582B). Lithostratigraphic Subunit Ia contains unlithified sediment with high porosity (65–82 vol%), low MAD bulk density (1.40–1.62 g/cm^3), low PWC *P*-wave velocities (~1600 m/s), and low thermal conductivity (0.9–1.2 W/[m·K]). In comparison, the underlying more lithified limestones of Lithostratigraphic Subunit Ib have much lower porosity (~25%), a higher average

PWC *P*-wave velocity (~3000 m/s), and a higher bulk density (~2.33 g/cm^3). The dark colored pillow basalts (L* of ~20 to 40) of Lithostratigraphic Unit II have higher natural gamma ray (NGR) values (~20 counts/s) and higher magnetic susceptibility (~500–1000 WRMSL instrument units) than the light-colored basalt.

References

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