IODP Expedition 400: NW Greenland Glaciated Margin

Site U1603 Summary

Background and Objectives

Site U1603 (proposed Site MB-23A) was cored on the lower slope below the Melville Bugt trough mouth fan at a water depth of 1801 m at 72°59.03′N, 62°58.8333′W. The site targeted a high-resolution sediment drift-channel levee sequence hypothesized to represent interactions between bottom contour currents and sediments supplied by northern Greenland Ice Sheet (NGrIS) fluctuations from the Early/Middle Pleistocene (up to 1 Ma) to present. The sediment sequence in Site U1603 intersects a series of continuous seismic reflections that are correlated to Seismic Units 9, 10, and 11 on the continental shelf, corresponding to the most recent stages in the developmental history of the trough mouth fan (Knutz et al. 2019). The main objectives of drilling at Site U1603 are (1) establish a chronology for the trough mouth fan development, (2) provide a sediment archive to test the hypothesis that the NGrIS underwent significant deglaciation at intervals within the frequency range of orbital eccentricity (~100–400 ky) (Schaefer et al. 2016), and (3) assess recent models for the change in orbital cycles through the mid-Pleistocene transition (MPT) (Clark & Pollard, 1998).

Coring was planned in three holes using the advanced piston corer/extended core barrel (APC/XCB) coring systems. The upper 250 m was to be triple cored and in the third hole it was planned to recover a single copy of material spanning 250–422 meters below seafloor (mbsf). Downhole logging, including the Versatile Seismic Imager (VSI), was also planned for the third hole.

Operations

IODP Expedition 400 began in Reykjavík, Iceland, at Skarfabakki Harbour at 0815 h on 12 August 2023. The Expedition 395 science party departed the vessel on 12 August and on 13 August the crew, staff, and science party of Expedition 400 boarded the vessel with the oncoming *JOIDES Resolution* Science Operator (JRSO) technical staff arriving at 0900 h and the science party at 1445 h. Immigration checks for those sailing were performed dockside in the afternoon and completed by 1600 h. The science party began expedition preparation and received orientations including life at sea and safety training, along with introductions to the laboratories during the rest of the port call. The two ice navigators were set up with internet access and the ice analysis and reporting routine was initiated. Freight was completed throughout the port call and included offgoing shipments of core and refrigerated and frozen samples as well as the loading of sepiolite (drilling mud), drilling equipment, and fresh and frozen foods. On 16 August fuel was bunkered and a boat drill was conducted.

The vessel was readied for departure and the pilot came aboard at 0745 h on 17 August. The tugs were secured shortly afterward and the last line was released at 0806 h, marking the official start of the transit. By 0822 h the tugboats were released, the pilot departed, and our sea passage to proposed Site MB-23A (Site U1603) began at 0824 h. The vessel remained underway until arriving at Site U1603 at 1355 h on 23 August. The thrusters were lowered and secured at 1412 h and the vessel was fully in dynamic positioning (DP) mode at 1420 h, ending the transit. The journey covered 1721 nmi at an average speed of 11.3 kt (including pilotage).

The first attempt to spud Hole U1603A was an APC barrel shot from 1802.0 meters below rig floor (mbrf), resulting in a water core. The pipe was lowered 5 m and a core barrel was shot from 1807 mbrf. Hole U1603A was spudded at 0425 h on 24 August with 4.65 m recovered. The seafloor was calculated at 1800.8 meters below sea level (mbsl) (1811.9 mbrf; mbrf is 11.1 m greater than mbsl). APC coring continued to Core U1603A-13H at 118.6 m core depth below seafloor, Method A (CSF-A). The advanced piston corer temperature (APCT-3) tool was run on Cores 4H, 7H, 10H, and 13H. The core liner shattered on Core 13H and had to be pumped out of the liner.

At 1515 h on 24 August the bridge notified the drill floor that an iceberg had entered the Red Zone (i.e., will be within 3 nmi of the vessel in less than twice the time it will take to trip up to 50 m CSF-A). The drill string was tripped up with the top drive from 109.1 m CSF-A to 43.21 m CSF-A at 1600 h. From 1600 h to 1715 h, the vessel tracked two icebergs. At 1715 h, with one of the icebergs entering the Termination Zone (within 1 nmi of the vessel) the order was given to pull the pipe clear of the seafloor. The drill string was again pulled up with the top drive, this time to 1778.3 mbrf, clearing the seafloor at 1742 h and ending Hole U1603A. The vessel was moved 500 m south in DP mode. The closest iceberg passed within ~0.6 nmi of the vessel. Once it was safe to do so, the vessel was moved back over location and offset 10 m northwest from Hole U1603A, coming into position at 2000 h on 24 August.

Hole U1603B was spudded at 2035 h on 24 August. Hole U1603B was washed down to 109.1 m CSF-A by 0100 h on 25 August. Coring began with Core U1603B-2H from 109.1 m CSF-A and continued to Core 5H at 147.1 m CSF-A. After an overpull and drillover of Core 5H, we switched to the half-length advanced piston corer (HLAPC) system. Coring with the HLAPC started with Core U1603B-6F and continued to Core 27F, shot from 243.9 m CSF-A at 0230 h on 26 August. The barrel pulled free from the formation with no overpull; however, the coring line could not pull the barrel up. The drill string was tripped back up to the vessel, with the bit clearing the rig floor at 1157 h, ending Hole U1603B. Once the bottom-hole assembly (BHA) was onboard the core barrel was recovered with 0.08 m of material, likely from the push down trying to free the barrel. The final depth for Hole U1603B was 244.0 m CSF-A.

The vessel was offset 10 m northwest and Hole U1603C was spudded at 0105 h on 27 August. The hole was drilled down over the next 7.75 h. Cores U1603C-2R to 9R advanced from 211.5 to 285.0 m CSF-A and recovered 22.78 m (33%). At 1945 h on 27 August ice moved within 3 nmi of the vessel and we raised the drill string to 22.3 m CSF-A and began waiting on ice

(WOI). At 0000 h on 28 August ice entered the 1 nmi exclusion zone. We raised the drill string, clearing the seafloor at 0009 h and ending Hole U1603C, and continued WOI. The vessel was moved 1200 m east-northeast and then 700 m east-southeast in DP mode to maintain a safe distance from the ice. By 0330 h the ice had cleared the site and the vessel was positioned 10 m northwest from Hole U1603C.

Hole U1603D was spudded at 0455 h on 28 August and, with a wash barrel, was drilled ahead to 102.0 m CSF-A. As ice once again neared the site, we decided to install a free-fall funnel (FFF) to allow us to reenter Hole U1603D. The FFF was deployed at 0950 h, and by 1030 h we resumed drilling ahead in Hole U1603D to 189.0 m CSF-A. At 1400 h ice moved within 3 nmi of the vessel and we raised the drill string to 22.3 m CSF-A by 1515 h and began WOI for the remainder of the day.

By 0015 h on 29 August the ice had cleared the site. The drill string was lowered to 169.6 m CSF-A, and we washed back to 189.0 m CSF-A before drilling ahead to 269.4 m CSF-A. Cores U1603D-2R to 8R advanced from 269.4 to 333.2 m CSF-A and recovered 14.62 m (24%). At 1400 h ice moved within 3 nmi of the vessel and we raised the drill string to 22.3 m CSF-A by 1545 h and began WOI. Once again ice entered the 1 nmi exclusion zone and we raised the drill string, clearing the seafloor at 1930 h. The vessel was moved 1000 m north in DP mode to maintain a safe distance from the ice. By 2157 h we began to move back toward the site and the vessel was in position over Hole U1603D by 2348 h on 29 August.

At 0100 h on 30 August we began preparing the subsea camera system to assist with reentering Hole U1603D. At 0320 h we successfully reentered the hole and recovered the subsea camera system. The drill string was lowered to 294.4 m CSF-A, and we washed back to 318.5 m CSF-A before encountering material that had fallen into the bottom of the hole. A center bit was dropped and we washed to 333.2 m CSF-A by 0800 h. Cores U1603D-9R to 18R advanced from 333.2 to 422.0 m CSF-A and recovered 28.69 m (32%). Sepiolite (drilling mud) was swept into the hole and the bit was released at 2315 h to prepare for logging Hole U1603D. We then tripped the drill string up with the bit positioned at 50.8 m CSF-A in preparation for logging.

The modified triple combination tool string, termed the quad combo, was rigged up and, following a repair to the logging winch, was deployed to the base of Hole U1603D (419.5 m CSF-A). The quad combo measures natural gamma ray (NGR), acoustic velocity, resistivity, magnetic susceptibility (MS), and density. Following a complete pass of the hole the quad combo was pulled to the rig floor and broken down. The VSI was rigged up and the protected species watch began at 1600 h on 31 August. The VSI was deployed but almost immediately experienced a communication issue. The tool was brought back on board and repaired. At 1800 h the VSI was deployed to 413.1 m CSF-A and stations were measured uphole until 2120 h when fog impacted visibility and the ability to monitor for protected species. After the VSI tool was brought back on board and broken down, the Formation MicroScanner (FMS)-sonic tool string was assembled and deployed. The FMS-sonic tool string was run and the tools were back on deck by 0345 h on 1 September. With logging completed we tripped the pipe out of Hole U1603D, clearing the rig floor at 0900 h and ending Hole U1603D.

An APC/XCB BHA was made up and we began tripping the drill pipe back to the seafloor at 1200 h. The vessel was offset 10 m northwest in DP mode and the pipe was pumped with a cleanout tool while the tracer pumps were running. Hole U1603E was spudded at 1745 h on 1 September and Core U1603E-1H recovered 6.94 m. Core 2H advanced to 16.4 m and recovered 9.75 m (103%). Cores 3H through 6H each advanced 9.5 m but recovered almost no material (less than 20 cm each). The deplugger was run in the pipe. Core U1603E-7F advanced from 54.4 to 59.1 m CSF-A and recovered 0.31 m (7%). Following Core 7F we decided to abandon Hole U1603E due to lack of recovery and the drill string was tripped out, clearing the seafloor at 0140 h on 2 September.

The vessel was offset 10 m southeast of Hole U1603A with the aim of improving recovery and allowing for better correlation with other holes. Hole U1603F was spudded at 0235 h on 2 September. Cores U1603F-1H to 5H advanced from 0 to 44.0 m CSF-A and recovered 45.49 m (103%). Core U1603F-6F (44.0–48.80 m CSF-A; 4.73 m recovered) was cored with the HLAPC system to help adjust core spacing to cover gaps in Hole U1603A. Cores U1603F-7H to 15H advanced from 48.8 to 134.3 m CSF-A and recovered 66.71 m (78%). The APCT-3 tool was run on Cores 4H and 10H. We then began pulling the drill string out of the hole, clearing the seafloor at 1935 h. The drill string was tripped up, with the bit at the surface at 0030 h. The drill floor was secured for transit and the thrusters were raised and secured for transit at 0145 h, ending Hole U1603F and Site U1603.

Principal Results

Lithostratigraphy

Site U1603 consists of six overlapping holes (Holes U1603A–U1603F) cored to a total depth of 422 m CSF-A. Based on 243.6 m of recovered sediment, the 422 m thick section is divided into four lithostratigraphic units (LSU). Named lithofacies are sedimentary, are present in all four units with variable predominance, and include: mud, calcareous mud, interlaminated to interbedded mud and sand, sandy mud with common clasts, and diamicton.

Sediments recovered are consistent with the site location at the base of the continental slope proximal to a glaciated margin and deposited during the Early to Late Pleistocene. The deposits from 0 to ~243 m CSF-A (LSU I and II) are consistent with downslope and along-slope sedimentation on a channel levee system with high sedimentation rates (~25 cm/ky). The upper ~42 m (LSU I) consists of mud with irregular sand laminae and dispersed clasts. A thick sequence of interlaminated to interbedded mud and sand is predominant between ~42–243 m CSF-A (LSU II) and is further divided into two subunits distinguished by laminae/bed thickness, proportion of mud vs. sand, and clast occurrence. LSU-IIA (42–145 m CSF-A) consists of finer laminae, thinner sand beds, and a lower proportion of sand, while LSU-IIB (~145–243 m CSF-A) has thicker laminae and beds, a higher proportion of sand, and a relatively higher clast abundance. From 243–374 m CSF-A, weakly stratified mud lithologies were dominant, sand lithofacies were rare, and clast occurrence increases significantly (LSU III). In the lower ~46 m of the Hole U1603D (LSU IV; 374–422 m CSF-A), weakly stratified muds similar in character to LSU III are present, but this unit also contains an interval of calcareous mud and various types of soft-sediment deformation that are absent in overlying LSU III.

Micropaleontology

Core catcher samples from Holes U1603A–U1603D, together with additional samples from split sections, were examined for foraminifera, diatoms, dinoflagellate cysts and other palynomorphs. The additional samples examined for all microfossil groups were taken within cores where variations in lithology were observed. Sampling targets included intervals of massive muds, bioturbation, and muds with dispersed clasts that coincided with low NGR values, as well as carbonate rich intervals. Mudline samples from Holes U1603A and U1603F were also examined. Cores from Holes U1603E and U1603F, which include a second copy of the upper ~130 m of the cored section, were not examined. Observations of foraminifera from palynomorph and diatom slide preparations were integrated in the overall foraminifera evaluations. Calcareous nannofossils were observed in smear slides by the Sedimentology team in one core catcher sample and two diatom slides. A cursory examination of these was attempted but requires further study by a nannofossil specialist.

The muds and interlaminated sands and muds typical of Site U1603 are generally barren of in situ microfossils. Where foraminifera appear, they remain as trace to rare occurrences, except for two distinct intervals in Cores U1603A-8H and U1603D-13R where they are common to abundant. Diatoms were found in about 6% of all samples examined with trace to rare amounts of specimens and species. Palynomorph preparations revealed persistent contributions of phytoclasts and reworked terrestrial pollen and spores. The observed microfossil specimens and assemblages for all groups are typical of cold-water polar environments and in situ dinoflagellate species are typical of coastal or neritic environments. Observed specimens and assemblages are broadly consistent with a Pleistocene age. The species have long stratigraphic ranges and provide limited age control. More detailed analysis of calcareous nannofossils may provide future constraints and a test of the paleomagnetic reversal interpretations and provisional age model.

One mudline sample was collected for sedimentary ancient DNA (sedaDNA) in Hole U1603A. A total of 60 additional samples for sedaDNA analysis were collected: 9 from Hole U1603E and 51 from Hole U1603F. Catwalk samples were generally taken at the bottom of Sections 1, 3, and 5 (if the section was available and the section bottom undisturbed). Additional samples were collected in the working half of split sections targeting nonstratified mud layers characterized by low values of NGR and MS. All samples were immediately stored at −86°C. To assess the potential for contamination during coring and the sectioning of cores on the catwalk, a perfluorocarbon tracer (PFT) was added to the drilling fluid, and the majority of samples have a contamination level close to or below detection limit.

Paleomagnetism

Pass-through paleomagnetic measurements from Site U1603 were performed to investigate the natural remanent magnetization (NRM) in a total of 313 archive section halves. Measurements were not made on 16 archive section halves that had highly disturbed sediments, and no pass-through measurements were made on core catcher samples. All measurements on section halves were made at 2 cm intervals; we measured the initial magnetization and the magnetization following stepwise peak alternating field (AF) demagnetizations at 5, 10, 15, and 20 mT. Inclinations from filtered data imply that periods of both normal and reversed polarity were recovered at Site U1603. Most inclination magnitudes fall under expected values for the latitude of Site U1603 during normal (positive inclinations) and reverse (negative inclinations) polarities.

A total of 188 discrete cube samples were taken from the working section halves from Holes U1603A, U1603B, U1603C, and U1603D. Generally, we collected one sample per section, avoiding visually disturbed intervals. We measured 54 samples on the AGICO JR-6A spinner magnetometer, and 146 samples on the superconducting rock magnetometer (SRM). Some samples were measured on both instruments to ensure cross-calibration. Anhysteretic remanent magnetization (ARM) was also measured on a subset of 45 discrete samples from Holes U1603A and U1603B. These measurements were compared with bulk MS. The relationship between ARM and MS is quasilinear, which suggests that the concentration of magnetic minerals is the primary control on both measurements, and supports the use of normalized remanence for estimating relative paleointensity.

Physical Properties

Physical property data were acquired on all cores of Holes U1603A, U1603B, U1603C, and U1603D using the Whole-Round Multisensor Logger (WRMSL) for wet-bulk density from gamma ray attenuation (GRA), MS, and *P*-wave velocity (PWL). We also measured NGR in all sections longer than 50 cm. Thermal conductivity was measured in one whole-round section per core, when possible. However, it was measured on one working half section per core if the sediment was too hard or the whole-round measurement readings were unreliable. For Holes U1603E and U1603F, only NGR and low-resolution MS were logged. These cores were sampled for pore water, thus equalization to room temperature was not possible, and therefore PWL measurements were not made. They were also sampled for sedaDNA, thus the GRA source was kept inactive during the WRMSL logging to avoid possible effects on the DNA.

Once the whole-rounds were split into two halves, we acquired X-ray imaging on the archive halves of every core. The Section Half Multisensor Logger (SHMSL) was used to measure point MS and color reflectance using the L*, a*, b* color system as well as red-green-blue color space (RGB) of the sediments with Digital Color Imaging. In addition, we determined *P*-wave velocities at discrete points on the working section halves for almost all cores from Site U1603. In general, we measured discrete *P*-wave velocity in 3 sections per APC cores and 2 sections per core for HLAPC and RCB cores. However, caliper *P*-wave velocity (PWC) was measured in all sections of Holes U1603E and U1603F to compensate for the lack of PWL measurements. The measurement interval within each section was changed to accommodate lithological variations. Two samples per core for moisture and density (MAD) were taken and processed from Holes U1603A, U1603B, U1603C, and U1603D to obtain discrete wet-bulk density, dry-bulk density, grain density, and porosity.

Prominent variations in physical property values occur at similar depths in NGR, density, and MS and are associated with major lithological changes in the cores. More uniform lithologies are reflected by more monotonous physical property signals. Accordingly, the physical properties obtained from Site U1603 provide valid and reproducible information on sediment composition and its variability for all cores.

Geochemistry

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1603. Headspace hydrocarbon gas measurements show low concentrations in the upper 150 m and higher concentrations of methane, with low yet consistent presence of ethane, in sediments below 150 m CSF-A depth. A key observation from IW analysis is a decrease in lithium and potassium with depth, possibly suggesting clay formation. A monotonic decrease in sulfate with depth to a minimum around 150 m CSF-A may provide evidence for a sulfate-methane transition zone. IW iron, manganese, and phosphate show elevated concentrations near the seafloor and sharp decreases to low concentrations with depth. Increases in IW calcium and alkalinity in the shallower depths may indicate dissolution of calcium carbonate minerals. Elemental analysis of solid material revealed overall low concentrations of carbon and nitrogen across most intervals, albeit individual layers were rich in calcium carbonate ($CaCO_3$) with contents of up to 60 wt%.

Stratigraphic Correlation

The physical property records of Site U1603 were compared, and correlated where possible, to establish a common depth scale. To minimize coring gap alignment, sequences from Holes U1603A, U1603B, U1603C, and U1603D were examined using whole-round MS and NGR data measured at 2 cm resolution with the WRMSL. In addition, NGR and MS data were measured at 5 cm resolution on sections from Holes U1603E and U1603F and examined in near real time to ensure adequate coring depths to fill the gaps in Hole U1603A. Since triple APC offset coring was abandoned in favor of reaching the total depth at Site U1603, the splice could only provide partial stratigraphic coverage. The difficulty was further magnified by low recovery rates below 105 m CSF-A. Thus, Holes U1603A, U1603B, U1603C, and U1603D are correlated to each other, but they were mostly aligned by the seafloor. Holes U1603E and U1603F were correlated to Hole U1603A, completing a splice of the upper 78 m composite core depth below seafloor

(CCSF-A). While it is still not possible to build a complete CCSF-A depth scale for Site U1603, the high recovery and core alignment between Holes U1603A, U1603E, and U1603F allows for the construction of a pseudosplice down to 98.5 m CCSF-A.

Age Model

The age model for Site U1603 is largely based on magnetostratigraphic interpretations from Holes U1603A, U1603B, U1603C, and U1603D. From the seafloor to ~194 m CSF-A, sediment is characterized by normal polarity, and is interpreted as the Brunhes Chron. At ~194 m CSF-A there is a transition to reversed polarity, likely representing the Brunhes/Matuyama boundary. We also observe a shallowing in inclinations in the lower part of Core U1603A-1H, likely representing the Laschamp excursion. Between the Laschamp excursion and the bottom of the Brunhes Chron, we estimate an average sediment accumulation rate of ~25 cm/ky. The normal polarity zone below ~327 m CSF-A in Hole U1603D is not well constrained due to gaps in recovery and drilling disturbance, however it may be interpreted as the Olduvai or Jaramillo Subchron.

Downhole Measurements

Downhole logging was carried out in Hole U1603D. A modified triple combo tool string, the quad combo, was deployed recording MS, NGR, electrical laterolog resistivity, acoustic velocity, and density tools. Upon completion of the downhole logging with the quad combo, vertical seismic profiling was attempted with the VSI. The VSI aimed to obtain an accurate time-depth relationship to tie the logging and coring results with the seismic data. Fifteen stations were planned for the geophones to record seismic images on the hole; however, a decrease in visibility due to fog resulted in terminating the VSI experiment after ten stations were attempted. The coupling between the geophone and the hole failed at the bottom station. The FMS was run together with the Dipole Sonic Imager (DSI) to obtain formation resistivity and velocity data. The DSI was used for calibration/ comparison with the velocities obtained on the quad combo. Logging measurements were crucial for covering recovery gaps during RCB coring. The downhole NGR and density logs have features in common with the equivalent laboratory data from Site U1603 with small offsets between log and core data due to the assignment of core depths when core recovery was not 100% and other effects. Additionally, the APCT-3 was deployed four times in Hole U1603A and two times in Hole U1603F.

References

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