IODP Expedition 400: NW Greenland Glaciated Margin

Site U1608 Summary

Site U1608 (proposed Site MB-06D) was cored at position 74°7.6818′N, 60°58.3172′W, water depth 607 meters below sea level (mbsl) on the middle section of the northwest Greenland shelf, west of the Melville Bay ridge and graben structures formed during Cretaceous rifting. The main coring targets are mounded contourite drift deposits of expected Pliocene age associated with Megaunit B (Knutz et al., 2015; 2019) and overlying sediments of Megaunit A, recording the transition into glacigenic deposits of earliest Trough Mouth Fan (TMF) progradation. The expanded interval of Megaunit B, captured at Site U1608, reflects deposition below a major incised escarpment that is at least 500 m tall and extends into disturbed sediment packages interpreted as mass-transport deposits. The base of the contourite drift accumulation is defined by Horizon c1 of probable Late Miocene age (Knutz et al., 2015). Site U1608 ends ~100 m above Horizon c1, which at this location is characterized by an erosional unconformity. In the overlying unit, Megaunit A, ten horizons are mapped using high-resolution seismic data and, including the seabed, these define 11 seismic units that each record progradation of the TMF system under the influence of grounded glacier ice (Knutz et al., 2019). TMF Seismic Unit 1 targeted at Site U1608 records the first advance of the northwest Greenland Ice Sheet onto the continental shelf, hypothesized to correspond to the Pleistocene/Pliocene boundary (Knutz et al., 2019). Combined, the cores from the middle shelf Sites U1608 and U1606 access archives of ocean and climate conditions presumably much warmer than today, which were buried by glacial deposits representing global cooling and expansion of northern hemisphere glaciers. These sites target the dynamic drift morphology to capture different parts of the Megaunit B strata in order to capture high-resolution records of the Pliocene ocean-climate system at high Arctic latitudes.

Operations

Hole U1608A

The vessel transited 23 nmi from Site U1607 to Site U1608. The thrusters were lowered and secured and the ship was fully in dynamic positioning (DP) mode at 0051 h on 26 September 2023. The rig crew made up a rotary core barrel (RCB) bottom-hole assembly (BHA) and the drill string was tripped to near the seafloor. Hole U1608A was spudded at 0435 h, tagging the seafloor at 606.9 mbsl. Cores U1608A-1R to 60R advanced from 0 to 561.0 m core depth below seafloor, method A (CSF-A) and recovered 267.35 m (47%). Sepiolite (drilling mud) was swept in the hole and the bit was released in the hole at 1555 h on 29 September to prepare for logging Hole U1608A. The hole was displaced with heavy mud (barite) and the pipe was tripped up, with the end of the pipe ultimately placed at 103.9 m CSF-A due to concerns about the condition and stability of the hole. The modified triple combo tool string was deployed to the base of Hole U1608A and tagged the bottom at 558.6 m CSF-A. Following a complete pass of the hole, the modified triple combo was pulled to the rig floor and broken down. The Formation MicroScanner (FMS; without sonic) tool string was then assembled and deployed at 0235 h on 30 September. After two successful logs the FMS tool was brought back on board and broken down. The Versatile Seismic Imager (VSI) was rigged up and deployed and the protected species watch began at 0730 h. Stations were measured uphole every 20 m, and the VSI was brought back on board by 1300 h. With logging completed we tripped the pipe out of Hole U1608A, clearing the rig floor at 1555 h. The drill floor was secured for transit and the thrusters were raised and secured for transit at 1630 h on 30 September, ending Hole U1608A and Site U1608.

Principal Results

Lithostratigraphy

The stratigraphy of Site U1608 is divided into four lithostratigraphic units (LSUs). The lithofacies include (1) bioturbated mud with dispersed sand, (2) calcareous mud, (3) sandy mud/muddy sand with or without dispersed clasts, and (4) clast-poor sandy diamicton. Lithofacies 1 and 3 are present in all LSUs, while lithofacies 2 and 4 occur only in LSUs II and IV.

Lithostratigraphic Unit I (LSU I) contains the upper 53.6 m CSF-A of the site and consists of washed gravel (a product of drilling disturbance) with diverse igneous, plutonic, and metamorphic clasts. LSU II, extending from 53.6 to 293.5 m CSF-A, contains bioturbated sandy mud/muddy sand with or without dispersed clasts, calcareous mud, and occurrences of clast-poor sandy diamicton. LSU III extends from 293.5 to 429.3 m CSF-A and contains meter to decimeter-scale intervals of bioturbated mud with sand and sandy mud to muddy sand with or without dispersed clasts. Overall, LSU III is distinguished from LSU II by a decrease in the abundance of sand, a significant reduction in the occurrence of the calcareous mud lithofacies, and an increase in the abundance of bioturbated mud with dispersed sand. Underlying LSU III is the 135.8 m thick LSU IV (429.3 to 561.46 m CSF-A) which consists of alternating meter to decimeter-scale intervals of bioturbated mud with dispersed sand and dm-scale intervals of sandy mud/muddy sand. This unit marks a downhole increase in the sand proportion as well as an increase in the occurrence of yellowish calcareous mud. In this unit, the calcareous mud commonly occurs as cm-scale bioturbated patches. Overall, the sedimentary succession recovered at Site U1608 is consistent with deposition in a marine shelf setting with sedimentary contributions from glacigenic and a minor hemipelagic biosiliceous sources.

Micropaleontology

Core catcher samples from the 60 cores of Hole U1608A were examined for foraminifera, diatoms, dinoflagellate cysts, and other palynomorphs. Samples were also taken for ancient sedimentary DNA (sedaDNA) analysis. The mudline was not recovered at Site U1608, and Cores U1608A-1R to 3R contain washed gravel without fine grained sediment suitable for microfossil analysis. All microfossil groups are present in Site U1608 cores and occur throughout much of the recovered sequence. Benthic foraminifera occur in 88% of samples while planktonic foraminifera are found in only 3 samples, represented in each case by a single specimen. Diatoms are observed in 70% of samples, and dinocysts are observed in 84% of the samples.

Foraminifera are absent in the upper ~85 m CSF-A. Below this depth they become rare to intermittently common to the base of the hole and consist of typical Arctic Neogene shelf-slope benthic species (Feyling-Hansen, 1976). The long ranging benthic species offer little age control, although the presence of *Cassidulina teretis* implies that the foraminifera-bearing sediments between ~85–524 m CSF-A are older than 700 ka (Early Pleistocene) but no older than Middle Miocene (Seidenkrantz, 1995). Diatoms are barren in the upper ~100 m CSF-A, below which they are present in most core catcher samples. The diatom assemblages are diverse and well preserved in some samples, providing both age and paleoenvironmental constraints. Palynomorphs occur in every sample in varying abundance, including the upper 100 m CSF-A where other microfossils are rare or absent. The dinoflagellate assemblages, which consist mostly of species associated with neritic, food-rich environments, are also diverse in some intervals, providing additional chronostratigraphic and paleoenvironmental insights. Pulses of terrestrially derived organic material are a distinct feature of Site U1608. This is evidenced by occurrences of micro/macrofossil wood and plant fragments in sieved foraminifera samples, as well as by smaller plant/wood fragments, pollen, spores, and fungal material in palynomorph preparations. These pulses of terrestrial material in the sieved (>63 µm) foraminifera samples occur intermittently, and at times intensely, from 85–488 m CSF-A.

Paleomagnetism

Pass-through paleomagnetic measurements from Site U1608 were performed using the superconducting rock magnetometer (SRM) to investigate the magnetization of a total of 201 archive section halves. Measurements were not made on core catcher sections. All measurements on section halves were made at 2 cm intervals, up to peak alternating field (AF) demagnetization of 20 mT. The inclinations from the filtered 20 mT step archive section halves are generally bimodal at the estimates of inclinations for normal and reverse polarities at this latitude calculated from the geocentric axial dipole (GAD), and the bimodal inclination distribution suggests that intervals of both normal and reverse polarity were recovered at Site U1608. A total of 192 discrete cube samples were collected from the working section halves; generally, we collected one sample per core section, avoiding visually disturbed intervals. Discrete specimens from Cores U1608A-9R to 40R were measured on the SRM up to a peak AF demagnetization of 50 mT. Cores U1608A-41R to 60R were only demagnetized to a peak field of 40 mT. We utilized a filtering method that assessed the magnetic stability of archive section half and discrete sample data and, using the filtered data, we defined 11 polarity zones at Site U1608.

Physical Properties

Standard measurements of physical properties were made on cores from Hole U1608A using the Whole-Round Multisensor Logger (WRMSL), Section Half Multisensor Logger (SHMSL), and 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.

Prominent variations in physical property values occur at similar depths in natural gamma ray (NGR) and density and are associated with major lithological changes in the cores. The correlation between these physical properties distinguishes five physical properties units (PP Units I–V) of Site U1608. PP Unit I (0–130 m CSF-A) includes mostly irregular values of NGR, magnetic susceptibility (MS), and density, which is largely due to poor recovery and partially due to the occurrence of washed gravel in the uppermost 50 m CSF-A of Site U1608. Thermal conductivity reaches a maximum value for Site U1608 in PP Unit I. Below, in PP Unit II (130–215 m CSF-A) high amplitude variability of NGR and MS corresponds to lithologies of mud, sandy mud, and muddy sand. Throughout PP Unit II density decreases slightly downhole. PP Unit III (215–315 m CSF-A) is characterized by low amplitude variability in NGR coupled with high amplitude variability in MS in the upper half of the unit, followed by an increase in NGR and a decrease in MS intensity and variability in the lower half of PP Unit III. NGR and MS trends in PP Unit III reflect the transition from sandy mud to muddy sand as the dominant lithology throughout the unit. Muddy sand is also the primary lithology of PP Unit IV (315–450 m CSF-A), although it also contains intervals of calcareous mud in the lower half of the unit where density becomes more variable. NGR and MS in PP Unit IV are both highly variable. PP Unit V (450–561 m CSF-A) is defined by low NGR and MS values, which further decrease downhole throughout the unit.

Geochemistry

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1608. Headspace hydrocarbon gas concentrations are low in the upper 50 m CSF-A. Below this depth, high concentrations of methane (average of 33,800 ppm) are found to the bottom of Hole U1608A. IW samples were not taken in the uppermost 9 cores of the hole due to low recovery. The main findings from IW analysis include downhole increases in alkalinity, potassium, magnesium, and phosphate to around 250 m CSF-A, and steadily decreasing values for these components below 300 m CSF-A. Elemental analysis of solid material revealed average concentrations of 0.5% organic carbon and 0.06% nitrogen throughout Hole U1608A.

Stratigraphic Correlation

To analyze the extent of the core gaps and further improve the depth assessment of the recovered material, we correlate the physical properties measured on the cores to the downhole logs obtained from the borehole. Whole-round MS and NGR measured on the cores were imported in Correlator v.4 as well as downhole MS and NGR data, which were imported into the software as a single core table. Ties between downhole data and core data were assessed based on visual and statistical matches of the properties. This procedure has some significant uncertainties due to the presence of large-scale features in the downhole logging data that do not resemble the record measured on cores in the laboratory. However, the overall cyclicity of the records is well matched between the downhole logs and the cores, and the relative depth offset of each core provides information that can be used confidently to improve the depth constraints of the cores. The resulting depth scale is referred to as core composite depth below seafloor (CCSF-A), even though it is not a scale resulting from the alignment of two or more holes. The difference between depth CSF-A and depth CCSF-A varies downhole from a few centimeters up to 10 m. The depth constraints provided by the downhole logging data allow an improved interpretation of the formation lithology, age, and physical properties.

Age Model

The initial age constraints are based on magnetostratigraphic interpretations on inclination with two additional biostratigraphic constraints. The diatom *Proboscia barboi* was identified in the interval between 180–507 m CSF-A and has an age range of 3.31–9.49 Ma (Koç and Scherer, 1996). The second potential constraint is from the occurrence of the diatom *Thalasssiosira nidulus* throughout material recovered from Site U1608, whose first occurrence is at 4.57 Ma (Koç and Scherer, 1996) on the Iceland Basin Plateau. With these considerations, we have two possible age models. There are also possible hiatuses identified in the seismic data at 96 and 535 m CSF-A, the former of which eliminates the highest normal polarity zone as a possible constraint. Model 1 is inconsistent with the occurrence of *P. barboi* above 238 m CSF-A, and in this model the transition from normal (N2) to reverse (R1) is correlated to C2An.1n. The average sediment accumulation rate for this age model is 18.5 cm/ky~~r~~. In Model 2, the transition from normal (N2) to reverse (R1) is correlated to C3n.1n and the N6-R5 reversal is correlated to C3An.1n. The average sediment accumulation rate for this age model is 15.1 cm/ky~~r~~.

Downhole Measurements

Downhole logging was carried out in Hole U1608A upon completion of the coring operations. The modified triple combo tool string deployed recording MS, natural gamma ray, electrical laterolog resistivity, acoustic velocity, and density tools. Two of the four runs (initial down and final up) covered the full length of the hole to 2 m above the bottom (561 m CSF-A). The caliper showed a stable hole and the instruments yielded reliable measurements; however, large washouts were observed down to 1020 meters below rig floor (mbrf), while the lower 157 m of the hole were homogeneous.

Three runs of the FMS tool (a down pass plus two up pass) were completed. Vertical seismic profiling was implemented with the VSI after the FMS run. The VSI aimed to obtain an accurate time-depth relationship to tie the logging and coring results with the seismic data and the geophones recorded the seismic signal at 24 stations located at an average spacing of 20 m. Successful measurements were made at 20 of the 24 planned stations; however, stations between 970–1030 mbrf need further processing. A protected species watch was in place before and during the use of the seismic source. Logging measurements were crucial for covering recovery gaps during RCB coring. Core logging and downhole logging results differ in absolute values, but the relative trends of the logs are comparable. Hence, logging data could be used for covering the formation recovery gaps with confidence.

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