IODP Expedition 400: NW Greenland Glaciated Margin

Site U1607 Summary

Background and Objectives

Site U1607 (proposed Site MB-07B), the easternmost site in the Expedition 400 site transect, was cored at 74°29.5499′N, 60°34.9900′W, water depth 739 meters below sea level (mbsl) on the middle shelf landward of the Melville Bay Ridge. Extensive seismic and limited borehole data indicate that this site captures Megaunits C and D1–D2, interpreted as a late-middle Miocene sediment drift that overlies a succession of mainly hemipelagic strata, possibly of early Miocene to Oligocene age (Knutz et al., 2022). Accordingly, Site U1607 may capture the time period from 6–30 Ma.

The sediment sequence comprising seismic Megaunits D1 and D2 represents gradual infilling of the remnant rift basin topography, including the Melville Bay Graben and adjacent ridge complex. The Melville Bay Graben was formed by continental rifting that started in the Early Cretaceous and ended during the early Paleocene as active seafloor spreading commenced in Baffin Bay (Gregersen et al., 2022). The overlying seismic Megaunit C is interpreted as a shelf-based sediment drift receiving fine-clastic input from nearby prodeltaic environments (Knutz et al., 2015). The boundary between Megaunits D2 and C is described as the mid-Miocene Unconformity (d1). It occurs within a conformable sequence in the basin but is shown as an erosional feature on the adjacent structural highs. The goal at this site is to reconstruct past ocean environments in northeastern Baffin Bay and terrestrial climates of Greenland, including testing the hypothesis that decreasing atmospheric CO_2 from the middle Oligocene to early Miocene is linked to the onset of ephemeral glaciation in northwest Greenland (Scientific Objective 2). Additionally, the site may provide data that can be used to investigate the influence of tectonic adjustments on the sediment record (Scientific Objective 3). The expected lithologies are claystone with silty to sandy intervals and siliceous ooze, consistent with predicted hemipelagic marine environments.

Operations

Hole U1607A

The vessel transited 17 nmi from Site U1606 to Site U1607. The thrusters were lowered and secured and the ship was fully in dynamic positioning (DP) mode at 1707 h on 15 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 U1607A was spudded at 2225 h, tagging the seafloor at 738.6 meters below sea level (mbsl).

Cores U1607A-1R to 60R advanced from 0 to 566.3 m core depth below seafloor, method A (CSF-A) and recovered 470.47 m (83%). On 20 September we began a bit change (70 h on bit). The pipe was raised to 53.4 m CSF-A and a free-fall funnel (FFF) was deployed at 1542 h. The subsea camera system was then deployed at 1652 h to observe that the FFF had landed in position and to ensure a clean exit from Hole U1607A. The bit cleared the seafloor at 1753 h and the subsea camera system was back on board by 1834 h. The drill string was then tripped up, with the bit at the surface at 2037 h. An RCB BHA was made up with a new C-4 bit and the drill string was tripped back to the seafloor. The subsea camera system was deployed at 2245 h and Hole U1607A was reentered at 0042 h on 21 September. The subsea camera was back on board at 0130 h. The drill string was lowered to 516.7 m CSF-A and we washed back to 566.3 m CSF-A. Cores U1607A-61R to 103R advanced from 566.3 to 978.0 m CSF-A and recovered 282.38 m (68%). A total of 103 cores were taken in Hole U1607A over a 978.0 m interval with 77% recovery.

Sepiolite (drilling mud) was swept into the hole and the bit was released at 1940 h on 24 September to prepare for wireline logging. The hole was displaced with heavy mud (barite) and the end of pipe was raised to 59.6 m CSF-A. The modified triple combo tool string was deployed to the base of Hole U1607A and a hard contact was encountered at 938 m CSF-A (40 m from the bottom of the hole). The drill pipe was raised to 42.1 m CSF-A for the main pass. Following a complete pass of the hole the modified triple combo was pulled up to the rig floor and broken down. The Versatile Seismic Imager (VSI) was rigged up and the protected species watch began at 0930 h on 25 September. The VSI was deployed to 930 m CSF-A and stations were measured every 30 m uphole until 1715 h, at which time the protected species watch also concluded. The VSI was brought back on board, and with logging completed we tripped the pipe out of Hole U1607A, clearing the rig floor at 2111 h. The drill floor was secured for transit and the thrusters were raised and secured for transit at 2124 h, ending Hole U1607A and Site U1607.

Principal Results

Lithostratigraphy

The stratigraphy of Site U1607 is divided into five lithostratigraphic units (LSUs) with subunits. Some of the named sedimentary lithofacies are present in all units with variable prominence, whereas others are characteristic of a particular unit. The lithofacies include (1) mud, sandy mud, and muddy sand with dispersed clasts, (2) calcareous mud, (3) bioturbated sandy mud and muddy sand, and (4) glauconite-rich sandy mud, muddy sand, and sandy granule conglomerate.

Lithostratigraphic Unit I (LSU I) contains the upper 3.58 m CSF-A of the site and consists of unlithified, soupy mud that likely represents Holocene deposition. LSU II, extending from 3.58 to 434.72 m CFS-A, contains bioturbated mud, sandy mud, muddy sand, calcareous mud, and dispersed clasts. This unit is subdivided into four subunits, LSUs IIA–IID, broadly following a downcore coarsening of sediment (mud to sand) and a decrease in dispersed clasts. LSU IIA is

53.49 m thick and contains meter-scale beds of bioturbated mud, sandy mud, and muddy sand with dispersed clasts and a few beds of cemented calcareous mud. Underlying LSU IIA, is 136.68 m thick LSU IIB which is lithologically similar to LSU IIA, distinguished by a color change from greenish gray to grayish brown, the first appearance downhole of iron sulfide filled burrows and common beds of cemented calcareous mud. Alternating mud and sandy mud to muddy sand lithologies on decimeter-scale is associated with LSU IIC, which is 157.55 m thick, and represents an increase in the abundance of sand. Calcareous mud remains common, but a significant reduction in the occurrence of dark fine-grained iron-sulfide filled burrows and a decrease in dispersed clasts occurs within LSU IIC. LSU IID (83.42 m thick), is distinguished from overlying LSU IIC by an increasing dominance of sand lithologies, a decrease in calcareous mud and carbonate cemented intervals, and rare occurrence of dispersed clasts. LSU III, which extends from 434.72 to 530.47 m CSF-A, consists of bioturbated sand, muddy sand, and sandy mud. A distinguishing characteristic of LSU III is that it consists of glauconite-rich bioturbated sand, muddy sand, and sandy mud. LSU IV, which is 315.08 m thick, shows a significant decrease in detrital glauconite and is subdivided into two subunits. LSU IVA is 171.63 m thick and has weakly stratified muddy sand and sandy mud as the dominant lithology. Although yellowish brown beds of calcareous mud occur in overlying units, they become more prominent in LSU IVA, with beds ranging from 3 to 77 cm in thickness. LSU IVB is 143.45 m thick and has a similar lithology to overlying LSU IVA. Marked differences include an increase in the dominance of sand over mud, the appearance of common pseudomorphs after ikaite and spherical calcareous concretions, and a decrease in calcareous mud. LSU V, which is 132.45 m thick, continues to the bottom of Hole U1607A. This unit is distinguished by the abrupt reappearance of abundant glauconite as sand to granule grade intraclasts in sharp-based, graded, and stratified sandy lithologies, which is interbedded with and ultimately transitions downhole to brown and gray, sparsely bioturbated mud. Overall, the sedimentary succession recovered at Site U1607 is consistent with marine deposition within a subbasin situated inland of the Melville Bay Ridge.

Micropaleontology

Core catcher samples and additional split-core samples from the 103 cores of Hole U1607A were examined for foraminifera, diatoms, dinoflagellate cysts, and other palynomorphs. The split core samples targeted thin (typically centimeterscale) calcareous mud horizons and/or intervals close to mollusk shells, where carbonate/foraminifera preservation may have been enhanced, and intervals adjacent to where diatoms had been found in core catcher samples. Mudline samples were also examined for each group and collected for sedimentary ancient DNA (sedaDNA).

Microfossils generally occur only sporadically and discontinuously in the muddy sands, sandy muds, and muds typical of Site U1607, apart from palynomorphs, which have more continuous occurrences. A combination of paleoenvironmental restrictions (i.e., shelf/neritic environments unfavorable to pelagic species) and diagenetic influences on porewater chemistry and preservation potential is likely responsible for the paucity of biomineralized skeletal remains in many intervals. Biostratigraphic results are therefore limited, but provide some degrees of age control in different parts of the hole.

Foraminifera are mostly limited to benthic species, with agglutinated species being most common. Diatoms are observed in 12% of the samples examined. Four samples from the weakly stratified very fine sands and muds of LSUs IV and V (634–918 m CSF-A) contain scarce planktonic foraminifera species. Dinoflagellate cysts are present in the uppermost three core catcher samples and two additional samples that were taken from Core U1607A-2R. No dinocysts were observed in core catcher samples from Core U1607A-19R to 74R, which is likely a result of dilution by terrigenous sediment input and a low concentration of dinocysts. Dinocyst abundances increase downhole from the core catcher sample of Core 74R. Postcruise palynological processing using hydrofluoric acid will provide more constraints on dinocyst abundances throughout this interval. Mollusk shells and their fragments are regular features of Site U1607 cores. Foraminifera shells, as well as mineralized burrow fills, are often pyritized.

The observed assemblages of all microfossil groups were generally composed of species with long geologic ranges. In terms of age control, all groups are consistent with Miocene ages, while downhole, some taxa are suggestive of Oligocene ages. The meager planktonic foraminifera assemblages are of low diversity and consist of few (5–20 specimens) small-sized individuals. The deepest occurrence of planktonic foraminifera, observed in the core catcher sample of Core U1607A-88R, is consistent with an early Miocene to late Oligocene age. The diatom species observed suggest Miocene ages and, downcore, the dinocyst taxa reflect middle to late Miocene and older ages. In general, the microfossils from the upper 500 m CSF-A of Hole U1607A are characteristic of coastal or neritic environments with ample food/nutrient availability, while below ~500 m CSF-A assemblages reflect more open marine environments, at times favorable to planktonic foraminifera. The prominence of agglutinated benthic foraminifera, which are more environmentally tolerant than calcareous species, is also consistent with a food-rich inner shelf environment corrosive to small calcitic tests. All microfossil assemblages have environmental and climatic affinities comparable to assemblages observed in the Miocene of western Baffin Bay and the Labrador Sea (Ocean Drilling Program Leg 105) and North Sea (Kaminski et al., 1989; King, 1989).

Paleomagnetism

Pass-through paleomagnetic measurements from Site U1607 were performed using the superconducting rock magnetometer (SRM) to investigate the remanent magnetization on a total of 491 archive section halves. Measurements were not made on core catcher sections. All measurements on archive section halves were made at 2 cm intervals, up to a peak alternating field (AF) demagnetization of 20 mT.

A total of 525 discrete cube samples were taken from working section halves. Generally, we collected one sample per core section, avoiding visually disturbed intervals. Of the 525 samples, 512 were taken using the parallel saw and the rest were sampled using the J-cubes by inserting them into the working section half. Of the discrete samples, 476 were measured on the SRM and stepwise demagnetized up to 50 mT. The remaining specimens were preserved for further study.

At Site U1607, we utilized a filtering method which assesses the magnetic stability of archive section half and discrete sample data. Above ~375 m CSF-A, we defined 13 magnetic polarity zones. Below ~375 m CSF-A, magnetic data were unreliable due to a diagenetic loss of remanence-carrying material, and it was not possible to define polarity intervals. Further constraint awaits other chronological information, including confirmation of possible unconformities or hiatuses.

Physical Properties

Standard measurements of physical properties were made on cores from Hole U1607A 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. A positive correlation is found between density and NGR counts for Site U1607. The correlation between these physical properties distinguishes five physical properties units (PP Units I–V) of Site U1607. PP Unit I (0–180 m CSF-A) is distinguished by a sharp increase downhole in NGR, magnetic susceptibility (MS), and density in the upper 50 m of material, followed by relatively constant values to 180 m CSF-A. Below, in PP Unit II (180–350 m CSF-A) high amplitude variability of NGR and MS reflects the broad variations in the lithology, which transition from more frequent intervals of mud to muddy sand and sandy mud moving downhole through the unit. PP Unit III (350–720 m CSF-A) is characterized by a decrease in NGR and density values compared to Unit II, which might reflect the transition from intervals of mud and sand to predominantly muddy sand towards the bottom of this unit. Muddy sand is also the primary lithology of PP Unit IV (720–825 m CSF-A), where NGR, MS, and density remain relatively constant relative to values observed in the lowermost interval of PP Unit III. PP Unit V (825–978 m CSF-A) is defined by a decrease in NGR and density to the bottom of the hole within a predominantly mud lithology.

Geochemistry

Samples for headspace gas, interstitial water (IW) chemistry, and bulk sediment geochemistry were analyzed at Site U1607. Headspace hydrocarbon gas measurements reveal high concentrations below 5 m CSF-A with methane concentrations up to 113,700 ppm. Ethane is found at lower concentrations of up to 725 ppm, and longer chain hydrocarbon gases (propane, butane, and pentane) are detected at low, yet consistent, levels at depths below 500 m CSF-A. The main findings from IW analysis include low salinity values within the upper 200 m CSF-A of the site. IW iron, manganese, sulfate, and phosphate show elevated concentrations near the seafloor and sharp decreases to low concentrations with depth. Lithium and barium both increase significantly with depth. Elemental analysis of solid material reveals calcium carbonate ($CaCO_3$) contents of largely <1%, while some intervals contain greater amounts (up to 59%). The contents of total organic carbon and total nitrogen increase notably with increasing depth.

Age Model

Initial age constraints of Site U1607 are based on magnetostratigraphic interpretations of inclination with two additional biostratigraphic considerations. The diatom *Proboscia barboi* is present at 198.7 m CSF-A and has an age range of 3.31–9.49 Ma (Koc and Scherer, 1996). The second possible constraint is from the co-occurrence of two diatoms (*Gnoithecium rogersii* and *Gnoithecium decoratum*) at 199.54 m CSF-A, whose age ranges overlap between 16 and 21 Ma (Suto, 2008). These two observations are mutually inconsistent and lead to two possible age models. There are also unconformities recorded in the seismic profile reflecting potential hiatuses at about 26 and 73 m CSF-A, the latter of which may eliminate the highest normal polarity zone as a possible constraint.

The first age model is based on the occurrence of *Proboscia barboi* at 198.7 m CSF-A, and in this model the transition from normal to reverse for the highest normal zone is correlated to Chron C4r.1r and the lowest reverse to normal transition is correlated to Chron C4Ar.2n. The average sediment accumulation rate for this age model is 19 cm/ky. The second age model is based on the co-occurrence of the *Gnoithecium rogersii* and *decoratum* species, and in this model the transition from normal to reverse for the highest normal zone is correlated to Chron C5Cn.2r and the lowest reverse to normal transition is correlated to Chron C6n. The average sediment accumulation rate for this age model is 13 cm/ky. Further refinement of the age model for Site U1607 must await shore-based studies.

Downhole Measurements

Downhole logging was carried out in Hole U1607A upon completion of the coring operations. A modified triple combo tool string was deployed recording MS, NGR, electrical laterolog resistivity, acoustic velocity, and density tools. Four runs (two down pass plus two up pass) were carried out with the sensors recording on the way down and up. Two of the runs (initial down and final up) covered the full length of the hole to 40 m above the bottom. Two calibration runs (one up and one down) were logged on the deepest 100 m of the hole. The caliper showed a homogeneous and stable hole with minimum washouts down to 880 m CSF-A.

Upon completion of the downhole logging with the modified triple combo, vertical seismic profiling was implemented with the VSI. The VSI aimed to obtain an accurate time-depth relationship to tie the logging and coring results with the seismic data. The geophones recorded the seismic signal at 33 stations located at an average spacing of 30 m, and three good shots were recorded in most of the stations. A protected species watch was in place before and during the use of the seismic source. Logging measurements were crucial for covering recovery gaps of RCB coring, especially near the bottom of Hole U1607A. Core logging and downhole logging results differ on absolute values, but the relative trends of the logs are comparable. Hence, logging data could be used to cover the formation recovery gaps with confidence.

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