IODP Expedition 403: Eastern Fram Strait Paleo-Archive

Sites U1621, U1622, and U1623 Summary

Background and Scientific Objectives

The Bellsund Drift coring sites are located on a plastered sediment drift that developed along the lower continental slope (1700–1800 meters below sea level [mbsl]) of the western margin of Svalbard under the influence of the northward flowing West Spitsbergen Current (WSC). The Bellsund Drift has built up over millions of years since the opening of the Fram Strait. The opening of the strait led to the onset of the contour current circulation system in the area, with development of sediment drifts covering large areas of the European North Atlantic margin, including the Norwegian Sea, Barents Sea, and western Svalbard along the eastern side of the Fram Strait. The Bellsund Drift recorded continental input associated with the expansion and retreat of the paleo-Svalbard-Barents Sea Ice Sheet (SBSIS) during the past glacial and interglacial cycles, and the variability of the warm WSC through its effect on the marine biological productivity in the water column. Its location, between the Storfjorden Through Mouth Fan (TMF) to the south and the Bellsund TMF to the north, provided some protection from direct glaciogenic input from the paleo-SBSIS during the past glaciations while still capturing a record of the ice sheet dynamics.

Piston core work in this area demonstrates that the Bellsund Drift is an excellent setting to recover continuous, expanded, and dateable sedimentary sequences for detailed paleoclimatic and paleoceanographic analyses. The sedimentological analyses indicate the consistent presence of contouritic deposition and the existence of short-lived, abrupt depositional events associated with prominent meltwater events.

The drill sites on the Bellsund Drift (Site U1621 [proposed Site BED-01A] and Site U1623 [proposed Site BED-02B]) were designed to recover an expanded sedimentary sequence to specifically examine suborbital oscillations over the last 100 ky, the Mid-Brunhes event, the mid-Pleistocene transition, and the primary establishment of shelf-edge glaciation in this area at about 1.3 Ma. Site U1621 was chosen because seismic profiles indicate a highly expanded sediment record down to ~0.75 Ma. Due to a discrepancy in coordinates transcription, Site U1622 was drilled into the Storfjorden TMF, ~8 km from the intended site. Site U1623 is located ~4.4 km down slope from Site U1621, selected to drill an expanded record down to ~1.3 Ma.

Operations

The vessel completed the 138.0 nmi transit from Site U1620 in 11.5 h at an average speed of 12.0 kt. Thrusters were down and secure, and the vessel was in full dynamic positioning (DP) mode at 0743 h (UTC + 2 h) on 7 July 2024, beginning operations at Site U1621. In total, we spent 4.27 d on Site U1621, and penetrated a maximum depth of 216.1 meters below seafloor (mbsf), with a combined penetration of 639.3 m. The cored interval of 517.3 m resulted in a recovered length of 464.62 m (90%). Site U1621 consists of three holes that stretch across a 40 m interval (20 m between holes). Hole U1621A is located on Seismic Line SV15-04; the other holes are offset by 20 m at a bearing of 22°. We took 89 cores in total, with 45% advanced piston corer (APC) use (40 cores), 24% half-length APC (HLAPC) use (21 cores), and 31% extended core barrel (XCB) use (28 cores).

The vessel made the 4.6 nmi transit from Site U1621 to Site U1622 in DP mode, beginning the transit when the bit cleared the seafloor at Hole U1621C. The bit was pulled to the rig floor during the transit and was replaced with an APC roller cone bit. The bit was deployed to depth while the ship was in transit, and it was ready upon arrival at the site. The vessel arrived on site at 0012 h on 12 July. At Site U1622 we spent 0.54 d in total and penetrated a maximum depth of 46.5 mbsf. The cored interval of 46.5 m resulted in a recovered length of 46.26 m (99%). Site U1622 consists of only one hole. During coring operations, it was discovered that the coordinates for Site BED-02B in the *Scientific Prospectus* did not correspond to the approved seismic shot point for the site. Upon discovery, coring was terminated, the correct coordinates were calculated, and the vessel departed for Site U1623. We took seven cores in total, with 86% APC use (six cores) and 14% HLAPC use (one core).

The vessel began the 4.4 nmi move from Site U1622 to Site U1623 in DP mode when the bit cleared the seafloor at 1315 h on 12 July, and it arrived on location at 1800 h on the same day, making the transit in 4.4 h with an average speed of 0.9 kt. In total we spent 10.3 d on Site U1623 and penetrated a maximum depth of 370 mbsf with a combined penetration of 1422.4 m. The cored interval of 1422.4 m resulted in a recovered length of 1314.38 m (92%). Site U1623 consists of seven holes. Hole U1623A is located on Seismic Line GAGE21-1HH-05. Holes U1623B, U1623C, and U1623G stretch across a 60 m long transect from Hole U1623A at a bearing of 22°. Holes U1623C and U1623D are 20 m apart at a bearing of 110°, with Holes U1623E and U1623F in the middle between U1623C and U1623D. Holes U1623B and U1623E did not recover a good mudline, and coring was abandoned after one core. It was determined that Hole U1623F sidetracked into an adjacent hole and coring was terminated after Core U1623F-22F. We took 205 cores in total, with 29% APC use (58 cores), 30% HLAPC use (62 cores), and 41% XCB use (85 cores).

To minimize magnetic overprinting on the cored sediment, nonmagnetic collars and core barrels were used for all APC and HLAPC coring at Sites U1621–U1623. Most holes had intervals where the sediments expanded due to the presence of gas, resulting in recoveries sometimes exceeding 100%, as well as intervals of poor recovery due to the presence of clast-rich glacial deposits. To mitigate the impact of expansion, the potential for core disturbance, and to release pressure, holes were drilled into the liner, both by the drill crew on the rig floor and by the technical staff on the core receiving platform. In addition, some XCB cores were advanced by 8 m to allow for gas expansion of the sediments in the liners.

Principal Results

Sediments throughout all holes are mainly siliciclastic, primarily composed of dark gray to greenish gray silty clay, with coarser intervals containing reddish gray to dark reddish gray sandy mud. The lithologies contain varying amounts of detrital clasts of <2 cm, and some single large clasts of >2 cm were identified both from visual core descriptions and X-radiographs. Clast abundance ranges from absent to dispersed (<1% of the split core surface) to common (1%–5%) to abundant (5%–30%). When clast abundance is between 5% and 30% and clasts >2 cm are observed on the split core surface, the lithology is designated as a diamicton. Smaller intervals of diamictons (<2 m thickness) are described from various intervals in different cores and sites, with a major change to more diamictic layers toward the base of Sites U1621 and U1623. In contrast to Sites U1618, U1619, and U1620, diagenetic overprint plays only a minor role in the sediments of Sites U1621, U1622, and U1623. Only small iron sulfide grains and sparse patches of authigenic carbonates are observed on the split core surface in the deeper part of the stratigraphic sequences. Sedimentary structures are not always visible on the split core surface, but primary and secondary structures are observed in the X-radiographs. Based on the lithological characteristics, sediments recovered from Sites U1621, U1622, and U1623 are divided into two primary lithostratigraphic units and additional subunits. Lithostratigraphic Unit I is predominantly composed of soft to firm dark gray to greenish gray silty clay with abundant slightly coarser intervals of (dark) reddish gray sandy mud. Clast content ranges from dispersed to abundant. The unit exhibits variable mineralogy, some intervals with higher percentages of biogenic material, and slight to moderate bioturbation. Sand patches and interbedded silty clay and silt layers are observed throughout the entire unit. Physical properties (magnetic susceptibility [MS], natural gamma radiation [NGR], gamma ray attenuation [GRA] bulk density, and color reflectance) show some cyclic fluctuations, which are most pronounced in the MS. In cores from Sites U1621 and U1623, coarser-grained intervals with clasts <2 cm are variably encountered and are classified as diamicton. Lithostratigraphic Unit II is characterized by layers of silty clay and sandy mud with variable amounts of clasts, and by the absence of sand patches or interbedded silty clay and silt layers. Physical properties are variable but without the cyclicity seen in Unit I. A significant increase in bioturbation is observed in dark sediments recovered in the upper part of Unit II, while the lower part contains increasing amounts of coarser-grained sediments with significantly increasing amounts of clasts >2 cm (i.e., diamicton). Unit II is divided into two subunits, IIA and IIB, with the boundary between the two subunits at the occurrence of significantly enhanced bioturbation of Subunit IIA.

Biostratigraphic and paleoenvironmental characterization of Sites U1621, U1622, and U1623 was conducted utilizing calcareous nannofossils, dinocysts, diatoms, and planktic foraminifers.

Diatoms are mostly barren in the studied sites except for some intervals with high abundances. Calcareous nannofossils are generally present at all sites, but regularly alternate with barren intervals in the record. Planktic foraminifers are found continuously in the upper sections of Holes U1621A and U1623A but are barren below. For dinoflagellate cyst (dinocysts) analyses, samples corresponding to potential warm intervals were selected based on lithological and physical properties, and on shipboard biostratigraphic evidence from other micropaleontological groups at Sites U1621 and U1623. Site U1622 was not investigated for dinocysts. Most of the studied samples have abundant dinocysts. Combined biostratigraphic information from all groups, together with paleomagnetic data, indicates a maximum late Pleistocene age for the sediments recovered at Sites U1621 and U1622, and mid-Pleistocene age for Site U1623. Microfossil assemblages indicate a surface Arctic-polar paleoenvironment under the influence of Atlantic waters and (seasonal) sea ice conditions.

Paleomagnetic investigation at Sites U1621, U1622, and U1623 focused on measurements of the natural remanent magnetization (NRM) before and after alternating field (AF) demagnetization of archive half sections and vertically oriented discrete cube samples. All archive half sections were measured except for some that had significant visible coring disturbance and core catchers. APC and HLAPC archive half sections were measured before and after 10 and 15 mT peak AF demagnetization. As XCB cores do not use nonmagnetic core barrels and are more susceptible to viscous isothermal remanent magnetization (VIRM) drill string overprint, XCB archive half sections required higher AF demagnetization steps to remove this overprint and were measured before and after 15 and 30 mT peak AF demagnetization. While not as common as at previous sites drilled during Expedition 403, some archive half sections from Sites U1621 and U1623 with high MS had NRM intensities that were too strong to be measured on the superconducting rock magnetometer and caused flux jumps even when the track speed was slowed by 10×. The archive section half data are supplemented by the study of discrete cube samples. Site U1621 sediments generally have well-defined magnetizations and good recovery, with three holes allowing assessment of coring deformation through comparison of reproducibility. Paleomagnetic studies on Site U1621 indicate that sediments in the upper half were deposited in the C1n (Brunhes) Chron. Many of the cores recovered at Site U1622 below 10 m display significant coring disturbance. This disturbance can explain much of the variability in the archive section half data. All cube samples are well-defined enough to determine polarity. Therefore, the data indicate that all sediments recovered from Site U1622 were deposited in the C1n (Brunhes) Chron. Much of the variability observed in the archive section half and some cube data of Site U1623 can be attributed to coring deformation. This variability is not reproducible between holes and anomalous inclinations should be interpreted with caution. Several paleomagnetic chrons and subchrons are identified at Site U1623, including the base of the C1n (Brunhes; 773 ka) Chron, the top of the C1r.1n (Jaramillo; 990 ka) Subchron, and the base of the C1r.1n (Jaramillo; 1070 ka) Subchron.

There is generally good correspondence between physical properties data collected at high resolution on the MS loop sensor and data collected at low resolution on the MS point sensor, with the MS point measurements picking up additional peaks in MS that were missed during the averaging in loop sensor measurements. Though some intervals of GRA bulk density are slightly lower than those measured on discrete samples, there is good correspondence between data from high- and low-resolution measurements. Due to the presence of clasts and gas in the sediments, *P*-wave velocity data are not considered reliable, and there is no detectable signal in either discrete or core logger data below ~20–30 mbsf at Sites U1621 and U1623. Thermal conductivity data generally increase with depth. Site U1622 is different from the other Bellsund sites, with lower MS and higher NGR and GRA compared to Sites U1621 and U1623. Overall, higher NGR values are observed at Site U1623 compared to Site U1621, which may be associated with higher clay content farther from the shelf edge. Compared to northern sites of Expedition 403, MS in Sites U1621 and U1623 is impacted by secondary alteration, and there are more apparent similarities between MS and other physical properties (e.g., NGR). However, greigite still drives some of the MS peaks. Overall, physical properties at Sites U1621 and U1623 appear to be influenced by oceanographic changes, glaciogenic deposition, and postdepositional processes. Site U1622 appears to capture a very dense, coarse, clast-rich deposit that may represent a buried debris flow, possibly of glaciogenic origin.

Stratigraphic correlation for Sites U1621 and U1623 was primarily accomplished using MS. Cores from all three holes at Site U1621 were used to construct the stratigraphic splice to ~188 m composite depth below seafloor (CCSF), with Hole U1621B serving as the backbone. For Site U1623, both a primary and an alternative splice were generated. The primary splice for Site U1623 is based on cores from Holes U1623A, U1623C, U1623D, and U1623F, and is complete to 404 m CCSF. The alternative splice is from 0 to 174 m CCSF. In construction of the alternative splice, cores from Hole U1623G were used as the backbone. Gaps in the upper 90 m were filled in with cores from Hole U1623F, and most gaps below this depth are filled in with cores from Holes U1623A, U1623D, and U1623G.

Samples for interstitial water (IW) chemistry, bulk sediment geochemistry, and headspace gas were analyzed at Sites U1621, U1622, and U1623. The main findings from IW analyses suggest diagenetic alteration of minerals and organic matter, except at Site U1622, which shows low organic matter diagenesis and an expanded iron reduction zone. The $CaCO_3$ and total organic carbon/total nitrogen ratios change with lithology, with high values in Lithostratigraphic Unit I and relatively low values in Lithostratigraphic Unit II. The $CaCO_3$ content fluctuates with apparent cyclic patterns at Sites U1621 and U1623 in Lithostratigraphic Unit I. Methane concentration sharply increases from near zero just below the sediment/water interface in Sites U1621 and U1623. At Site U1622, methane concentrations are lower than at other sites drilled during Expedition 403.

Microbiology sampling at Sites U1621 and U1623 was guided by preliminary shipboard chronologies and lithological interpretation, targeting warm interglacials and a period of SBSIS advance and retreat from ~30 ka to present day. At Site U1621, sedimentary ancient DNA (sedaDNA) samples were taken at the mudline of Hole U1621A, and samples of split cores were taken from Hole U1621C. In total, 62 sedaDNA horizons were sampled. At Site U1623, sampling of split cores was performed on Hole U1623C, with a total of 30 horizons sampled. To evaluate possible drill fluid contamination in the sedaDNA samples, 100 chemical perfluorocarbon (PFT) tracer controls were analyzed shipboard (n = 66 from Site U1621, n = 34 from Site U1623). Positive controls of the drill fluid were taken from the top of the core to determine whether the tracer had been correctly dispensed, while negative controls of the sediment were taken directly adjacent to the sedaDNA samples to assess whether drill fluid had penetrated the interior of the core.

During APC coring in Holes U1621A and U1623A, in situ formation temperature was measured every third core (U1621A-4H, 7H, 10H; U1623A-4H, 7H, 10H, and 13H) using the advanced piston corer temperature (APCT-3) probe. For Hole U1622A, in situ temperature measurements were performed once during Core U1622A-7F. Temperature increases linearly with depth, and the slope of linear regression provides a typical geothermal gradient for oceanic sediments. For Holes U1621A and U1623A, the heat flow in the sediments and the temperature at the seafloor were calculated from the measured thermal conductivity in Cores U1621A-1H to 6H and U1623A-1H to 14F, respectively, and from the formation temperature measurements.

Planned downhole logging runs in Hole U1623C using the triple combo and Formation MicroScanner (FMS)-sonic strings were cancelled as the logging tool string was unable to pass through the bit. A second attempt at downhole logging was performed in Hole U1623D using the triple combo and FMS-sonic strings to obtain multiple in situ measurements. After the bottom-hole assembly was set at 104 mbsf, the tool string was lowered to 260.5 mbsf for the first downlog. Subsequently, the tool string was pulled up for the first uplog from 260.0 to 142.7 mbsf. To increase data recovery, the strings were lowered again to 257.6 mbsf and pulled up to the surface for second uplog. After the triple combo, the FMS-sonic string was lowered. For the first image uplog, the FMS-sonic string was pulled up from 259.2 to 143.5 mbsf. To increase data recovery, the tools were lowered again to 238.2 mbsf, where the tools encountered an obstruction they could not pass, and they were pulled up to the surface for the second image uplog. The average heave was estimated at 1 m peak to peak. The heave compensator was utilized during the logging operation.

Logging data were sent for processing to the Lamont-Doherty Earth Observatory (LDEO). The triple combo acquired density, NGR, and electrical resistivity data. For several depth levels however, the data should be interpreted with caution because the irregularly enlarged borehole (washouts) affects eccentralization and/or good contact of tools onto the borehole wall. Due to technical issues, the Magnetic Susceptibility Sonde could not acquire valid MS data in Hole

U1623D. NGR and density show almost the same trends as shipboard scanning data, indicating that core and log depth scales can be readily correlated. The differences between depth scales can be assumed to be <1 m. The FMS-sonic string successfully logged NGR, acoustic velocity, and borehole resistivity images. The processed *P*-wave velocity data show increasing values with depth. Due to the capacity of FMS calipers, borehole resistivity images have 25% recovery of all borehole walls at every depth. The images indicate several vertical lines of low resistivity that suggest drilling-induced tensile fractures resulted from higher compressional stress than compressional strength of the formation. However, those lines are not apparently symmetric, thus we are not confident on their relationship to the natural compressional stress.