IODP Expedition 403: Eastern Fram Strait Paleo-Archive

Site U1620 Summary

Background and Scientific Objectives

The Svyatogor Ridge is a northwest to southeast (NW–SE) elongated contouritic sediment drift lying on young (<10 Ma) oceanic crust. This sediment drift has a length of 46 km and a width of 5 km and is located ~130 km from the western margin of Svalbard on the northwestern flank of the ultraslow spreading Knipovich Ridge, south of the Molloy transform fault (MTF). The sediment record at Svyatogor has been influenced by multiple factors, including the locally complex tectonic history, the evolution of the West Spitsbergen Current (WSC), the development of regional ice sheets, and the presence and migration of methane gas with likely biotic and abiotic sources.

It has been hypothesized that the Svyatogor Ridge (Site U1620 [proposed Site SVR-03A]) and Vestnesa Ridge (Sites U1618 and U1619 [proposed Sites VRE-03A and VRW-03A]) sediment drifts had once been contiguous and similarly NW–SE oriented, with sedimentation controlled by the main branch of the WSC and additionally controlled by tectonic-related MTF bathymetry. Over the past 2 Myr, tectonic offset along the MTF separated the Svyatogor and Vestnesa sediment drifts. The sediment cover across the Svyatogor Ridge once again became limited compared to Vestnesa, as displacement along the MTF has moved the ridge further away from the main north/northwestern meandering path of the WSC, which is controlling the sedimentation today. The MTF right-lateral offset also impacted on the geometry of the Vestnesa Ridge, by turning its main axes westward.

The chronostratigraphy at the Svyatogor site is largely unknown because the exploration was mostly limited to the geophysical survey focused to characterize the unique fluid flow system of this ridge. Because of the underlying young crust and the proximity to the ultraslow spreading Knipovich Ridge, the Svyatogor sediment drift likely contains a unique combination of biogenic derived methane and abiotically derived gas generated from the serpentinization of exhumed mantle rocks. This complex system contributes to an extensive occurrence of free gas, gas hydrate, and fluid flow systems in the region, with gas chimney and transform faults acting as major pathway for fluid migration.

Site U1620 on the Svyatogor Ridge was chosen for its distal location from the western margin of Svalbard, therefore having a reduced (yet discernable) continental impact on the sedimentation and an enhanced paleoceanographic signal that is mainly driven by the oceanic current. The relationship among sediment drift development, bathymetry, and tectonic motion are additional factors unique to this location that can be examined. Furthermore, as this is an almost unexplored area, the documented presence of a young oceanic crust and active seepage system can drive unexpected new findings in relation to fluid flow, diagenesis, and the microbial community.

Operations

The vessel completed the 62.8 nmi transit from Site U1619 to Site U1620 in 6.2 h at an average speed of 10.1 kt. The thrusters were down and secure, and the vessel was switched from cruise mode to dynamic positioning (DP) mode at 0256 h (UTC + 2 h) on 29 June 2024, starting Site U1620 and Hole U1620A.

In total we spent 7.58 d on site and penetrated to a maximum depth of 616 meters below seafloor (mbsf), with a combined site penetration of 1026.2 m. The cored interval of 1026.2 m resulted in a recovered length of 1132.2 m (105% recovery). Site U1620 consists of four holes that span a 200 m transect (100 m between holes, with Holes U1620B and U1620C at the same location). We collected 126 cores in total, with 30% using the advanced piston corer (APC; 38 cores) and 70% using the extended core barrel (XCB; 88 cores). To minimize magnetic overprinting of the cored sediment, the nonmagnetic collars and core barrels were used for all APC coring. Holes U1620A, U1620C, and U1620D had intervals where the sediments significantly expanded due to the presence of gas, resulting in recoveries often exceeding 100%. To mitigate the impact of expansion and 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. XCB cores were often advanced by 6–8 m to allow for gas expansion of the sediments within the core liner. Core U1620B-1H recovered an insufficient mudline, thus Hole U1620C was spudded at the same location. Hole U1620D is halfway between Holes U1620A and U1620B/U1620C, about 100 m away, respectively. Following the end of coring operations, Hole U1620D was prepared for downhole logging at 0700 h on 6 July. Only the triple combo tool string was deployed at this site. The bit was pulled out of the hole after the logging ended, clearing the seafloor at 1423 h and the rig floor at 1800 h on 6 July. The rig floor was secured for transit and the vessel switched from DP to cruise mode at 1909 h on 6 July, ending Hole U1620D. All thrusters were up and secure at 1920 h, and the vessel began its sea passage to Site U1621 (proposed Site BED-01A) at 1930 h on 6 July.

Principal Results

The sediments throughout all cores in Holes U1620A–U1620D are primarily siliciclastic, mainly composed of dark gray to dark greenish gray silty clay, with coarser intervals containing clayey silt, sandy clay, and sandy mud, and display increasing lithification with depth. These lithologies contain varying amounts authigenic mineral precipitates and/or detrital clasts. Small (<1–2 cm) to large (>2 cm) clasts are identified throughout most cores from visual description and Xradiograph observations. When present, clast abundance ranges from dispersed (observed on <1% of the split core surface) to common (1%–5%) to abundant (5%–30%). When the sediment is poorly sorted, with clast abundance between 1% and 30% and with large clasts (>2 cm), the lithology is designated as a diamicton. While sedimentary structures are sometimes not visible on the split core surfaces, they are more commonly visible in the X-radiographs, available predominantly from Hole U1620D. Based on these characteristics, the sediments recovered from Site U1620 are divided into two primary lithostratigraphic units (Units I and II) with Lithological Unit I, subdivided into Subunits IA and IB.

Biostratigraphic analyses at Site U1620 were conducted for calcareous nannofossils, dinocysts, diatoms, and planktic foraminifers. All holes were analyzed for calcareous nannofossils and diatoms, whereas only Holes U1620A and U1620D were analyzed for dinocysts and planktic foraminifers. Diatoms and planktic foraminifers are consistently present to abundant only in the upper ~40 m of the site. Below that depth, rare diatoms were recorded between 100 and 120 mbsf in Holes U1620A and U1620D, while rare planktic foraminifers reappear only below ~600 mbsf in Hole U1620D. In all holes, calcareous nannofossils appear intermittently while dinocysts are present throughout. Several biostratigraphic events of Pleistocene age are recorded by calcareous nannofossils at Holes U1620A, U1620C, and U1620D, and by dinocysts in Hole U1620A. Planktic foraminifers, calcareous nannofossils, and dinocysts converge on a Late Pliocene age for the lower part of Hole U1620D. Overall, biostratigraphic data show that Site U1620 ranges from Late Pliocene to Pleistocene and, together with paleomagnetic data, enables the development of an age-depth model for Site U1620.

Paleomagnetic investigation of Site U1620 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 some that had significant visible coring disturbance and core catchers. APC archive half sections were measured before and after AF demagnetization. As XCB cores do not use nonmagnetic core barrels and are more susceptible to the viscous isothermal remanent magnetization drill string overprint, XCB archive half sections required higher AF demagnetization steps to remove this overprint. Some archive half sections with high magnetic susceptibility (MS) had NRM intensities that were too strong to be measured on the superconducting rock magnetometer and caused flux jumps even when track speed was slowed by 10×. This reduced the ability to collect quality data in these intervals. Following insight gained from previous work during IODP Expedition 403 at Sites U1618 and U1619, and consistent with observations made in the region during Ocean Drilling Project (ODP) Leg 151, discrete cube samples preferentially sampled low MS intervals when possible in an effort to avoid sampling greigite-rich layers, with approach varying based on the specific core and based on who was sampling. The major polarity zones that reflect the C1n (Brunhes; 0–773 ka), C1r-C2r (Matuyama; 773–2595 ka), C2n (Upper Olduvai; 1775 ka), and C2An (Gauss; 2595–3596 ka) chrons are preliminarily identified.

The physical properties measured at this site included MS, gamma ray attenuation (GRA) bulk density, natural gamma radiation (NGR), *P*-wave velocities, and moisture and density (MAD). In general, a good correlation between GRA bulk density and discrete MAD sample measurements is observed. Similar to previous sites, the presence of gas hampered the analysis of *P*-wave velocities, thus the data are not considered reliable. MS, NGR, and GRA generally display a positive linear correlation down to ~150 mbsf, associated with Lithostratigraphic Subunits IA and IB. Below ~150 mbsf, MS correlation with other physical properties ceases. A notable feature at Site U1620 is the prevalence of peaks with MS values orders of magnitude higher than the background. The outsized peaks are infrequent in the upper part of the record but are prominent below ~150 mbsf. These MS maxima are likely associated with authigenic Fe-sulfides and can indicate diagenetic alteration. Lithostratigraphic Unit II has a bimodal distribution in MS. The lower mode likely tracks depositional processes, and the higher mode represents units affected by authigenic processes. NGR and GRA continue to be well-correlated at depth and are good markers of lithological changes downcore. The variability of GRA and NGR at depth is likely associated with periodicity of layers observed in Lithostratigraphic Unit II. This variability is expressed in the bimodal distribution of GRA in Unit II, and possibly indicates changes in ocean/climate interactions. GRA and NGR increase with depth but not with MS peaks, indicating that magnetically strong constituents are not limited to a specific lithology or degree of compaction. This supports the interpretation that outsized MS peaks represent a postdepositional component. Overall, physical properties at Site U1620 appear to be influenced by oceanographic changes, glaciogenic deposition, and postdepositional processes.

Stratigraphic correlation between holes at Site U1620 was primarily established using MS data from the Whole-Round Multisensor Logger. Although the holes are located relatively far from each other (100 to 200 m apart) and below ~100 mbsf, the records are often overprinted with high MS spikes due to abundant authigenic greigite, and common features to correlate among the holes could be identified. Below ~100 mbsf, expansion of the sediments caused many gaps in the cores that resulted in relatively high growth factors and voids, which likely affected the physical properties (e.g., density) leading to some stratigraphic inconsistencies among holes. Two spliced intervals were created, one from 0 to ~191 m core composite depth below seafloor (CCSF) based on correlations among the three holes (U1620A, U1620C, U1620D), and one from ~191 to ~271 m CCSF based on a correlation between Holes U1620A and U1620D. Only Hole U1620D extends below 271 m CCSF.

Samples for interstitial water (IW) chemistry, bulk sediment geochemistry, and headspace gas were analyzed at Site U1620. The main findings from IW analysis suggest organic matter diagenesis, as well as diagenetic alteration of mineral phases, resulting in the release and consumption of various trace and major elements. Elemental analysis of solid material revealed overall high concentrations of carbon and nitrogen across most intervals, with this variation corresponding to the lithostratigraphic units. Seismic surveys of the Svyatogor Ridge show a gas hydrate system that is heavily influenced by a tectonic regime, consisting of detachment faults that allow for fluid migration from basement rocks upward toward the sediment/water interface. The IW geochemistry, bulk sediment geochemistry, and headspace gas reflect the influence of deep fluid flow migration. Methane (C_1) concentrations are generally high in all holes (generally >5,000 ppm). Ethane (C_2) concentrations follow a similar trend to methane, before diverging from the trend and sharply rising at the start of Lithostratigraphic Subunit IB. Propene (C_3), propane (C_3), *iso*-butane (C_4), *n*-butane (C_4), *iso*-pentane (C_5), *n*-pentane (C_5), and *iso*-hexane (C_6) also trend with ethane. C_1/C_2 ratios can suggest the origin of hydrocarbons. The high C_2–C_6 hydrocarbon intervals in Lithostratigraphic Subunit IB and Unit II imply early low-temperature diagenesis of organic matter or originate from abiotic processes, one candidate for which may be the serpentinization of ultramafic rocks at the nearby ultraslow-spreading mid-ocean ridge in this region.

Sedimentary ancient DNA (sedaDNA) samples were taken at the mudline of Hole U1620A, at lower resolution on the core receiving platform (i.e., catwalk) from Hole U1620C, and at a higher resolution for selected intervals on split cores on Hole U1620D, totaling 113 sedaDNA samples. In addition to this, two 10 cm whole-round samples were taken at 300 and 400 mbsf from Hole U1620D. To evaluate possible drill fluid contamination in the sedaDNA samples, 141 chemical perfluorocarbon tracer (PFT) controls were analyzed shipboard. Positive controls of the drill fluid were taken from the top of the core to determine whether the tracer was 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. In total 112 PFT samples were negative, and 29 samples were positive, and thus might indicate potential contamination.

In situ temperature of formation was measured during Cores U1620A-4H, 7H, 10H, and 13H, and Cores U1620C-4H, 7H, 10, and 13H using the APC temperature tool. While coring using the XCB, in situ formation temperature was measured before Cores U1620A-19X and 31X and Cores U1620D-38X and 44X using the Sediment Temperature 2 tool. Temperature increases almost linearly with depth, with a heat flow higher than expected for similar settings. In Hole U1620D, downhole wireline logging using the triple combo tool string was performed to obtain multiple in situ properties. The drill bit was set at a depth of 71.5 mbsf to stabilize the hole. The triple combo string was run to a depth of ~580 mbsf for two runs. During triple combo logging, 10 sections of the hole between 127.5 and 347.5 mbsf were noted to be 2–3 inch undergage, indicating that the hole closed in at a speed of about 1 inch/h. Due to poor hole stability, the second planned logging run with the Formation MicroScanner-sonic tool was cancelled and operations were terminated. Logging data were processed at Lamont-Doherty Earth Observatory.