IODP Expedition 396: Mid-Norwegian Continental Margin Magmatism

Site U1573 Summary

Highlights

Site U1573 consists of one rotary core barrel (RCB) hole with the objective to characterize the basement nature of the outer seaward-dipping reflectors. Hole U1573A resulted in coring about 90 m of late early Eocene sediments that lie on top of basaltic basement. The 54 m of drilled basement consists of massive sheet flows that were emplaced in a shallow marine setting which are interlayered by sediments. The upper 300 m of the shallow sediments at the site were washed as an approaching storm did not leave enough time to core the entire hole.

Background and Objectives

Site U1573 (proposed Site VMVM-09A) is located in the southern part of the Lofoten Basin just north of the Vøring Plateau at 3167 m water depth. This part of the Vøring Margin has hardly been explored since the 1960s and 1970s. Site U1573 is located on magnetic anomaly 23 near the border between the Vøring and Lofoten Margins. The only available basement samples prior to Expedition 396 in this area are from Deep Sea Drilling Project (DSDP) Leg 38 Site 343. They drilled basement from 253 to 284 m below seafloor (mbsf) and recovered about 5 m of highly altered basalts that were interpreted to be part of a sill intrusion.

Compared to the Vøring Margin, the Lofoten Margin is characterized by a narrower rift system, less extensive breakup-related magmatic crustal thickening, and a rapid increase of water depth from the shelf into the Lofoten Basin. The Lofoten Margin consists of three segments that are characterized by different fault dip directions and separated by crustal transfer systems. The southernmost transfer system, i.e., the Bivrost Lineament, separates the Lofoten Margin from the Vøring Margin. Wide-angle seismic data suggest about 12 km thick oceanic crust in the southern part of the Lofoten Basin, much thinner than the ~20 km thick crust of the Vøring Plateau. This difference in crustal thickness should have resulted in a very different vertical movement history of the Lofoten Margin than for the Vøring Margin. A previously calculated early Eocene bathymetric gradient from the Vøring to the Lofoten Margin of 500–1000 m water depth on the Lofoten Margin during breakup would imply submarine lava emplacement on the Lofoten Margin, as opposed to the subaerial volcanic emplacement environment on the Vøring Margin. This bathymetric gradient has been attributed to rapid initial margin subsidence along a deep-rooted low-angle detachment fault. Reflection seismic data reveal a horizontal basement reflection underlain by seaward-dipping reflectors with lower seismic amplitude and shorter lateral extent than the main set of seaward-dipping reflectors on the Vøring Margin. These outer seaward-dipping reflectors are a common feature of volcanic rifted margins and have been interpreted as submarine lava flows.

The stark difference between the observed subaerial lava flows at Ocean Drilling Program (ODP) Site 642 and the submarine conditions predicted by gravity modeling require a distinctly different subsidence history for the Vøring and Lofoten Margins. Thus, the first objective of drilling Site U1573 was to obtain information on the emplacement environment based on the facies of the recovered basalt and sediments. As such, reaching this first objective directly tests the predictions of the concept of seismic volcanostratigraphy. The second objective was to establish the timing of volcanism on the Lofoten Margin, in particular whether there is evidence of a time gap between the emplacement of the seaward-dipping reflectors of the Vøring Margin on Skoll High (Sites U1571 and U1572) and the outer seaward-dipping reflectors. The third objective of Site U1573 was to constrain the conditions in the melt region during the presumably late phase of breakup volcanism. This includes not only any constraints on the composition of the mantle before melting and the ambient temperature and pressure from the geochemistry and petrology of the encountered rocks, but also any signs of evolution of the melts in crustal magma chambers during breakup volcanism.

Operations

Site U1573 consisted of a single hole, drilled first without coring using the RCB coring system with a center bit from the seafloor to 300.0 mbsf, and then cored to a final depth of 440.9 mbsf, including 54.4 m into basement. The average penetration rate within the basement section was ~1.82 m/h. There were frequent jammed liners and core catchers which contributed to relatively low core recovery rates within basement (average 43%). Coring in Hole U1573A was terminated at 1830 h on 20 September 2021 because of severe weather and heavy sea conditions that were expected over the operational area for the following day. The last core recovered was Core U1573A-19R at 1925 h on 20 September. The drill string was pulled back aboard at 2200 h. The bottom-hole assembly (BHA) was broken down and the drill collars were secured in the drill collar rack. The rig floor was secured at 0705 h on 21 September, ending Hole U1573A and Site U1573. A total of 101.0 h or 4.2 days were spent on site. Eighteen cores were recovered with the RCB system over 140.9 m, recovering 101 m (72%).

Principal Results

Lithostratigraphy

Site U1573 consists of a single hole that was drilled to 440.9 mbsf, with the recovered core interval spanning 300 to 440.9 mbsf. The 140.9 m thick succession consists of both sediments and basalts that are divided into four lithostratigraphic units. The criteria for the division of the units are based on significant lithological changes, which are supported by physical properties variability. Units I, II, and III are sedimentary, and Unit IV consists of basalt and interbasaltic sediments.

- Unit I [300.0–330.59 mbsf] consists of dark greenish gray to very dark gray claystone with rare weak parallel lamination or fining-upward sequence. Slight to heavy bioturbation is present throughout the unit and diagenetic pyrite is observed locally.
- Unit II [330.59–378.47 mbsf] consists of dark greenish gray to very dark gray claystone with moderate bioturbation, alternating with very dark gray organic-rich claystone with thin parallel lamination. Rare ash beds or ash-rich beds are present locally.
- Unit III [378.47–381.51 mbsf] consists of very dark gray to very dark bluish gray volcaniclastic claystone mudstone with sand.
- Unit IV [381.51–440.45 mbsf] consists mainly of gray to very dark gray aphyric basalt and interbasaltic claystone to sandstone.

Biostratigraphy

All sedimentary core catcher samples and selected samples from intercalated sedimentary beds in the igneous facies from Hole U1573A were processed for calcareous, siliceous, and organic microfossils. Calcareous and siliceous biogenic material was largely absent. However, most samples were productive for palynology, including some samples from between the igneous facies, and most yielded age diagnostic dinocysts, which indicate a late early Eocene age for the entire interval.

Paleomagnetism

Lithologic Unit I is characterized by the average intensity of magnetization of 0.05 A/m and median coercivity of 2.73. This coercivity may be owed to sedimentary hematite or goethite. The unique discrete sample measured is not ferromagnetic, devoid of magnetite, as the average bulk magnetic susceptibility (MS) is 0.447×10^{-3} SI.

Lithologic Unit II has 0.05 A/m average intensity of magnetization. The median coercivity (3.04), MS ($\kappa < 1.03 \times 10^{-3}$ SI) and the corrected degree of anisotropy ($P_j < 1.105$) are higher than Unit I. High κ is owed to small contributions from magnetite. High coercivity and P_j may be due to higher goethite/hematite ratio and/or larger iron-sulfide (e.g., pyrrhotite) population in the ash. Multiple minerals carrying remanence are evident from the three types of remanent magnetization identified in four discrete samples. The low and medium coercivity component is erased by alternating field of 20 mT and 70 mT, respectively. The high coercivity component is stable throughout the demagnetization process, i.e., in 120 mT field.

Lithologic Unit III has average magnetization intensity of 0.07 A/m, which is slightly higher than Unit I and Unit II. In contrast, the medium coercivity (2.53) is lower than in Unit I and Unit II. Lower median coercivity can be related to domination of volcanic material, which usually is richer in iron-sulfide (e.g., pyrrhotite) but poorer in goethite and hematite. Note that goethite and hematite have higher coercivity than iron-sulfides. No discrete samples were measured.

Lithologic Unit IV has high average magnetization intensity (2.6 A/m) and median coercivity (6.02). Such high coercivities may be owed to a larger goethite/hematite ratio. The unit is ferromagnetic with the highest bulk MS, indicating the dominance of magnetite. However, the corrected degree of anisotropy is the lowest among all the units. This indicates that the magnetic fabrics are carried dominantly by magnetite, and the populations of pyrrhotite and hematite are small. Three magnetization components are conspicuous from the demagnetization behavior of the discrete samples.

Unit I has four short periods of magnetic reversals between Sections U1573A-2R-1 (300 mbsf) and 2R-5 (306.71 m). This is followed by a long episode of magnetic reversal starting at Section 4R-2 (321.05 mbsf) and going to Section 5R-5 (333.91 mbsf) in Unit II. After this, the magnetic polarity flips several times at a relatively higher frequency (within a couple of meters) until Section 7R-3 (350.98 mbsf). It then remains reversed until Section 8R-3 (361.72 mbsf). After that, the polarity stays dominantly normal in the rest of the hole, i.e., down to Section 18R-2 (436.74 mbsf). Preliminary data from paleomagnetic analyses suggest a predominance of normal polarity at the top of the cored succession, which we tentatively assign to magnetochron C22n (48.57–49.34 Ma).

Geochemistry

Site U1573 in the Lofoten Basin provided a unique opportunity to sample an outer seaward-dipping reflector sequence on a magma-rich passive continental margin. The sampled lavas are noteworthy in that the higher silica and low-Ti compositions are chemically distinct from both typical mid-ocean ridge basalts and large igneous province magmatism. The sedimentary package recovered above the lavas is limited to 100 m. As seen at previous sites, high organic matter production and/or preservation is found within volcaniclastic sediments, suggesting a causal relationship. The interstitial water (IW) samples show a diagenetic environment controlled by basalt weathering, with processes consuming alkalinity in the overlying sedimentary strata. There is also strong evidence of authigenic carbonate formation above the sediment/basalt contact, linked to the liberation of calcium during the weathering of primary silicates.

Physical Properties

The sedimentary overburden is characterized by downward increasing density consistent with increasing compaction. Increased scatter in MS is observed over ash-rich intervals within sedimentary section. The hard rock basement sequence reveals basalt-dominated compositions and generally high density and velocities. The presence and nature of interlava sediments with lower velocity (~2000 m/s) compared to the higher velocity basaltic flows (~4500 m/s) give first insights into the geological causes of the outer seaward-dipping reflector seismic reflectivity.