IODP Expedition 396: Mid-Norwegian Continental Margin Magmatism

Site U1565 Summary

Highlights

Site U1565 drilled two short holes to determine the nature of the subbasalt basement in the western part of the Kolga High. Both holes recovered altered granitic basement below ~25 m of glacial sediments.

Background and Objectives

Site U1565 (proposed Site VMVM-20A) is located at 2071 meters below sea level (mbsl) on the western flank of Kolga High, a pronounced structural high within the Jan Mayen Corridor. The site was located using a combination of conventional 3-D and high-resolution seismic data. Comprehensive 3-D seismic mapping shows that the Kolga High is covered by a variable-thickness Paleogene basalt unit, overlying a complex and undefined subbasalt sequence which is locally intruded by Paleogene sills and dikes. Seaward dipping reflector wedges exist on the Møre Marginal High towards the south and similar, but smaller, seismic reflections lap onto the western part of the Kolga High. There is a classic lava delta and escarpment defining the eastern limit of the high. The basalt cover is absent in two small (5 × 3 km-sized) areas just west of the summit of the Kolga High. Here, the seismic data show a transparent seismic basement that extends down to a strong seismic reflection at about 7.5 s two-way traveltime (TWT). The gap in the basalt cover makes the Kolga High a unique place on the Vøring and Møre margins where the subbasalt sequence can be sampled with shallow coring.

The primary objective of Site U1565 was to core and sample the subbasalt geology that is largely unconstrained along the Mid-Norwegian Margin. Sampling the subbasalt succession would provide important constraints on the rifting history both in time and space as well as constraints on the vertical movements of this margin segment prior to breakup. We expected to sample the subbasalt rocks after penetrating about 25–30 m of Neogene sediments. The plan was to core for two days or to a maximum depth of 200 meters below seafloor (mbsf) to recover representative samples of the basement rocks to characterize the lithologies and alternation. As we encountered altered granitic basement immediately below the soft sediment cover in Hole U1565A, we decided to drill a second hole approximately 140 m towards the west to verify the lateral continuity of the basement rocks, rather than spending time deepening the initial hole at a very low penetration rate.

Operations

Site U1565 consisted of two shallow holes. Hole U1565A was cored with the rotary coring system to 28.0 mbsf. Coring was stopped because of very slow penetration rates while drilling into granite that was sampled in Cores U1565A-3R and 4R. With the objective to confirm the lateral extent of the granite, a second hole was added to the plan, U1565B. This hole was drilled 138 m west-northwest of the first hole, in the direction of the next site, U1566. Hole U1565B was cored to 31.7 mbsf and yielded similar core material as Hole U1565A. Operations were ended at 0215 h on 16 August 2021 and the drill string was pulled clear of the seafloor to begin the short transit of 900 m to the next site.

Nine cores were recorded for the site. The rotary core barrel (RCB) system was used exclusively. The RCB system cored 59.7 m and recovered 19.66 m of core (33%). A total of 34.25 h or 1.4 days were spent on Site U1565.

Lithostratigraphy

The lithology of Holes U1565A and U1565B can be divided into two units. Unit I consists of unconsolidated sediment and Unit II consists of altered granite. The boundary between the two units was determined using the drilling data, where the bit depth shows a sharp decrease in the rate of penetration from about 15 m/h to 1–2 m/h at 20.9 mbsf in U1565A and 28.0 mbsf in U1565B. The thickness of granite drilled in Holes U1565A and U1565B is 7.1 m and 3.6 m, respectively. Unit I is 7.1 m thinner in Hole U1565A than in Hole U1565B. High-resolution seismic data show that the expected overburden thickness is the same in both holes. The thickness discrepancy in the drilling data is attributed to uncertainties in the determination of the seabed depth for RCB drilling, as seabed depth was determined using the increase in torque in Hole U1565A and the mudline recovery in Hole U1565B.

The sediments of Unit I in Hole U1565A are primarily composed of olive brown to reddish-brown clay, whereas Unit I in Hole U1565B is mainly composed of brown, grayish-brown to dark gray clay. Generally, this unit contains varying amounts of silt, sand, calcareous nannofossils, and planktonic foraminifera, with diatoms common in the first core section of Hole U1565A (U1565A-1R-1). Amphibolite and granite dropstones also are observed in this core. The unit is overall moderately to very well sorted. Smear slide analyses indicate that Unit I consists of abundant undifferentiated clay-sized minerals, rare to trace foraminifers and nannofossils, with larger silt and sand-sized grains comprised of common quartz and undifferentiated feldspar, and rare lithics. Trace amounts of diatoms, zircon, chlorite, and glauconite are also present. Slight to moderate drilling disturbances were observed in parts of the unit. The base of Unit I in Hole U1565B, directly above Unit II, consists of a mixture of sand, subrounded yellow brown clay clasts, and granules to medium pebbles, with a poorly sorted grain size. Smear slide analysis of matrix material from this interval indicates abundant undifferentiated clay-sized minerals with rare nannofossils, rare organic debris, and trace diatoms. Silt and sand grains consist of common undifferentiated feldspar, rare quartz, and rare lithics. Dark gray polymetallic concentric nodules were observed at the base of Unit I in Hole U1565A (Interval U1565A-2R-1, 75–79 cm). Portable X-ray fluorescence spectrometer (pXRF) data collected from nodules at ~5.80 mbsf (Section U1565A-2R-CC) showed that their composition consists of low to moderate concentrations of transition metals (10.7 wt% Fe_2O_3, 2.6 wt% Mn_2O_3, 210 ppm Ni, 80 ppm Cu, and 94 ppm Zn). The silica content (~35 wt%) is considered relatively high for such nodules and suggests the presence of clay materials.

The transition between lithostratigraphic Unit I and Unit II was not retrieved in Hole U1565A. Based on the low penetration rates and drilling data, we cored 7.1 m into Unit II in Hole U1565A, recovering more than 3 m of granite. At Hole U1565B, the transition between the two units was recovered in Core U1565B-4R and we cored 3.6 m into basement, recovering only ten pebbles and a 10 cm core of highly altered granite conglomerate. Unit II represents one igneous lithologic unit consisting of moderately to highly altered medium grained biotite granite with local mafic or felsic enclaves. Throughout Unit II, the granite rocks remain mineralogically and texturally consistent. Discrete fine-grained enclaves are present in parts of Unit II. Observations of two thin sections confirmed the mineralogy and pervasive alteration observed at macroscopic scale. Alkali feldspars are generally partially or totally replaced by undetermined brownish clay minerals and zeolite. Biotite grains show corona of limonite.

Biostratigraphy

Before hitting igneous materials, unconsolidated mixed gray and brown sands, silts and clays with intervals containing gravel, and larger clasts, interpreted as ice-rafted detritus, were recovered from Unit I in Holes U1565A and U1565B. Clay- and silt-rich samples from Sections U1565A-1R-CC to 2R-CC, and from U1565B-1R-CC through 4R-CC, were analyzed for microfossil content. All sedimentary samples yield common-to-trace diatoms, in situ and reworked dinoflagellate cysts, reworked sporomorphs, rare ostracods, common-to-trace benthic foraminifers, and common planktonic foraminifers. The age-diagnostic microfossils indicate an overall Quaternary age. In addition, palynomorphs (mainly dinocysts) indicate reworking from Paleogene and (lower) Cretaceous strata while pollen and spores also indicate reworking from lower Cretaceous rocks. Diatoms and foraminifers are common in the mudline samples and suggest a middle Pleistocene–Holocene age.

Paleomagnetism

The sediments of Unit I show consistent and continuous variations in inclination and intensity, despite drilling disturbance. Some of the locally high values of magnetic inclination (>80°) might be due to drilling induced magnetization. The sediments have an average intensity of $\sim 3.6 \times 10^{-2}$ A/m, a magnetic susceptibility (K) of $\sim 707 \times 10^{-6}$ SI and a low magnetic anisotropy P' (~1.001). The nonhorizontal magnetic foliation suggests drilling disturbance. In Holes U1565A and U1565B, the geomagnetic polarity is normal, except in the interval 5.58–5.78 mbsf in Hole U1565A, where a magnetic reversal may occur. The sediments have higher magnetic coercivity than the granites. One discrete sample shows limited demagnetization up to a field of

100 mT, indicative of a high coercivity magnetic phase (goethite or hematite) and confirms the normal polarity of this interval.

The granites of Unit II have an average magnetic intensity of 1.17×10^{-2} A/m, likely due to loss of magnetite through alteration, and a magnetic susceptibility (K) of 212×10^{-6} SI with a low degree of anisotropy P' (~1.001). Two discrete samples show a normal polarity and the presence of a low coercivity phase (magnetite, titanomagnetite, or maghemite) consistent with thermal remanent magnetization.

Geochemistry

Alkalinity in the mudline samples of Holes U1565A and U1565B is similar, between 2.1 and 2.3 mM. Downcore, alkalinity increases linearly to a value of 3.5 mM in the lowermost interstitial water (IW) sample. Measured pH is around 7.9 in the mudline samples, and between 7.7 and 7.9 in the IW samples. PO_4^{3-} values vary, with no clear trends, ranging between 2.1–7.1 µM. Ammonium (NH_4^+) is higher in the mudline sample from Hole U1565A (41 mM) than in Hole U1565B (26 mM). Downcore NH_4^+ values show no trend, with values ranging between 32–69 mM (average 45 mM).

Elemental compositions of IW samples were analyzed by either ion chromatography (IC) or inductively coupled plasma–atomic emission spectrometry (ICP-AES). Mudline water compositions varied between the two holes, with most elements (Br^-, Cl^-, Mg, K, Na, and SO_4^{2-}) being more concentrated in Hole U1565B than in Hole U1565A. The exception is Ca, which displays the opposite trend, with higher values in the mudline of Hole U1565A. IW concentrations of Ca also display a decreasing trend downcore (from 10.4–11.7 mM), mirrored by increases in chloride (540–556 mM), bromide (0.82–0.84 mM) and Na (466–481 mM). Dissolved Mg, K and SO_4^{2-} concentrations are stable throughout. ICP-AES data show higher concentrations of most measured elements (K, Na, Fe, S, and Sr) in the mudline from Hole U1565B than in Hole U1565A, with some (Mn, P, and S) near-zero in Hole U1565A, but present in Hole U1565B. Many elements (B, Fe, Sr, P, and Na) show little or no trend downcore, while Ca and Si concentrations increase with depth. Mn and Fe increase in the middle two IW samples, before decreasing again by the base of the analyzed sediments. Only S shows a reverse trend, with decreasing concentrations downcore. Ba is below detection limits in all samples, and Fe is below detection level in two of the samples.

Total carbon, total inorganic carbon (TIC), calcium carbonate, total organic carbon (TOC), total nitrogen (TN), and sulfur were determined on six discrete sediment samples. Bulk sediment total carbon and TN were determined by elemental analysis, and TIC was determined by coulometer. TIC content ranges from 1.25 wt% in the upper section of the cored sediments (0.09–2.91 mbsf) to below 0.01 wt%, with an average value of 0.69 wt%. Assuming TIC is purely representative of $CaCO_3$, values range from <0.1 wt% to 10.4 wt%. Total carbon varies between 0.2–1.6 wt% (average 1.2 wt.%). TOC is between 0.17–0.63 wt% (average 0.33 wt%), with no clear trend downcore. TOC/TN ratios are between 3–25, with an average value of 9, representative of primarily marine organic matter. In all samples, H and S values are below detection limits.

Physical Properties

Physical properties data acquired at Site U1565 include density, magnetic susceptibility (MS), *P*-wave velocity, natural gamma ray (NGR), color reflectance, X-ray imaging, thermal conductivity, and spectral imaging. The gamma ray attenuation (GRA) bulk density varies from 1.4 g/cm^3 to 1.79 g/cm^3. Moisture and density (MAD) measurements collected for each section yielded very similar bulk density values (average 1.69 g/cm^3, n. 11) and measured grain density values vary from 2.63 to 2.79 g/cm^3 with an average of 2.72 g/cm^3. Porosities range from 9% to 67%, reflecting the sediment's uncompacted nature. The MS measured on the whole-round and split sections are very similar and range from ~34 to 90 units. An MS peak (566 units) occurring in Section U1565A-1R-1 correlates to a dropstone found in the core.

Thermal conductivity measured at 40 cm in Section U1565A-2R-1 yielded an average value of 1.42 W/(m·K). The NGR values for the sedimentary unit vary from 27.7 to 38.1 counts/s with an average of 33 counts/s. A MAD sample collected at 61 cm in Section 2R-1 yielded a bulk density of 1.78 g/cm^3, grain density of 2.7 g/cm^3, and porosity of 55%. The *P*-wave velocity measured at 60 cm in Section 2R-1 using the Gantry system resulted in 1530 m/s in the *x*-direction, and 1510 m/s in the *z*-direction.

Cores U1565A-3R and 4R penetrated granitic basement. Density of the hard rocks in these core sections is up to 2.275 g/cm^3, yielding an average corrected bulk density of 2.56 cm^3. MAD measurements revealed relatively high porosities in the granite cubes. The MS values in the hard rocks are significantly lower than those of the overlying sediments (ranging from 0 to 22 SI units).