IODP Expedition 341: Southern Alaska Margin

Site U1417 Summary

Background and Objectives

Site U1417 (proposed Site GOA18-2A) is located in the distal Surveyor Fan in the Gulf of Alaska. The area was originally drilled at Site 178 (~2 km from Site U1417) during Leg 18 of the Deep Sea Drilling Project with around 40% recovery, most of which was late Pleistocene in age. Site U1417 is ~60 km from the Surveyor Channel, which delivers sediment to this site via overbank processes. This site was chosen to provide a sedimentary record of Neogene glacial and tectonic processes occurring in the adjacent orogen. Drilling targets are three major regional seismic boundaries and associated seismic sequences. Sequences I (deepest) and II exhibit layered, laterally semi-continuous reflectors consistent with turbiditic deposition. Sequence III (shallowest) is thinly layered and contains reflectors that are laterally continuous, flatter, and smoother than those in the other sequences. The shallow primary target for Site U1417 is the Sequence III/II boundary, which is mappable throughout the Surveyor Fan and is proposed to represent an increase in sediment supply to the site as a result of an intensification of glaciation at the mid-Pleistocene transition (MPT). The deeper primary target is the Sequence II/I boundary, which is proposed to correspond to the onset of tidewater glaciation, and start of Surveyor Fan deposition in the late Miocene. All of Sequences II and III are estimated to correspond with the Neogene and would include early tectonic uplift of the St. Elias orogen within the Miocene, pre-glacial to glacial conditions from the late Miocene to Pleistocene including the initiation of the northern Cordilleran ice sheet (NCIS) and the intensification of Northern Hemisphere glaciation, and the potential intensification of glacial extent following the MPT. These sequences may also contain a provenance record reflecting the locus of sediment created during the exhumation and uplift of the St. Elias Mountains.

Principal Results

At Site U1417, Holes U1417A–U1417E were drilled to total depths of 168.0, 358.8, 225.0, 470.3 mbsf, and 709.5 m CSF-A, respectively. In Hole U1417A, only the 9.5 m-long (full) APC system was used. In Holes U1417B–U1417D, both the full and the half APC (4.7-m long) coring system were used to refusal. Following refusal of the half APC system, the XCB system was used in Hole U1417B to 358.8 m CSF-A and to 470.3 m CSF-A in Hole U1417D. In Hole U1417E, the RCB system was used to interval core from 264 to 302.2 m CSF-A and to continuously core from 399.0 to 709.5 m CSF-A. A total of 198 cores were recovered for the site. A total of 811.18 m of core over an 836.5 m interval were recovered using the APC system (97% recovery). The cored interval with the XCB system was 381.8 m with a recovery of 140.77 m of core (37%). The cored interval with the RCB system was 348.7 m with a recovery of 146.92 m of core (42%). The overall recovery percentage for Site U1417 was 70%.

Real-time stratigraphic correlation at Site U1417 was achievable because of the presence of high-amplitude signals in the physical property data. The depths of the cores acquired from each hole (m CSF-A) cannot be directly correlated without this step. Thus a composite depth scale at Site U1417 was constructed from 0.0–750.82 m CCSF-A with data from all holes and includes core expansion. A splice was chosen that consists of one complete and continuous interval from the mudline to 220.4 m CCSF-D. The composite depth scale (CCSF-A scale) and the splice (CCSF-D scale) are based primarily on the stratigraphic correlation of whole-round magnetic susceptibility, GRA density, natural gamma radiation, split-core color reflectance, and digital line-scan images. Of these variables, magnetic susceptibility and gamma density offered the most reliable tools for correlation at Site U1417; the other variables served primarily as verification data. Finally, an additional depth scale (CCSF-B) was created to compress and shift the correlated cores back into the correct total drilled interval (~708 m) and most results are reported in this depth corrected, composite depth scale.

The sedimentary succession cored at Site U1417 extends from the Miocene to Holocene. Mud with varying amounts of biogenic and coarser facies is the dominant lithology observed throughout all holes at Site U1417. There are noticeable variations in the amount of biogenic components, ash, lonestones, diamicts, and interbedded mud/sand and mud/silt lithologies. The sediment recovered at Site U1417 contains twelve lithofacies that are identified based on variations in the amount of mud, silt, and sand, the style of interbedding of lithologies, and abundances of ash, lonestones, diamict, and biosiliceous material. Based on characteristic facies associations, five major lithostratigraphic units and 12 subunits have been defined. The contacts between lithostratigraphic units at Site U1417 are usually gradational.

Lithostratigraphic Unit 1 is denoted by dark gray mud with subordinate thin interbeds of volcanic ash and varying amount of biosiliceous material. Dispersed granule to pebble-size lonestones (outsized clasts) commonly occur through the unit. Lithostratigraphic Unit 2 contains gray to greenish-gray mud with distinct thin interbeds of fine sand and coarse silt beds commonly having sharp lower contacts and are massive to normally graded. Lithostratigraphic Unit 3 contains clast-poor and clast-rich diamict interbedded with bioturbated gray mud. Lithostratigraphic Unit 4 consists of dark gray to greenish, well-indurated mud lacking lonestones that is commonly highly bioturbated with common *Zoophycos* trace fossils. Diatom bearing intervals are common in the mud, and fine sand beds are rare. Unit 5, subdivided into ten subunits, is composed of dark gray, moderately bioturbated diatom-rich mud, that is often color-banded, with interbeds of diamict and sand, and thick intervals of diatom ooze. The subunits are identified based on the relative abundance of diamict versus diatom ooze intervals. Poorly sorted clast-rich diamict beds have sharp lower contacts and gradational upper contacts. Diamict beds contain subrounded to rounded mud clasts and some beds contain plant debris. Clast-poor to clast-rich diamict beds have sharp contacts and are dominated by angular black granules of shale and possibly coal (60% total organic carbon). Carbonate-cemented siltstone and sandstone beds are occasionally recovered. Bioturbation in the subunits of diatom ooze is absent to heavy and includes *Zoophycos* trace fossils.

The biostratigraphy of radiolarians, diatoms, and planktic and benthic foraminifera indicate that the sediment intervals recovered at Site U1417 are late Pleistocene to Miocene in age. The preservation and abundance of all fossil groups vary downhole. For the upper 50 m CCSF-B, both calcareous and siliceous microfossil groups are preserved and vary from poor to good in preservation. From 50–200 m CCSF-B, siliceous microfossils are preserved. Planktic foraminifera are also preserved, however, some barren intervals are observed, while benthic foraminifera are poor to absent. From 200–280 m CCSF-B, calcareous microfossils are more consistently observed while siliceous microfossils are nearly absent. Calcareous microfossils are rarely observed from 300–450 m CCSF-B, due to limitations of disaggregation, and no samples were analyzed in Hole U1417E due to induration. From 300–450 m CCSF-B some siliceous microfossils are observed. Between 450–600 m CCSF-B, siliceous microfossils are largely absent and rare abundances are observed from 600–708 m CCSF-B. Diatom biozones are constrained above 200 m CCSF-B and indicate an age of Pleistocene. Radiolaria datums are constrained above 250 m CCSF-B and include Pleistocene to late Pliocene fauna. A second zone of good age constraint occurred from 325–425 m CCSF-B and included microfossils that are Pliocene in age. Below 600 m CCSF-B there are rare occurrences of datum species that are Miocene in age. Planktic foraminifera coiling directions and subarctic radiolarian taxa abundances indicate cooler conditions from 0–250 m CCSF-B, within the Pleistocene, than deeper in the Site. Cool, temperate radiolarian taxa are present throughout the record but have higher relative abundance in the Pliocene and Miocene. Rare occurrences of coastal diatoms, diatom-resting spores, and shallow water benthic foraminifera indicate at least some component of the sediments are derived from shelfal to coastal depths.

The Brunhes/Matuyama boundary and the upper Matuyama Chronozones containing the Jaramillo (1r.1n) Subchronozone are clearly identified. Two short intervals of normal polarity are observed below the Jaramillo Subchronozone with the older of the two tentatively interpreted as the Cobb Mountain Subchronozone. The Gauss (2An) to Matuyama (2r) polarity transition is clearly and reproducibly observed between Holes. Below this depth, however, variable polarity interpretations can be made for the base of the Gauss (2An) and the normal the normal polarity subchrons of the Gilbert (2Ar). A tentative correlation to the oldest of these subchrons (Thvera, 3n.4n) is made. This interval is underlain by extended recovery of material with reversed polarity consistent with the lower part of the Gilbert Chronozone. Below 500 m CCSF-B the inclination data are derived from a single Hole (U1417E) and therefore caution must be employed with any polarity interpretation made. Using the smoothed and expanded inclination record an interpretation is made that is generally consistent with the biostratigraphic datums down to a depth of ~600 m CCSF-B. Below 600 m CCSF-B the placement of polarity boundaries is equivocal.

All the available paleomagnetic and biostratigraphic age datums were integrated to construct minimum and maximum preliminary shipboard age models, which together span most of the uncertainty in the datums based on shipboard work. Based on these initial age models, sediment accumulation rates increase through time, peaking at values of about ~110 m/Ma in the interval 0–2.5 Ma.

The physical property data collected for Site U1417 includes routine runs on the multi-sensor logger tracks for all of the Holes and discrete sampling on Holes U1417A, U1417D, and U1417E. Track-based bulk density and *P*-wave velocity recorded to ~220 m CCSF-B generally increase with depth from 1.5–2.0 g/cm^3 and ~1500–1600 m/s average, respectively. Discrete values are similar for the overlapping depths and then show ranges from 2.0–2.1 g/cm^3 and ~1600 to over 1800 m/s, respectively. Below ~420 m CCSF-B, isolated elevated velocities (~2420–5700 m/s) are correlated to cemented intervals, while lower values (<1650 m/s) are associated with diatom oozes. Natural gamma ray (NGR) values gradually increase down hole between 0–220 m CCSF-B in Holes U1417A–U1417D, interrupted by a short-term decrease in counts between 220–360 m CCSF-B, and partially recovering to higher values below 360 m CCSF-B. Low NGR counts below 220 m CCSF-B may partly be attributed to the smaller-diameter of recovered core and/or section voids during XCB coring. The track GRA and magnetic susceptibility (MS) measurements were normalized using the MS point source measurement. These normalizations reduced ~50% of the variance in the XCB/RCB sections, showing that these measurements are affected by core section recovery volume. However, the decrease in NGR observed between 225–360 m CCSF-B persists in a reduced form below 300 m CCSF-B and we propose that the lower volume-normalized NGR values between 300–360 CCSF-B correspond to a lithology change in the late Pliocene. Discrete moisture and density (MAD) samples indicate that this interval is a zone of low density/high porosity values. There is close agreement between bulk density derived from GRA and MAD. Shear strength increases with depth with a change in slope at ~40 m, with greater variance in the data below 100 m CCSF-B.

Routine headspace gas analyses were carried out on samples from Holes U1417A, U1417B, U1417D, and U1417E, and 196 samples were taken for analyses of carbonate, carbon, and nitrogen content. Furthermore, 78 interstitial water samples were taken for porewater characterization. Solid phase geochemical results indicate that Site U1417 is a typical oligotrophic, deep-water, sub-Arctic setting with low

TOC (generally 0.1–0.6 wt%), TN (0–0.3 wt%) and carbonate content (0–1.5 wt%). Notable higher deviation of these values occurred in specific lithologies (e.g., diatom oozes, diamicts, and cemented siltstones of Lithostratigraphic Unit 5). The strongest organic matter remineralization, as indicated by the ammonium and alkalinity profiles, occurs in the upper ~40 m CCSF-B, and at ~375 m CCSF-B. Total sulfate depletion is reached around 200 m CCSF-B, apparently linked to authigenic carbonate formation consuming dissolved magnesium and alkalinity. Methane was by far the dominant hydrocarbon gas detected, and its concentration was generally very low. However, it varied by several orders of magnitude at the Site (maximum concentration: 5117 ppmv at ~500 m CCSF-B), and methane production was restricted to an interval between 420 and 650 m CCSF-B. An up-core decrease in methane concentration is not related to anaerobic methane oxidation in a sulfate-methane transition. However, a deep sulfate-methane transition exists at the bottom of the methanogenic zone around 650 m CCSF-B, with sulfate likely provided from a deep aquifer at the basement-sediment contact. Chlorinity and sodium concentrations are elevated from 10–60 m CCSF-B. Barite is dissolved in a sulfate-depleted zone below 200 m CCSF-B, and possibly re-precipitates as authigenic barite upon contact with sulfate-containing pore waters. Down-core calcium and lithium increases may indicate significant leaching of underlying oceanic basalt by seawater, probably infiltrated through adjacent faults.

Downhole logging measurements in Hole U1417E were made after completion of RCB coring to a total depth of 709.5 m DSF (drilling depth below seafloor). Four tool strings were deployed in the following order: the Triple Combo, the FMS-Sonic, the MSS tool string, and the VSI tool string. The borehole was variable in diameter, ranging from the maximum extent of the logging tools calipers (18 inches) to as small as <5 inches. The logging data were affected by the rugosity of the borehole wall, particularly in the interval between 87 and 305 m WSF (wireline depth below seafloor). Despite the rugose borehole, adequate travel times were recorded at one depth station during the VSP. Based on hole condition and characteristic trends and features in the data, two distinct logging units were identified for Hole U1417E. Logging Unit 1 is defined primarily by highly variable borehole diameter. Within this unit, gamma ray, magnetic susceptibility, and compressional wave velocity (Vp) logs are the most robust to borehole conditions. Logging Unit 2 (305 to 624 m WMSF) is characterized by improved borehole conditions and the quality of the logging data is higher throughout this unit. It can be subdivided into two subunits. Subunit 2A (305 to 476 m WMSF) shows elevated gamma ray, density, and velocity values relative to the unit above. Magnetic susceptibility (MS) shows higher amplitude variability and co-varies with gamma ray. Subunit 2B (476 to 624 m WMSF) is distinguished by an initial, rapid decrease in density, resistivity, and velocity with depth, followed by general increases. Magnetic susceptibility (MS) displays lower signal in this subunit. Together, these data indicate that downhole logs are likely responding to variations in lithology.

Core-downhole logging integration for Site U1417 included comparing lithostratigraphic unit boundaries, core recovery, the distribution of clast-rich and clast-poor diamicts, sand units, and MS measurements made in the borehole and on cores. In general, logged and whole core MS exhibit similar trends and variability when compared over the same measured interval. We observe that transitions between intervals of high and low MS in the log data correspond to several lithostratigraphic boundaries in the core. Shipboard correlations of downhole logging data with core-based physical properties measurements focused on the depth interval from ~305 to 615 m CCSF-B/WMSF, where borehole condition is best and thus the logging data is of higher quality. The natural gamma ray log shows good agreement with the core NGR to within a few meters; in a new technique, the latter of these measurements has been corrected for volume using gamma ray attenuation density (GRA). The bulk density data also show a variable agreement between log, track measurements of core, and discrete core samples. The downhole density log values generally correspond to the higher end in the range of GRA values. Discrete MAD measurements overlap with the density log, showing a similar range in values. Discrete *P*-wave velocity measurements on core show good correspondence with the *P*-wave velocity (Vp) log down to ~430 m CCSF-B/WMSF. Below this depth, the Vp log shows generally higher velocities than the discrete core data.

Seismic lines LOS-01 (MGL1109MSC01) and LOS-14 (MGL1109MSC14), acquired in 2011 aboard the R/V *Marcus Langseth,* cross the U1417 primary site. In preparation for core-log-seismic integration, Seismic Sequence I was divided into 3 subsections, IA, IB, and IC. Subsection IC was further subdivided into intervals IC1 and IC2. Two checkshots at ~211 m WMSF correlate to the seismic data at 5.87 s twtt within Seismic Sequence II, allowing some confidence for integration above this depth. Sequence III is characterized by smooth, continuous reflectors and limited seismic transparency. Based on a preliminary travel time-depth relationship, Seismic Sequence III corresponds with dark gray mud with thin beds of volcanic ash (Lithostratigraphic Unit IA) and gray mud with thin beds of volcanic ash and diatom ooze (Unit IB). Smooth, continuous reflectors that are semi-transparent in the seismic profile characterize seismic Sequence II. Based on our correlations this, Sequence II corresponds with lithostratigraphic units consisting of a gray mud with 1–5 cm thick interbeds of fine sand and coarse silt (Unit II), and thick beds of clast-poor and clast-rich diamict interbedded with gray mud (Unit III), and a highly bioturbated gray mud with diatom bearing intervals (Unit IV). The Lithostratigraphic Units III and IV correlate generally to the region of the Seismic Sequence II–I boundary, which is located at the top of a prominent grouping of high-amplitude reflectors. Lithostratigraphic Unit IV–V boundary lies near the top or within these reflectors and represents a change from to highly bioturbated gray mud with diatom bearing intervals (Unit IV) to gray mud with sandy diamict, interbedded silt and sand, and diatom ooze (Unit V). Due to the lack of checkshots deeper in the borehole, precise correlation between and within Seismic Sequence I, Lithologic Units IV and V, and Logging Unit 2 will need to be undertaken post-cruise.

Highlights

Expedition 341, Site U1417 in the distal Surveyor Fan provides a, ~700 m thick, high-recovery record of Miocene–Pleistocene changes in sediment flux, lithology, and transport/depositional processes. This distal site records the terrigenous flux from the Yakutat Terrane collision/subduction and a late Neogene reorganization of depositional processes to channel-overbank deposition within Fan coincident with the appearance of ice-rafted debris. Chronology for this distal record comes from biostratigraphic datums and high-quality paleomagnetic stratigraphy to assemble an integrated age model. Establishment of a spliced record from the mudline to 220.4 m CCSF-D provides a unique opportunity to describe depositional changes in the northeast Pacific during the mid-Pleistocene climate transition. Variable preservation of biogenic-rich intervals during the Neoegene suggests that the modern high-nutrient low chlorophyll Gulf of Alaska has experienced episodic periods of enhanced productivity. Detailed study of these sediments, logs and correlation with the regional seismic data should provide a significant increase in our understanding of the interplay between tectonics and climate as recorded in the distal part of a glaciated, orogenic system.