IODP Expedition 341: Southern Alaska Margin

Site U1418 Summary

Background and Objectives

Site U1418 (proposed Site GOA16-1A) is located at 3667 m water depth on a slightly elevated region of the proximal Surveyor Fan. It is located between a modern channel that feeds into the Aleutian Trench, here referred to as the Aleutian Trench Channel, and a wide channel-like feature, termed the Bering Channel, that appears to be inactive but likely terminated into the Trench when active. These two channels appear to originate at the base of the slope seaward of the continental shelf break between Bering Trough and the Pamplona zone. This Site also lies below the westward flowing Alaska Current, a boundary current within the Alaska Gyre that commonly contains eddies and meanders and seasonally high productivity is often associated with these eddies. The Site likely has been supplied with sediment from hemipelagic settling and/or gravity flows through these adjacent channels, creating a thick (~1 km) seismically stratified deposit. A large deposit of chaotic seismic facies interpreted as a mass transport deposit (MTD) is found below these stratified units. The top of the MTD forms a seismic reflector that can be mapped to Site U1417 (Surveyor Fan Sequence II–III boundary), where the reflector is ~0.9–1.2 Ma in age based on magnetostratigraphy at that site. Consequently, the depocenter at Site U1418 may contain an expanded mid-late Pleistocene sedimentary sequence. Near-horizontal reflectors of varying intensity are mappable over tens of kilometers, implying deposition from suspension and/or overbank flow from turbidity currents. The uppermost stratified seismic units are classified as subunits that are expected to be time-correlative with Sequence III at Site U1417, with the lowermost chaotic unit (Seismic Unit II*) interpreted as a mass transport deposit (MTD). These Seismic Unit boundaries are therefore primary targets while drilling to the base of Sequence III and the top of the Seismic Sequence II*. The drilling objectives at the Site are to develop a high temporal resolution, proximal sedimentary record of mid-late Pleistocene glacial-interglacial dynamics, fan sedimentation and development, and paleoceanography. A primary objective of drilling at Site U1418 is to constrain the timing of glacial events of the Pacific side of the northern Cordilleran ice sheet (NCIS) as reflected in ice rafting, gravity flow processes and proximal fan strata formation. The observation of an abandoned and buried Bering Channel above the

MTD suggests that it formed subsequent to the MTD, perhaps as a consequence of mid-late Pleistocene changes in glacigenic sediment delivery. An expanded Pleistocene record of glacigenic sediment deposition also allows for the documentation of the spatial and temporal behavior of the geomagnetic field (paleointensity and paleomagnetic secular variation) during this time period in an under-sampled region of the globe.

Principal Results

At Site U1418, Holes U1418A–U1418F were drilled to total depths of 209.9, 17.0, 230.7, 305.8, 181.6, and 948.7 m CSF-A, respectively. In Holes U1418A–U1418D, both the full-length (9.5-m long) and the half-length APC (4.7-m long) coring system were used to refusal. The full-length APC system was used in Hole U1418E, and the RCB system was used in Hole U1418F. Cores from Hole U1418B were collected to cover the sediment section that was disturbed in the first two cores from Hole U1418A. Following a drilled interval to 78 m CSF-A, cores were collected from Hole U1418E to fill in gaps identified by stratigraphic correlation. Following refusal of the half-length APC system, the XCB system was used in Hole U1418D to 305.8 m CSF-A, after which the hole was terminated because of mechanical cutting shoe failure during XCB operations. In Hole U1418F, the RCB system was used to drill down to 260.0 m CSF-A, and continuously core to 948.7 m CSF-A. A total of 185 cores were recovered for the site. A total of 819.08 m of core over an 810.0 m interval was recovered using the APC systems (101% recovery). The cored interval with the XCB system was 48.5 m with a recovery of 22.8 m of core (47%). The cored interval with the RCB system was 688.7 m with a recovery of 498.2 m of core (72%). The overall recovery for Site U1418 was 86%.

Real-time stratigraphic correlation at Site U1418 was achievable because of the presence of strong signals in the physical property data. A composite depth scale at Site U1418 was constructed from 0.0–948.7 m CCSF-A with data from all holes and includes core expansion. A splice was chosen that results in one complete and continuous interval from the mudline to 271.4 m CCSF-D. Below that depth, intervals of correlation were found between holes, but were not considered sufficiently continuous to warrant development of a deeper “floating” shipboard splice. The composite depth scale (CCSF-A scale) and the splice (CCSF-D scale) are based primarily on the stratigraphic correlation of the whole-round magnetic susceptibility, GRA density, natural gamma radiation, and color reflectance data. As with Site U1417, an additional depth scale (CCSF-B) was created to compress and shift the correlated cores back to produce the correct total drilled interval and most results are reported in this depth-corrected, composite depth scale.

The sediment recovered at Site U1418 spans the early Pleistocene to the Holocene. Mud and interbedded mud and silt account for over 90% of the core recovered, but the remaining minor facies are distinctive and allow for organization into lithostratigraphic units. Lithofacies include massive mud with and without lonestones, laminated mud, silt, interbedded silt and mud, sand, muddy diamict, interbedded mud and diamict, diatom ooze, biosiliceous ooze to bearing, calcareous/carbonate bearing mud, volcanic ash, volcaniclastic mud and sand, sedimentary rock, and intrastratal contorted mud with diamict. These facies reflect deposition from suspension fall out, sediment gravity flows, large-scale mass wasting, ice rafting, variation in marine primary productivity, and volcanic eruptions. Based on facies associations, four major lithostratigraphic units, numbered I to IV, have been defined. Unit II is further subdivided into subunits A–D based on the characteristics of diamict intervals. The contacts between lithostratigraphic units at Site U1418 are usually gradational.

Unit I is a dark gray to dark greenish gray mud with interbedded silt that alternates with intervals of up to 15.5 m thick of color-banded dark gray mud. Bioturbation is mostly absent or slight, except in diatom ooze and diatom-bearing to diatom-rich mud, which has greater bioturbation intensity and black mottling occurs within numerous cores. Graded sand beds with sharp lower contacts, as well as ash beds and volcaniclastic-bearing to volcaniclastic-rich mud occur irregularly. Lonestones appear below approximately 3 m CSF-A. Unit II extends over 546 m and is dominated by mud with clast concentrations ranging from dispersed to abundant and interbedded with intervals of clast-poor diamict that range in thickness from a few centimeters to over one meter. Unit II is divided into four subunits based on the relative thickness and occurrence of the diamict facies within the mud facies. Subunits IIA and IIC are dark gray to dark greenish gray muddy clast-poor diamict interbedded with dark gray mud and/or mud with dispersed clasts. The mud is diffusely laminated and coarse sand, granules, and lonestones of variable composition are present within both the diamict and mud. Subunits IIB and IID are dark gray to dark greenish gray laminated mud that is interbedded with mud with dispersed clasts and clast-poor diamict. Some intervals are calcareous bearing, and volcanic ash is observed as burrow fills and in dispersed intervals of moderate to heavy bioturbation. Lonestones were observed throughout. Unit III is composed of laminated and bioturbated dark gray mud with thinly bedded, very dark calcareous-cemented gray sandstone and siltstone that are minor but distinctive components. Clast-rich muddy diamict containing rip-up clasts was deposited near the base of the unit. A small number of lonestones occur throughout this unit. Microfossils and ash are also rare. Unit IV is a very dark greenish gray mud mixed with a very dark gray clast-rich muddy diamict. Both facies are characterized by soft sediment deformation and intrastratal contortions. There is a range of soft sediment deformation fabrics and normal faults are common in this unit.

Based on the downcore occurrence of microfossils at Site U1418, three distinct intervals were identified. Occurrence of a rich siliceous and calcareous community is observed in the upper 200 m CCSF-B. Between 200 to 600 m CCSF-B, calcareous microfossils are consistently preserved, while numerous intervals are barren of siliceous microfossils. Below 600 m CCSF-B, sediments are mostly barren of siliceous microfossils, while the more consistent occurrence of planktic and benthic foraminifera suggests that calcareous productivity persisted. The rare occurrence of diatoms and radiolarians below 200 m CCSF-B impeded identification of reliable biostratigraphic datums below this depth. The oldest datum encountered is the last occurrence of the planktic foraminifer *Neogloboquadrina inglei*, which suggests sediments around 600 m CCSF-B are older than 0.7 Ma. Strong variations in environmentally sensitive planktic foraminifera and radiolarians record the alternation of warming and cooling intervals during the last 1.2 Ma, and variable bottom water oxygenation are suggested by species changes in the benthic foraminifera. Variations in diatom abundance and changes in species composition indicate changes in paleoproductivity, transport from shallow coastal waters and a period of sea ice influence over Site U1418.

The natural remanent magnetization (NRM) intensities of the all cored material were strong before and after demagnetization. Intensities show variability at both the meter and 10s of meter scale. Inclinations of the RCB sections reveal an almost continuous sequence allowing correlation to the geomagnetic polarity timescale. A clear Brunhes/Matuyama polarity transition is present between ~640–660 m CSF-A with some of the transition recovered. The polarity transitions into and out of the Jaramillo (1r.1n) Subchronozone are clearly observed. Two short intervals of normal polarity are observed below the Jaramillo Subchronozone with the older possibly indicating the Cobb Mountain Subchronozone (C1r.2n); this interpretation is consistent with the biostratigraphic datums.

All the available paleomagnetic and biostratigraphic age datums were integrated to construct minimum and maximum preliminary shipboard age models that together span most of the uncertainty in the shipboard datums. The shipboard minimum and maximum age models are calculated in increments of 0.2 Ma, between 0 and 1.2 Ma. Sediment accumulation rates in the past 0.2 Ma are 1.2 to 1.5 m/ka, and are on average a bit lower, ~0.7 m/ka (±0.5 m/ka uncertainty) over the interval 0.2–1.0 Ma. At ages ~1.0–1.2 Ma, paleomagnetic constraints suggest even lower sediment accumulation rates of 0.4 ± 0.3 m/ka.

The physical property data collected for Site U1418 includes routine runs on the multi-sensor logger tracks for all Holes and discrete sampling on Holes U1418A, U1418B, U1418D, and U1418F. Whole-round GRA density averages ~1.96 g/cm^3 in the APC cores, and displays down-hole cyclic variability on the order of ~0.4 g/cm^3, abruptly decreasing at ~220 m CCSF-B corresponding to the transition to XCB coring. Whole-round GRA density from XCB/RCB cores averages ~1.9 g/cm^3 but fluctuates with depth. Volume-corrected mass, or specific, magnetic susceptibility (χ) averages around ~50 cm^3/g down-hole at the site. A high-amplitude cyclic variability between 60–120 cm^3/g is present in the core above ~220 m CCSF-B, transitioning to reduced variability centered at ~40 cm^3/g in the deeper sections. A return to MS of above 60 cm^3/g below 810 m CCSF-B may reflect the transition to Lithostratigraphic Units III and IV. Between ~110–180 m CSF-A, gas expansion prevented compressional wave (*P*-wave) measurement on the PWL. Reasonable measurements of *P*-wave velocity on the PWL could not be obtained below ~200 m CSF-A because of void spaces within the core liners associated with XCB coring in Hole U1418D. Whole-round *P*-wave velocity values gradually increase downhole, closely following GRA densities, ranging from ~1450 m/s at the sea floor to up to ~1650 m/s at ~200 m CSF-A. *P*-

wave caliper tool values show significant scatter from ~100–200 m CCSF-B depth, likely due to the presence of methane gas within the cores. Below ~200–700 m CCSF-B, velocities are as high as ~1700 m/s, increasing abruptly at ~700 m CCSF-B to ~1750 m/s and again at ~800 m CCSF-B to >1800 m/s after which velocities begin to increase at a faster rate, reaching ~2100 m/s by ~908 m CCSF-B. Natural gamma-ray values fluctuate between 16 and 45 counts per second, and high-frequency variations are likely coupled with changes in clay lithologies, and consequently parallel trends in GRA bulk density and *P*-wave velocity from the track measurements, particularly above 230 m CCSF-B. A transition to lower volume-normalized NGR values below 810 m CCSF-B corresponds to Lithostratigraphic Units III and IV. Shear strength increases at a near-constant rate down hole, and ranges from very soft (0–20 kPa) to very stiff (120–180 kPa). Values drop slightly below the trend between ~100 m and ~130 m CCSF-B, in the interval with high methane gas levels.

Routine headspace gas analyses were carried out on samples from Holes U1418A, U1418C, U1418D and U1418F, and 117 samples were analyzed for carbonate, carbon and nitrogen. A total of 105 interstitial water samples were taken for pore water characterization. Solid phase geochemical results characterize Site U1418 as an oligotrophic, deep-water, sub-Arctic setting. Although both total organic carbon (TOC) (0.2–1.0 wt%) and total nitrogen (TN) (0–0.1 wt%) contents are low, their respective accumulation rates are higher than at Site U1417 due to increased sedimentation rates at Site U1418. The carbonate contents are also low (0–5 wt%), but slightly higher than Site U1417, and anti-correlated with TOC content. Similar to Site U1417, chlorinity, sodium, bromide and salinity are elevated in the uppermost 30 m CCSF-B. Higher organic matter accumulation rates at Site U1418 are reflected in the more pronounced diagenetic processes occurring here in comparison to Site U1417. Strong organic matter remineralization occurs at ~30 m CCSF-B, 70 m CCSF-B, and 150 m CCSF-B, as indicated by the ammonium, alkalinity, and methane profiles. Based on the composition of interstitial waters, Site U1418 can be broadly sub-divided into two biogeochemical zones, one reaching from the seafloor to ~70 m CCSF-B (suboxic-anoxic diagenesis), and the other reaching from ~70 m CCSF-B to the bottom of the cored section (methanogenesis). Thus, Site U1418 documents a classic catabolic reaction sequence including the reduction of manganese, iron, sulfate, and methanogenesis. Sulfate depletion is reached at ~76 m CCSF-B, and methane increases from ~80 m CCSF-B (ranging from 5,000 to 63,000 ppmv), marking a distinct sulfate-methane transition zone. Elevated ammonium and alkalinity around 500–600 m CCSF-B indicate organic matter degradation by methanogenesis, probably related to labile marine organic matter availability.

Logging at Site U1418 was done in Hole U1418F and consisted of successful triple combo logs, without the porosity sonde, above 600 m and FMS/sonic logs above 582 m WSF. The downhole-logged interval in Hole U1418F was assigned to one logging unit because the character of the logs changes gradually downhole with no major steps in the base levels. At the scale of this unit, the natural gamma radiation signal ranges on average from 35 to 55 gAPI units, with the exception of anomalously low values corresponding to washed-out intervals. The natural radiation signal is generally dominated by potassium and thorium content, with uranium contributing in minor way. For the most part, the three radioactive elements co-vary, suggesting that they are mainly responding to clay mineralogy or content. Density measurements do not show specific characteristics in the logged interval. Resistivity data reveal a slight decrease with depth over the logged interval, which is counter to the expected increasing trend with depth due to compaction; however, lower mean values below 462 m WMSF may simply be a response to the wider borehole diameter in this interval. Magnetic susceptibility data vary around a relatively consistent mean value downhole and velocity measurements have a generally increasing trend with depth.

Sediment core descriptions, whole core physical properties measurements, and downhole logging data obtained from Site U1418 were combined in order to examine the coherence between the different data sets and evaluate the completeness of the recovered sediment record. High and low magnetic susceptibility measurements derived from the sediment core correlate with intervals of high and low MS values in the logging data. At a finer scale (less than 10 meters), we observe high MS in the logging data associated with diamict and sand layers, while low values are observed to occur in intervals with diatom ooze, mud with laminations, and bioturbated mud. With the exception of the washed-out sections, the natural gamma ray log shows reasonable agreement with the volume-corrected core NGR, with a similar range in values and similar features occurring within a few meters offset in depth.

Correspondence was also noted between the lithologic units, the distribution of diatom ooze and mud with clasts, and downhole changes in variables calculated from spectral gamma ray and total gamma ray. The bulk density log is strongly affected by the irregular borehole size throughout much of the borehole, giving density values close to water density in washed-out intervals. However, the highest downhole density values show reasonable correspondence with maximum density values in the range of the GRA data, and show good agreement with the trends in discrete moisture and density (MAD) measurements. The *P*-wave velocity log indicates higher formation velocities than discrete *P*-wave measurements on core over the logged interval. The separation in velocity estimations increases with depth downhole. The discrete measurements may be biased toward lower velocity matrix material, while the downhole log is integrating lower velocity matrix and higher velocity clasts, which were found to be a significant feature in all lithostratigraphic units described at this site. Alternatively, the presence of gas in the formation may also play a critical role, as even though gas would affect both core and downhole log measurements of velocity, gas expansion in cores may have caused cracking and the development of void spaces leading to poor contact with the instrument transducers and resulting in anomalously low velocities.

For preliminary correlation between lithostratigraphic units, logging units and features observed in the seismic data, lithostratigraphic and logging unit boundaries were converted from depth in meters (CCSF-B; for core data) or meters (WMSF; for logging data) to two-way travel time (twtt) using the average velocities of each unit. High-amplitude features within Seismic Unit IIIC could be associated with thick beds of mud separated by silt-rich intervals observed within Lithologic Unit I. The boundary between Seismic Units IIIB and IIIC at ~5260 ms twtt is located at the top of the youngest aggradational package that comprises the northwest flank of the Bering Channel. At Site U1418, this boundary marks a subtle down-section change from higher to lower amplitude horizons, which is clearly resolved on the high-resolution profile GOA-3202. Based on our traveltime-depth conversions, this boundary coincides with the boundary between Lithostratigraphic Units I and II at ~257 m CCSF-B. The boundary between Lithologic Units IIA and IIB (~335 m CCSF-B) correlates to a reflector that lies between two high-amplitude packages within Seismic Unit IIIB. The Seismic Unit IIIB–IIIA boundary correlates with the boundary between Logging Unit 1D and 1E at ~500–510 m WMSF. There is a decrease in both the density and velocity log values at this boundary. At the top of Seismic Unit IIIA, starting at ~5540 ms twtt, we observe both an increase in amplitude and a shift into slightly more chaotic facies. Below ~5750 ms twtt, the seismic reflections are less stratified and more heterogeneous. The strata here are no longer parallel and internal truncations and lobate geometry indicate either a more energetic depositional environment or structural deformation. Lithologic boundaries separating Units IIB, IIC, IID and III are all located within Seismic Unit IIIA. Seismic Unit II* is defined by chaotic seismic facies starting at ~5880 ms twtt. Some internal structure can be observed within the upper ~100 ms of Unit II*. The transition out of this structure into the non-coherent facies below may be equivalent to the Unit III–IV boundary and the transition into a mass transport deposit.