International Ocean Discovery Program
Expedition 379 Scientific Prospectus

Amundsen Sea West Antarctic Ice Sheet History: development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment

Karsten Gohl
Co-Chief Scientist
Department of Geosciences
Alfred Wegener Institute
Helmholtz-Center for Polar and Marine Research
Germany

Julia S. Wellner
Co-Chief Scientist
Department of Earth and Atmospheric Sciences
University of Houston
USA

Adam Klaus
Expedition Project Manager/Staff Scientist
International Ocean Discovery Program
Texas A&M University
USA

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Abstract

The West Antarctic Ice Sheet (WAIS) is largely marine based and thus highly sensitive to both climatic and oceanographic changes. Therefore, the WAIS has likely had a very dynamic history over the last several million years. A complete collapse of the WAIS would result in a global sea level rise of 3.3–4.3 m, yet the world's scientific community is not able to predict its future behavior. Moreover, knowledge about past behavior of the WAIS is poor, in particular during geological times with climatic conditions similar to those expected for the near and distant future. Reconstructions and quantifications of partial or complete WAIS collapses in the past are urgently needed for constraining and testing ice sheet models that aim to predict future WAIS behavior and the potential contribution of the WAIS to global sea level rise. Large uncertainties exist regarding the chronology, extent, rates, and spatial and temporal variability of past advances and retreats of the WAIS across the continental shelves. These uncertainties largely result from the fundamental lack of data from drill cores recovered proximal to the WAIS. The continental shelf and rise of the Amundsen Sea are prime targets for drilling because the records are expected to yield archives of pure WAIS dynamics unaffected by other ice sheets and the WAIS sector draining into the Amundsen Sea Embayment (ASE) currently experiences the largest ice loss in Antarctica (Paolo et al., 2015).

We propose a series of drill sites for the ASE shelf where seismic data reveal seaward-dipping sedimentary sequences that span from the preglacial depositional phase to the most recent glacial periods. Our strategy is to drill a transect from the oldest sequences close to the bedrock/basin boundary at the middle–inner shelf transition to the youngest sequences on the outer shelf in the eastern ASE. If the eastern ASE is inaccessible due to sea ice cover, a similar transect of sites can be drilled on the western ASE. The core transect will provide a detailed history of the glacial cycles in the Amundsen Sea region and allow comparison to the glacial history from the Ross Sea sector. In addition, deep-water sites on the continental rise of the Amundsen Sea are selected for recovering continuous records of glacially transported sediments and detailed archives of climatic and oceanographic changes throughout glacial–interglacial cycles. We will apply a broad suite of analytical techniques, including multiproxy analyses, to address our objectives of reconstructing the onset of glaciation in the greenhouse to icehouse transition, processes of dynamic ice sheet behavior during the Neogene and Quaternary, and ocean conditions associated with the glacial cycles.

The five principal objectives of Expedition 379 are as follows:

1. To reconstruct the glacial history of West Antarctica from the Paleogene to recent times and the dynamic behavior of the WAIS during the Neogene and Quaternary, especially possible partial or full WAIS collapses, and the WAIS contribution to past sea level changes. Emphasis is placed in particular on studying the response of the WAIS at times when the pCO_2 in Earth's atmosphere exceeded 400 ppm and atmospheric and oceanic temperatures were higher than at present.
2. To correlate the WAIS-proximal records of ice sheet dynamics in the Amundsen Sea with global records of ice volume changes and proxy records for air and seawater temperatures.
3. To study the relationship between incursions of warm Circumpolar Deep Water (CDW) onto the continental shelf of the Amundsen Sea Embayment and the stability of marine-based ice sheet margins under warm water conditions.
4. To reconstruct the processes of major WAIS advances onto the middle and outer shelf that are likely to have occurred since the middle Miocene and compare their timing and processes to those of other Antarctic continental shelves.
5. To identify the timing of the first ice sheet expansion onto the continental shelf of the ASE and its possible relationship to the uplift of Marie Byrd Land.

Schedule for Expedition 379

International Ocean Discovery Program (IODP) Expedition 379 is based on IODP drilling Proposal 839-Full and 839-Add (available at **http://iodp.tamu.edu/scienceops/expeditions/amundsen_sea_ice_sheet_history.html**). Following evaluation by the IODP Science Evaluation Panel, the expedition was scheduled for the research vessel (R/V) *JOIDES Resolution*, operating under contract with the JOIDES Resolution Science Operator (JRSO). At the time of publication of this Scientific Prospectus, the expedition is scheduled to start in Punta Arenas, Chile, on 18 January 2019 and to end in Punta Arenas, Chile, on 20 March 2019. A total of 56 days will be available for the transit, drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see **http://iodp.tamu.edu/scienceops**). Further details about the facilities aboard the *JOIDES Resolution* can be found at **http://iodp.tamu.edu/publicinfo/drillship.html**.

Introduction

For decades, the Amundsen Sea Embayment (ASE) drainage sector has been considered the most vulnerable part of the West Antarctic Ice Sheet (WAIS) because of the great water depth at the grounding line and the lack of substantial ice shelves (Hughes, 1981). Glaciers in this configuration are thought to be susceptible to rapid or runaway retreat (Schoof, 2007). Recent models suggest that a threshold leading to collapse of WAIS in this sector may have been passed already (Joughin et al., 2014) and that much of the ice sheet could be lost even under relatively moderate greenhouse gas emission scenarios (DeConto and Pollard, 2016). Model projections are limited by lack of constraints in several areas, most notably in a lack of detailed reconstructions about glacial history.

Drilling in the ASE will provide tests of several key questions about controls on ice sheet stability. First, it will offer a direct record of glacial history in a drainage basin that receives ice just from the WAIS, allowing clear comparisons between the WAIS history and low-latitude records. Ice draining into the ASE is grounded below sea level and thus allows a test of the marine ice sheet instability through correlation of the ice history to sea level changes. Although there is currently only a very small ice shelf in front of the grounding line today, the embayment has had ice shelves during some points of its history (Kirshner et al., 2012) that will allow examination of the grounding line history relative to the ice-shelf history. Today, warm Circumpolar Deep Water (CDW) is impinging onto the Amundsen Sea shelf, causing melting of the underside of the ice; reconstructions of past CDW intrusions (Hillenbrand et al., 2017; Minzoni et al., 2017) will assess the ties between warm water and large-scale changes in past grounding line positions. These tests will take place in the drainage basin that currently has the largest negative mass balance of ice of anywhere in Antarctica (Paolo et al., 2015) and is thus of prime interest to future predictions. Finally, this expedition will take place as part of a suite of Antarctic IODP expeditions, allowing large-scale reconstructions and comparisons between different drainage basins.

Background

The fourth assessment report of the Intergovernmental Panel on Climate Change [IPCC] (2007) highlighted the fact that the response of continental ice sheets to climatic changes and their contribution to global sea level change is the largest unknown variable in predicting future sea level change. The fifth and latest assessment report of the IPCC (2013) includes more information about the likely contributions to sea level change from the Antarctic, but it still remains one of the primary unknowns in predictions of future change. In addition, the 2013 IPCC assessment report emphasizes that if there is a substantial increase to the rate of sea level rise in the next century, it is likely to come from marine-based ice, like that in the ASE.

The WAIS rests on a continental shelf that typically deepens toward the interior of the Antarctic continent. This fore-deepened continental shelf, and thus the base of the ice, is largely below sea level. Therefore, the marine-based WAIS is sensitive to global sea level rise and regional oceanographic and atmospheric changes, and its history has been highly dynamic (e.g., Joughin and Alley, 2011). A complete WAIS collapse would raise the global sea level by 3.3–4.3 m (Fretwell et al., 2013), whereas the collapse of its Amundsen Sea drainage sector would raise the sea level by ~1.5 m (Vaughan, 2008). Over the most recent decades, glaciers draining into the ASE (Figure **F1**) thinned at an alarming rate, their flow speed dramatically increased, and their grounding lines retreated significantly, thereby contributing to present sea level rise at a faster rate than any other glacier on Earth (e.g., Joughin and Alley, 2011; Joughin et al., 2012; Paolo et al., 2015).

The present ice loss in the ASE is mainly attributed to sub–ice shelf melting induced by relatively warm CDW upwelling onto the shelf and spreading through deep bathymetric troughs toward the grounding zones (e.g., Joughin et al., 2012). It is unclear, however, whether the current ice loss results from ongoing deglaciation since the Last Glacial Maximum (LGM) (e.g., Bentley, 2010), recent climatic/oceanographic warming, or recent internal ice sheet dynamics (Joughin and Alley, 2011; Joughin et al., 2012). If the WAIS has undergone similar thinning and retreat in the past, the factors driving that retreat can be compared to modern conditions.

The reconstruction and quantification of WAIS collapses during the Neogene and Quaternary will provide constraints for ice sheet models predicting future WAIS behavior and resulting sea level rise. Numerous modeling studies have tried to link the waxing and waning of the WAIS to various forcing mechanisms (e.g., Pollard and DeConto, 2009; Holden et al., 2010; DeConto and Pollard, 2016; Sutter et al., 2016) (Figure **F2**). However, large uncertainties exist regarding the spatial and temporal variability of past ice sheet advance and retreat. These uncertainties are mainly caused by the lack of data from cores drilled proximal to the WAIS. The only existing drill cores along the Pacific Antarctic margin outside the Ross Sea are from Deep Sea Drilling Project (DSDP) Leg 35 in the Bellingshausen Sea (Hollister et al., 1976) and Ocean Drilling Program (ODP) Leg 178 on the Antarctic Peninsula margin (Barker et al., 2002). Results of Leg 178 Site 1097, drilled on the shelf, revealed a major late Miocene change in sequence geometry on the outer shelf, which may indicate a change in the typical extent of glacial advances, the dynamic behavior of ice streams, or glacial sediment transport (Barker et al., 2002; Bart et al., 2005; Larter et al., 1997). Scheuer et al. (2006a, 2006b) used this information by correlating seismic horizons to Leg 178 Sites 1095 and 1096 on the continental rise and interpreted transitions from preglacial to intermediate and full glacial conditions from the eastern Bellingshausen Sea to the Amundsen Sea.

The most detailed results on Neogene WAIS history stem from the Antarctic Geological Drilling (ANDRILL) project in the western Ross Sea, which recovered early Miocene (~20 Ma) to Quaternary sequences in Cores AND-1B (Naish et al., 2009) and AND-2A (Passchier et al., 2011). Pliocene data from Core AND-1B indicate that orbitally induced oscillations of the WAIS resulted in transitions from grounded ice and/or ice shelves to open-water conditions (Naish et al., 2009; McKay et al., 2012). However, previous seismic stratigraphic work on the Ross Sea shelf beyond Site AND-1B revealed only seven shelf-wide grounding events (Alonso et al., 1992). Given the location of Site AND-1B, which is subject to overriding from both the East Antarctic Ice Sheet (EAIS) and the WAIS, the ANDRILL results are likely not representative of the WAIS outlets in the Amundsen and Weddell Seas. Sedimentary records from the Ross Sea and the Weddell Sea provide only an integrated archive of WAIS and EAIS dynamics, whereas those from the ASE will provide a unique pure WAIS signal. Although the Filchner-Ronne Ice Shelf extends far into the southern Weddell Sea, making grounding line proximal positions difficult to access, only small and narrow ice shelves exist in the ASE today (Figure **F1**).

Oceanographic setting

Pine Island Bay and the ASE are characterized by persistent sea ice cover (e.g., Jacobs et al., 2012) that has decreased significantly in recent decades (Parkinson and Cavalieri, 2012). Water mass temperatures within Pine Island Bay typically range between −1.5° and 0°C. The exception to this is warm CDW, which can reach 3.5°C, that impinges onto the shelf through deep glacially carved troughs (Walker et al., 2007; Jacobs et al., 2011, 2013) and at times reaches into some of the smaller bays and fjords on the inner shelf (Minzoni et al., 2017). Productivity in the Amundsen Sea is among the highest in the Southern Ocean, with phytoplankton blooms related to sea ice polynyas (Arrigo et al., 2008; Minzoni et al., 2017). CDW is widely considered to be the main external driver of contemporary glacier retreat in the Amundsen Sea, and recent work has shown that it can vary on multidecadal to centennial timescales in response to wind stress at the continental shelf edge (Jenkins et al., 2016).

Geological setting

Constraints on past ice sheet dynamics and the main characteristics of the ASE continental shelf and rise (Figure **F1**), derived from geophysical and geological studies, are as follows:

- The 500–700 m deep shelf is incised by two major paleo–ice stream troughs (Pine Island and Dotson-Getz), whose tributaries originate from ice-stream/glacier fronts on the innermost ultradeep (as deep as 1600 m) shelf and converge at the transition from the inner to middle shelf. Both troughs extend toward the outer shelf, thereby becoming shallower and wider.
- The shelf geometry consists of a large pre- and synrift basin on the midshelf between basement cropping out on the inner shelf and buried basement highs on the outer shelf. A subordinate basin within the large midshelf basin may be associated with motion along an early West Antarctic Rift System (WARS) branch.

- At least 4 km of preglacial strata were eroded by ice from the present inner shelf and coastal hinterland. At least five major erosional unconformities indicate phases of significant WAIS advances.
- Prograding sequences and subglacial bedforms on the outer shelf, subglacial tills recovered in cores, and radiocarbon dates on calcareous microfossils and organic matter in overlying sediments indicate that ground ice expanded to the outer shelf during the LGM and earlier glacial periods.
- The continental rise is dominated by thick sedimentary deposition centers and by sediment drifts, which indicate strong bottom-current activity.

Seismic data analysis from the ASE rise reveals that sediment drift formation began in Eocene/Oligocene times (Uenzelmann-Neben and Gohl, 2012) (Figure F3). This observation indicates bottom current activity and hence a cold climate for the late Paleogene in the area, which today lies under the influence of Antarctic Bottom Water originating in the Ross Sea. The seismic records from the continental rise along the entire Marie Byrd Land margin mark the base of the sediment drifts throughout the Amundsen Sea and into the Ross Sea (Lindeque et al., 2016a, 2016b). These records provide insight into the sedimentation processes from preglacial to glacial times, variations in ocean-bottom circulation, early ice sheet growth, and intensification toward the present icehouse regime. However, this insight is hampered by vague stratigraphic age estimates only derived from long-distance seismic correlation to the Bellingshausen Sea and Ross Sea.

Seismic records from the ASE shelf (examples in Figure F4) show dipping strata of the midshelf that are possibly of Cretaceous to Miocene age and buried by aggradational, less consolidated strata of presumed Pliocene–Pleistocene age (Lowe and Anderson, 2002; Gohl et al., 2013b). Since the mid-Miocene, the outer shelf and slope have undergone first progradational and then aggradational deposition (Nitsche et al., 1997; Hochmuth and Gohl, 2013; Gohl et al., 2013b). Several unconformities, possibly indicating phases of subglacial erosion and ice advance, separate the dipping strata. Although most of the inner ASE shelf is void of major sedimentary cover (Gohl et al., 2013a, 2013b), a few small and shallow basins can be observed along its eastern border (Uenzelmann-Neben et al., 2007) and in front of Pine Island Glacier (Nitsche et al., 2013; Muto et al., 2016).

The eastern and western ASE shelves are separated by a bathymetric and structural high (Nitsche et al., 2007; Gohl et al., 2013b). Oceanward dipping midshelf strata north of outcropping basement can be observed in seismic data from the Dotson-Getz Trough (Wellner et al., 2001; Graham et al., 2009; Weigelt et al., 2009; Gohl et al., 2013b) (Figure F4) and exhibit alternating sequences of low and high reflectivity, which are interpreted as Miocene episodes of ice sheet advance and retreat. The glacial sequence stratigraphic model by Powell and Cooper (2002) proposes that glacial advances develop morainal banks consisting of unstratified diamictons, sands, and gravels, leading to a chaotic or semitransparent seismic reflection pattern. In contrast, stratified muds are deposited during glacial retreat, which is expressed in seismic profiles as a succession of closely spaced continuous reflectors. Boundaries between the acoustic units are sharp, but without drilling, the timing of ice sheet oscillations remains unconstrained. Similar seismic facies occur on the Ross Sea and Antarctic Peninsula shelves, where drill cores confirmed that the chaotic/transparent units correspond to massive diamictons whereas acoustically stratified seismic facies correspond to distal glaciomarine sediments (Anderson and Bartek, 1992; Bart and Anderson, 2000; Eyles et al., 2001).

The current seismostratigraphic model of the ASE shelf was developed by long-distance correlation of seismic data to those of the Ross Sea shelf which show striking similarities (Gohl et al., 2013b) (Figure F4). Adopting the ages of the seismostratigraphic units and unconformities on the Ross Sea shelf, which are relatively well constrained by DSDP Leg 28 and ANDRILL records (e.g., De Santis et al., 1999; McKay et al., 2009), the shelf basin formation model (Figure F5) for the ASE shows the development from a Cretaceous synrift basin to glacially dominated strata in the Neogene and Quaternary (Gohl et al., 2013b). The seismostratigraphic record from the ASE shelf is consistent with records from the Ross Sea (Bartek et al., 1991; Chow and Bart, 2003) and James Ross Basin in the northwestern Weddell Sea (Smith and Anderson, 2010), indicating a Miocene intensification of glaciation (De Santis et al., 1997) in accordance with findings from the Core AND-2A (Warny et al., 2009; Passchier et al., 2011) and the Shallow Scientific Drilling on The Antarctic Continental Margin (SHALDRIL)-II drill cores (Anderson et al., 2011; Anderson and Wellner, 2011).

Apart from ice sheet dynamics inferred from the geometries and acoustic facies of seismic reflections, the ice-drainage pattern in the ASE at the LGM and its substrate control were investigated by the analysis of sub- and proglacial bedforms visible in swath bathymetry surveys and acoustic subbottom profiler data (e.g., Larter et al., 2009). The subglacial bedforms on the shelf document that grounded ice expanded to the outer shelf or even the shelf edge during the recent past (Wellner et al., 2001; Lowe and Anderson, 2002; Graham et al., 2009, 2010; Jakobsson et al., 2012; Nitsche et al., 2013). The analysis of subglacial and glaciomarine sediments recovered in cores from the ASE shelf confirmed an LGM age for the last WAIS advance, allowed reconstructing its retreat history (Lowe and Anderson, 2002; Smith et al., 2011; Kirshner et al., 2012; Hillenbrand et al., 2013a), and indicated dynamically evolving drainage systems (Ehrmann et al., 2011). Recently, studies analyzing benthic foraminiferal assemblages (Minzoni et al., 2017) and the chemical composition (i.e., stable carbon isotopes and magnesium/calcium ratios) of benthic and planktic foraminifer shells in ice-proximal marine sediments from the inner shelf (Hillenbrand et al., 2017) showed that variable inflow of CDW was the primary driver for grounding line retreat along the coast of the ASE throughout the Holocene and since the 1940s. Sedimentary sequences from the Amundsen Sea continental slope and rise spanning glacial–interglacial cycles back to 1.8 Ma were investigated by multiproxy analyses in order to find evidence for or against a WAIS collapse during the Quaternary (Hillenbrand et al., 2002, 2009; Konfirst et al., 2012) as was previously suggested (e.g., Scherer et al., 1998; Scherer, 2003). One of these studies found a mid-Pleistocene depositional anomaly that may be indicative of a WAIS collapse between 621 and 478 ky ago (Hillenbrand et al., 2009). All these studies provide a strong sedimentological framework for interpreting drill cores.

Seismic studies/site survey data

A network of seismic lines (Lowe and Anderson, 2002; Uenzelmann-Neben and Gohl, 2012, 2014; Hochmuth and Gohl, 2013; Gohl et al., 2013b; Lindeque et al., 2016a) (Figures F1, F3, F4) together with multibeam bathymetry, subbottom profiler data, and samples from gravity and piston coring form the basis of selecting the best possible drill sites in order to achieve the scientific objectives. Most of the proposed 22 primary and alternate drill sites were surveyed with crossing multichannel or single-channel seismic lines. Seven sites are covered with single seismic lines or are located a few kilometers off the next seismic crossing line. The supporting site survey data for Expedition 379 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P839 for proposal number).

Scientific objectives

The scientific goals and plan for this expedition are built on five hypotheses about WAIS dynamics and related paleoenvironmental and paleoclimatic conditions.

1. *Hypothesis H1: the WAIS responded to atmospheric and/or oceanic warming by major retreat from the shelf or by even partial to full collapse.*

Ice sheet models hypothesize that past climate warming caused major deglaciation of the WAIS (e.g., DeConto and Pollard, 2016). For instance, during the early middle Pliocene, Earth's climate was ~3°C warmer than the present (e.g., Haywood et al., 2009) and thus as warm as predicted for the end of this century, although atmospheric pCO_2 was ~400 ppm and other climatic boundary conditions were similar to the present (Pagani et al., 2010). The reasons for such a high atmospheric temperature during a time with modest greenhouse-gas forcing are still unknown. Results from Core AND-1B suggest repeated WAIS collapses during warm early middle Pliocene and Pleistocene interglacials, for example during marine isotope Stage 31 (Naish et al., 2009; Pollard and DeConto, 2009; McKay et al., 2012; Villa et al., 2012). The hypothesis of WAIS collapses needs confirmation with a less ambiguous record from an outlet drainage basin exclusively affected by the WAIS. In drill cores from the ASE margin, WAIS collapses would be recognizable by biogenic sedimentary sequences deposited during times with permanent open-water conditions and reduced supply of glaciogenic debris from the West Antarctic hinterland, similar to those documented in the AND-1B record (Naish et al., 2009). Such sediments would contain abundant microfossils and probably tephra layers from the Marie Byrd Land volcanic province (e.g., Le Masurier and Rex, 1991; Wilch et al., 1999), which are important for dating the sediments and reconstructing paleoenvironmental conditions in the ASE. Thus, the drill cores will help to answer the crucial question: did the WAIS collapse during the Neogene and Quaternary as previously suggested, and if yes, when and under which environmental conditions?

2. *Hypothesis H2: ice-proximal records of ice sheet dynamics in the ASE correlate with global records of ice-volume changes and proxy records for atmospheric and ocean temperatures.*

The post-LGM retreat of the WAIS from the ASE shelf was episodic (e.g., Lowe and Anderson, 2002; Graham et al., 2009, 2010; Jakobsson et al., 2012). The retreat episodes were likely triggered by different processes, including sea level rise, sub–ice shelf erosion by warm deep-water advection, destabilization of the ice sheet by subglacial meltwater outbursts, and grounding line retreat into overdeepened inner-shelf basins (Jakobsson et al., 2011; Smith et al., 2011; Kirshner et al., 2012; Hillenbrand et al., 2013b). These observations raise questions concerning the linkage between climate and glaciological forcing in regulating WAIS deglaciation. Throughout the Cenozoic era, unexplained discrepancies are observed between Earth's temperature and global ice volume reconstructed from proxies in deep-sea sediments, climate models, sea level estimates, and ice cores for the last 800 ky. Re-examination of previously studied cores highlights ongoing uncertainty about the timing of early ice sheet growth (Carter et al., 2017); the results of the AND-1B record (Naish et al., 2009) and Integrated Ocean Drilling Program Expedition 318 to the Wilkes Land margin (Cook et al., 2013) reignited the debate as to whether the Antarctic ice sheets underwent major collapses during Pliocene interglacials. Such collapses are neither directly recognizable from oxygen isotope proxies at far-field sites nor confirmed by the apparently persistent glaciation of the Antarctic Peninsula since the latest Miocene (Smellie et al., 2009) and repeated Pliocene ice sheet advances across the shelf observed in seismic profiles all along the Antarctic margin (e.g., Larter et al., 1997; Nitsche et al., 1997; Bart and Anderson, 2000; Smith and Anderson, 2010; Bart, 2001). Indeed, results from SHALDRIL cores and other data from the eastern Antarctic Peninsula shelf indicate progressive cooling and associated decline in vegetation over the past 37 My, culminating in early Pliocene ice sheet expansion onto the continental shelf (Anderson et al., 2011). Results from Leg 178 cores from the western Antarctic Peninsula margin are consistent with repeated ice sheet advances throughout the Pliocene (Eyles et al., 2001; Hillenbrand and Ehrmann, 2005; Hepp et al., 2006; Bart, 2001) but also indicate significant oceanic warming during Pliocene interglacials (Hillenbrand and Cortese, 2006; Escutia et al., 2009; Hepp et al., 2009; Bart and Iwai, 2012). The proposed drill cores from the ASE will decipher whether the WAIS responded directly to the orbitally paced climatic cycles of the Pliocene and Quaternary or it varied at periods determined by its internal dynamics, as findings from Leg 178 suggest for the Antarctic Peninsula Ice Sheet (Barker et al., 2002). Similar to drill cores from the Ross Sea and Antarctic Peninsula shelves (Eyles et al., 2001; McKay et al., 2009), the proposed drill cores from the ASE shelf will probably be incomplete because of glacial erosional unconformities. To obtain complete sedimentary sequences, at least one site will core deep-sea drifts on the continental rise offshore from the ASE. Similar drift sediments drilled on the western Antarctic Peninsula continental rise during Leg 178 provided excellent archives of Neogene to Quaternary ice sheet dynamics and paleoenvironmental changes (e.g., Hillenbrand and Ehrmann, 2005; Hepp et al., 2006, 2009; Escutia et al., 2009; Bart and Iwai, 2012). A comparable potential has already been demonstrated for Pleistocene drift sediments recovered from the Amundsen Sea continental rise (Hillenbrand et al., 2009).

3. *Hypothesis H3: the stability of marine-based WAIS margins is and has been controlled by warm deep-water incursions onto the shelf.*

In model experiments, incursions of relatively warm CDW onto the West Antarctic continental shelf have been implicated in regulating WAIS behavior on orbital and suborbital timescales (Thoma et al., 2008; Pollard and DeConto, 2009). Therefore, paleorecords of CDW upwelling are urgently needed to understand the relationship between WAIS dynamics and ocean circulation. Producing proxy records of past CDW incursions from marine sediment cores is still a challenge but has recently been demonstrated to be possible in sediments from the ASE shelf (Hillenbrand et al., 2017). With recent observations of present CDW advection predominantly through the paleo–ice stream troughs of the ASE (e.g., Arneborg et al., 2012), drilling on the ASE shelf has a good chance to recover sample material suitable for applying benthic foraminifer–based proxies to reconstruct past CDW upwelling onto the shelf and its effect on WAIS dynamics.

4. *Hypothesis H4: major WAIS advances onto the middle and outer shelf occurred since the middle Miocene.*

Seismic data revealed progradational and aggradational deposition on the outer shelf and slope of the ASE probably since the mid-Miocene (e.g., Nitsche et al., 1997, 2000; Hochmuth and Gohl, 2013; Gohl et al., 2013a). Numerous unconformities within strata on the shelf document frequent advance and retreat of grounded ice from the late Miocene until the Pliocene/Pleistocene according to the stratigraphic age model by Gohl et al. (2013a). The preservation of buried grounding-zone wedges in the Pliocene/Pleistocene sequence on the outer ASE shelf is consistent with prolonged continuous accumulation of (glaci-)marine sediments in an open-marine setting, probably during a long interglacial period with a significantly reduced WAIS, as observed on the Ross Sea shelf during the early Pliocene. However, the models of grounded ice advance and retreat across the ASE shelf are based on long-distance correlations of seismic facies and characteristics, which must be tested by drill core data to constrain past WAIS extent.

5. *Hypothesis H5: the first WAIS advance onto the inner ASE shelf occurred during the Oligocene and was related to the uplift of Marie Byrd Land.*

The onset of major glaciation in West Antarctica is still undated because of sparse drill cores. Records of ice-rafted debris suggest that glaciers must have reached the coast of the Ross Sea in the early to mid-Oligocene (Miller et al., 2008). Ice sheet models (e.g., DeConto and Pollard, 2003) reconstructed an early WAIS nucleus in the mountain chain extending from elevated Marie Byrd Land over the Ellsworth Mountains to the southern Antarctic Peninsula. The exhumation and erosion history of Marie Byrd Land, and especially the Marie Byrd Land dome, is important for the interrelations between ice sheet and lithosphere dynamics (e.g., Rocchi et al., 2006; Wilson and Luyendyk, 2009; Wilson et al., 2012a, 2012b) because (1) exhumation and erosion change topography, which in turn influences glacier movements by slope steepness; (2) exhumation is often associated with surface uplift, and high altitude favors formation of glaciers; and (3) glaciation changes erosion rates and, due to isostatic adjustment, exhumation rates. This relationship can be investigated by detailed provenance and thermochronological analyses of Neogene drill samples from the ASE midshelf and existing rock samples from the hinterland.

Operations plan/drilling strategy

Proposed drill sites

The primary aim of our proposed drilling campaign is to obtain core and log data from oceanward-dipping strata along a transect from the presumed Late Cretaceous to Paleogene sequences close to the boundary with bedrock on the inner shelf to the presumed Pliocene to Pleistocene sequences on the outer shelf and continuing onto the continental rise for continuous high-resolution records (Tables **T1**, **T2**, **T3**, **T4**; Figure **F6**). To record past CDW upwelling onto the ASE, where the Thwaites and Pine Island Glaciers have previously been extended onto the shelf, our highest priority core transect will be located within the Pine Island paleo–ice stream trough in the eastern ASE (Figure **F1**; Tables **T1**, **T2**). The existing seismic sections of both the western and eastern ASE (Gohl et al., 2013b) (Figure **F4**) indicate that the dipping strata of the middle shelf are cut by major unconformities that likely represent significant episodes of ice sheet expansion onto the shelf and subglacial erosion. The upper part of the section consists of numerous prograding wedges. If these wedges are analogous to similar features observed in the Ross Sea and off the Antarctic Peninsula, they reflect higher frequency glacial oscillations during the Pliocene–Pleistocene. The observed sequences of strong and continuous reflections probably represent glaciomarine sediments that were deposited under seasonal or permanent open-water conditions and therefore should contain microfossils and possibly tephra layers.

If sea ice conditions during the drilling expedition are unsuitable for accessing the first priority sites in Pine Island Trough, a core transect targeting strata of comparable age and cross-shelf position will be drilled in the Dotson-Getz paleo–ice stream trough of the western ASE. Each scientific hypothesis in the proposal can also be addressed in the Dotson-Getz core transect (Table **T2**). The biostratigraphic studies and the multiproxy analyses of the sediments recovered from the shelf will focus on interglacial strata. Even if the shelf sequences are incomplete (because of hiatuses resulting from subglacial erosion or because of low core recovery) and thus hamper magnetostratigraphic interpretations, the microfossils and biomarkers of the interglacial strata will enable us to date the sediments and test Hypotheses H1–H5. Taking into account the likelihood of hiatuses in the shelf records, we plan to investigate more continuous, high-resolution records to be drilled at continental rise sites. Here, the drill targets are identified according to the interpreted seismostratigraphy by Uenzelmann-Neben and Gohl (2012, 2014) (Figure **F3**). By following this shelf-to-rise transect drilling strategy, we expect to obtain excellent control on the extent, frequency, and rapidity of WAIS advance and retreat and the role of CDW in regulating ice sheet retreat from the shelf.

In the unlikely worst-case scenario of extensive sea ice cover on both sides of the ASE shelf, we have also included a third priority set of targets on the continental rise. This third set of targets will still allow us to work on Hypotheses 1–3. However, if this third work area is the only area we are able to reach, our final two hypotheses will not be addressed directly (Table **T2**).

We have defined several distinct potential drill sites for the shelf and continental rise, providing sufficient alternatives to respond to variable ice-cover situations, and we have prioritized the sites such that the main objectives can be addressed at multiple different locations (Tables **T1**, **T2**).

In the following sections, we describe the drill sites in more detail, sorting them into groups with alternate sites around their primary sites based on their common scientific objectives and drill targets. A summary is presented in Table **T1**, with priorities listed in Table **T2**. The seismostratigraphic units, unconformities, and age estimates of the shelf are from Gohl et al. (2013b), and those of the rise are from Uenzelmann-Neben and Gohl (2012, 2014).

We plan to core two holes at each primary site using the advanced piston corer (APC)/extended core barrel (XCB) and rotary core barrel (RCB) systems and then collect log data in the deeper RCB hole at each site (Table **T3**; Figure **F6**).

Continental shelf sites

Proposed sites ASSE-03B (primary) and ASSE-10A, ASSE-04B, ASSW-02B, and ASSE-06B (alternates)

Primarily located on the middle shelf of the eastern embayment, proposed Sites ASSE-03B and ASSE-04B are on the western and eastern flanks of the glacial central Pine Island Trough, respectively, proposed Site ASSE-10A is in the middle of this trough, and proposed Site ASSE-6B is on a ridge between the central Pine Island Trough and the Abbott Trough. Proposed Site ASSW-02B is located in the glacial Dotson-Getz Trough of the western embayment. Common to these sites is that they are located for drilling into glacial sediment sequences from the presumed middle Miocene to Pliocene/Pleistocene, thereby obtaining records from the transition to full glacial conditions, the early Pliocene warm period, and the transition to cooling in the late Pliocene. The trough sites have the potential to sample material for tracing past CDW events if interglacial sequences are preserved. The major truncational Unconformity ASS-u4, which possibly separates the mid-Miocene from the late Miocene, will be penetrated to provide age constraints for advances of grounded ice to the middle shelf. At proposed Sites ASSE-04B and ASSE-10A, we may even be able to drill well below the mid-Miocene Unconformity ASS-u3. We expect to core alternating diamicton and thin diatomaceous ooze.

Proposed sites ASSE-11A (primary) and ASSE-05C, ASSE-07B, ASSE-12A, ASSE-08C, and ASSW-03B (alternates)

Primarily located on the middle to outer shelf of the eastern embayment, proposed Site ASSE-11A is in the middle of the outer Pine Island Trough West, proposed Site ASSE-05C is on the western flank of this trough, and proposed Sites ASSE-7B and ASSE-12A are on the outermost shelf. Proposed Site ASSE-08C is located in the outer Pine Island Trough West, whereas proposed Site ASSW-03B is located on the outer shelf of the glacial Dotson-Getz Trough of the western embayment. In contrast to those around proposed Site ASSE-03B, this suite of sites sitting on a progradational wedge focuses even more on the Pliocene to Pleistocene shelf sequences and the full glacial conditions after the late Miocene climate cooling, including the pronounced early Pliocene warm period followed by late Pliocene cooling. The proposed trough Sites ASSE-11A, ASSE-08C, and ASSW-03B have the potential to sample material for tracing past CDW events if interglacial sequences are preserved. Proposed Sites ASSE-11A and ASSE-05C may reach the mid- to late Miocene after penetrating Unconformity ASS-u4. We expect to core alternating diamicton and thin diatomaceous ooze.

Proposed site ASSE-02C (primary, no alternates)

Proposed site ASSE-02C is located on the eastern flank of the midshelf Pine Island Trough and is expected to recover core from the preglacial to early glacial sequences up to the middle Miocene. According to recently collected MeBo70 seabed drill records from the northward dipping sequences of the middle shelf about 70 km farther south (Gohl et al., in press), it is very likely that we will drill into the Cretaceous below Unconformity ASS-u2 and sample Paleocene to Oligocene sequences above Unconformity ASS-u2, thus bridging the Eocene–Oligocene climate transition. We expect to core alternating diamicton and thin diatomaceous ooze in the upper part of the hole and preglacial mudstone and sandstone from the older sequences below.

Proposed sites ASSE-01C (primary) and ASSE-09A and ASSW-01B (alternates)

The sites located on the southern middle shelf in the Pine Island Trough are proposed Sites ASSE-01C and ASSE-09A on the eastern shelf and proposed Site ASSW-01B in the Dotson-Getz Trough of the western shelf. The objective of these sites is to obtain records from early glacial sequences and thus the onset of major West Antarctic glaciation and the Mid-Miocene Climate Optimum. According to the seismostratigraphic interpretation, this site should penetrate the early to middle Miocene, thereby avoiding the Unconformity ASS-u3 at proposed Sites ASSE-01C and ASSE-09A, and may reach the Eocene and Oligocene above Unconformity ASS-u2-if the first analyses of MeBo70 seabed drill cores, collected 70 km farther south (Gohl et al., in press), can be confirmed. We expect to core alternating diamicton and thin diatomaceous ooze in the upper part of the hole and preglacial mudstone and sandstone from the older sequences below.

Continental rise sites

Proposed sites ASRE-05B (primary) and ASRE-03B, ASRE-06A, ASRE-01B, ASRE-02B, ASRE-04A, and ASRW-01C (alternates)

Proposed Sites ASRE-05B, ASRE-03B, ASRE-06A, and ASRE-04A are located on the flanks of sediment drift deposits on the rise about 120–150 km north of the ASE shelf edge, proposed Sites ASRE-01B and ASRE-02B are on the lower continental slope north of the Abbott Trough and Pine Island Trough East of the eastern ASE, and proposed Site ASRW-01C is on the lower slope northeast of the Dotson-Getz Trough of the western ASE. The drift deposits are well imaged in the seismic data. All sites were picked in locations of regular, undisturbed deposition to obtain records from presumed early Miocene to Pliocene/Pleistocene times. We assume that continuous sedimentation at a relatively high rate took place on these drifts, similar to that observed on other drift deposits. The aim of the lower slope sites is to collect cores from the outer parts of trough-mouth fan systems where seismic data suggest regular, undisturbed deep-sea deposition. Compared to the sites on the sediment drifts (grouped around proposed Site ASRE-05B above), these sites are slightly more ice-proximal. From all these sites, we expect to recover high-resolution records from the presumed onset of major West Antarctic glaciation, the Mid-Miocene Climate Optimum, the Miocene–Pliocene transition, and the early mid-Pliocene warm interval to the glacials/interglacials of the Pleistocene and Quaternary. We expect to drill mostly fine-grained hemipelagic biogeneous mud/silt and fine-grained turbiditic material.

Logging/downhole measurements strategy

Wireline logging is planned for all sites. We will use the triple combination (triple combo) tool string, which acquires formation resistivity, density, porosity, natural (spectral) gamma radiation, and borehole diameter data. The Formation MicroScanner (FMS)-sonic tool string will provide an oriented 360° resistivity image of the borehole wall, as well as formation acoustic velocity, natural gamma radiation, and borehole diameter data. These data will provide the only in situ formation characterization and are the only data where core recovery is incomplete, allowing some level of interpretation even in core gaps. For example, individual clasts in diamict will be apparent in the FMS resistivity images, and silica-cemented layers will be clear in the resistivity and density logs. Porosity, gamma ray, sonic, and density logs together will provide additional constraints on the depositional history.

We also plan a third logging run at all sites to conduct a check shot survey. Check shot surveys give depth to traveltime conversion; a combination of sonic velocity and density data will be used to generate a synthetic seismic profile at each site. Synthetic seismic profiles based on check shot surveys for each hole will enable lithostratigraphy to be tied to seismic stratigraphy and thus extend the knowledge gained from the cores over a much broader area. To reduce the risk of incomplete logging resulting from bad hole conditions in the deep-penetration sites, we may elect to log in two stages: the upper 500 m of the section in the first APC/XCB hole and the lower part in the second RCB hole. However, this option is not in the current plan and would only be practical if extra time became available. Although we plan to log all sites, if we do not have sufficient time for all the planned logging, we might elect to only conduct a check shot at one shelf site and one rise site.

Risks and contingencies

We expect to encounter severe environmental conditions (ice/weather) throughout the expedition in addition to very challenging drilling conditions on the shelf. These conditions will impact our operations, and no contingency time for any anticipated delays are included in the primary drilling, coring, and logging plan (Table **T1**; Figure **F6**). If operations need to be cut back due to time constraints, options include but are not limited to (1) reducing the amount of XCB coring penetration and switching to the RCB system earlier and (2) conducting check shots only at one shelf site and one rise site.

Ice conditions

Satellite images and ship-born observations have shown that the sea ice and iceberg cover on the ASE shelf has changed from being severe in the 1980s and 1990s to almost ice-free conditions in mid-January to March 2010. Atmospheric researchers relate this phenomenon to an enduring shift in the Southern Annular Mode (Turner et al., 2009). Ice cover returned in the ASE in the 2010–2011 season but did not reach the same large extent as observed in the 1980s and 1990s. Figure **F7** illustrates worst- and best-case scenarios of ice cover in the ASE encountered in mid-February 2006 and 2010, respectively. We address the potential risk of unpredictable ice cover with a strategy of numerous identified alternate sites that will allow a choice of a drill site in ice-free water. Table **T2** demonstrates our prioritization of primary and alternate sites with respect to access and drilling feasibility. The table also illustrates how each hypothesis can be addressed at multiple drill sites, not just the first priority option. Icebergs pose an additional threat to drilling operations, and the *JOIDES Resolution* will have to move off site if an iceberg approaches too close to a site location. In these instances, we will have a free-fall funnel (FFF) ready to deploy that would allow for hole reentry after the iceberg passes. No contingency time is included in the expedition plan for time lost due to ice or weather impacting our ability to access or remain on the drill sites. Because of their high scientific priority, we have put the shelf sites first in our planned operations. However, we likely must occupy the rise site first until ice conditions improve enough on the shelf for us to access those sites.

Coring in glacial sediment

Past drilling with riserless systems has shown less than optimum core recovery of pre-Holocene sediments on Antarctic shelves. This problem can be minimized with improved techniques and a careful drilling strategy. Weather conditions are of primary importance in reducing vessel heave and thus variations in the weight-on-bit during drilling, which can affect core recovery. Scheduling drilling for the best possible weather and ice window is the primary strategy to reduce risk. The use of passive heave compensation can minimize the effects of vessel motion on core recovery and will be used to the extent possible (and active heave compensation for wireline logging). Although sea ice cover is certainly a significant overall risk, its presence nearby can substantially dampen waves, and thus ice may help to mitigate the problems associated with heave. FFFs may be used at sites with unconsolidated coarse till near the surface. In case we encounter persistent problems with penetrating the shallow section on the shelf, we will also have a back-up reentry system with casing that can be drilled-in if necessary. Because we are largely targeting consolidated, older, and more compacted or lithified sequences than on some Antarctic drilling legs by DSDP, ODP, and the Integrated Ocean Drilling Program, better recovery is expected.

The potential for poor core recovery on glaciated shelves should not be used as an argument to refrain from riserless drilling in these locations because such ice-proximal records are desperately needed to resolve regional differences in Antarctic ice sheet dynamics. In our well-planned shelf-to-rise transect strategy, the potential gaps caused by potential recovery problems and hiatuses due to reoccurring events of glacial erosion can be bridged. Each cored sediment section, even short ones, that can be recovered and dated will be of unprecedented scientific value. It should be noted that the Ross Sea shelf sites of DSDP Leg 28, despite their relatively poor core recovery with the technology of the 1970s, resulted in enough material to constrain fundamental chronological, stratigraphic, and paleoclimatic parameters of this embayment. Not only are they still being cited in numerous publications, they are still being sampled for new analyses.

Other operational risks

The proposed penetration at some sites (as deep as 1400 m) presents several challenges for successful collecting of cores and log data. Hole stability is always a risk during coring and logging operations, and the risk increases with longer open-hole sections. Casing long open-hole sections (especially over intervals of unconsolidated sediment) is the best way to mitigate this risk and ensure that deep objectives can be achieved; however, no casing is currently planned for any holes during this expedition. Casing adds a significant amount of operational time and could also be compromised if ice approached the site. FFFs can be deployed to allow reentry capability if we have to move off site during coring operations, but there are several risks associated with these FFF deployments. The FFF can be dislodged while pulling out of the hole or can become buried or impossible to use for reentry. The use of an FFF also leaves the open-hole section open for a longer duration, which can contribute to hole stability problems. A stuck drill string (or logging tool string) is always a risk during operations and can consume expedition time with attempts to sever the stuck drill string. If the drill string cannot be extracted, then additional time is spent to sever the stuck pipe. This process can result in the complete loss of the hole, lost equipment, and lost time while starting a new hole. The *JOIDES Resolution* generally carries sufficient spare drilling equipment to enable the continuation of coring, but the time lost to the expedition can be significant.

Downhole logging risks

The upper parts of holes have been open longer before logging, and high levels of fluid circulation might have been used to raise the cuttings and clear the hole. Therefore, the hole could be washed out (wide) over intervals through unconsolidated sediment, which would reduce log quality for those tools that need good contact with the borehole wall (e.g., density, porosity, FMS resistivity images, and Versatile Seismic Imager [VSI] check shots). Second, there is a risk of bridging where the hole closes up, which would mean either not reaching the total depth of the hole or, in the worst-case scenario, getting a tool string stuck in the hole. We will obtain hole condition information needed to plan for logging while coring and during the preparations for downhole logging. Permitting requirements may prevent us from deploying the density tool source in the triple combo tool string. Sufficient heavy mud will be available to displace each hole to be logged to reduce the risk of hole collapse during wireline logging.

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted on the Web at **http://www.iodp.org/program-documents**. This document outlines the policy for distributing IODP samples and data. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of Co-Chief Scientists, Staff Scientist, and IODP Curator on shore and curatorial representative on board ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Each member of the science party is obligated to perform scientific research for the expedition and publish the results. To initiate this process, all shipboard scientists (and any potential shore-based scientists) will be required to submit a research plan and associated sample and data request ~6 months before the expedition (see **http://iodp.tamu.edu/curation/samples.html**). Based on these research plans, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and cruise objectives. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that will evolve between scientists during the expedition. Modification of the strategy during the expedition must be approved by the Co-Chief Scientists, Staff Scientist, and curatorial representative on board ship.

The minimum permanent archive will be the standard archive half of each core. The coring plan as presented in this document plan will provide only a single copy of the formation at each site (e.g., one working half from which samples can be taken for personal research). All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

If some critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling by a single investigator. A sampling plan coordinated by the SAC may be required before critical intervals are sampled.

Our plan is to restrict shipboard sampling to those samples required for shipboard characterization/measurements, any samples that are ephemeral, and possibly very limited, very low resolution samples for personal research that are required to define plans for the postcruise sampling meeting. Whole-round samples may be taken for, but not limited to, interstitial water measurements and petrophysical measurements as dictated by the primary cruise objectives, approved research plans, and the shipboard sampling plan that must be finalized during the first few days of the expedition.

Nearly all personal sampling for postexpedition research will be postponed until a shore-based sampling meeting that will be implemented ~3–5 months after the end of Expedition 379 at the IODP Gulf Coast Repository (College Station, Texas, USA). All collected data and samples will be protected by a 1 y moratorium period following the completion of the postexpedition sampling meeting, during which time data and samples will be available only to the Expedition 379 science party.

Expedition scientists and scientific participants

The current list of participants for Expedition 379 can be found at **http://iodp.tamu.edu/scienceops/expeditions/amundsen_sea_ice_sheet_history.html**.

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Table T1. Summary of proposed drill sites on continental shelf and rise of the Amundsen Sea Embayment.See Scientific objectives for descriptions of scientific hypotheses (H); numbers here match descriptions. Alternate sites are listed below their primary sites. Drill site locations are shown in Figure F1. Coring and logging time estimates are shown in Figure F9 and Tables T3 and T4. (Continued on next page.)

Site	Location	Drill targets	Scientific hypotheses (H) and objectives	Site selection criteria and seismic site data
Continental shelf				
ASSE-02C (primary)	Eastern ASE, central Pine Island Trough, middle shelf	Preglacial to early glacial sequences, Late Cretaceous to early Miocene	H 4, 5; greenhouse-to-icehouse transition, Eocene–Oligocene climate gradient, timing of early West Antarctic glaciation	Single-line MC seismics (7 km north of cross-line): penetrating early Miocene and reaching Late Cretaceous, avoiding structural complication
ASSE-01C (primary)	Eastern ASE, central Pine Island Trough, middle shelf	Preglacial to early glacial sequences, late Oligocene to mid Miocene	H 4, 5; transition from preglacial to glacial, timing of onset of major West Antarctic glaciation	Crossing MC seismics: continuous early Miocene; avoiding unconformity ASS-u3 but penetrating into late Oligocene
ASSE-09A (alternate)	Eastern ASE, central Pine Island Trough, middle shelf	Preglacial to early glacial sequences, Eocene/Oligocene to mid Miocene	H 4, 5; transition from preglacial to glacial, timing of onset of major West Antarctic glaciation	Crossing SC/MC seismics: continuous early Miocene; avoiding unconformity ASS-u3 but penetrating into Oligocene and Eocene
ASSW-01B (alternate)	Western ASE, Dotson-Getz Trough, middle shelf	Preglacial sediment sequences, early to mid Miocene	H 4, 5; timing of onset of glaciation, transition from preglacial to glacial, mid-Miocene climate optimum	Crossing SC/MC seismics: capturing most of early to mid Miocene; intentionally penetrating Unconformities ASS-u3 and -u4
ASSE-03B (primary)	Eastern ASE, central Pine Island Trough, middle shelf	Glacial sediment sequences, mid Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Crossing MC seismics: continuous mid Mio.; penetrating major glacial unconformity ASS-u4 (full glacial advance conditions)
ASSE-10A (alternate)	Eastern ASE, central Pine Island Trough, middle shelf	Glacial sediment sequences, mid Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Crossing SC/MC seismics: continuous mid Mio.; penetrating major glacial Unconformities ASS-u4 (full glacial advance conditions) and ASS-u3 (erosional truncation?)
ASSE-04B (alternate)	Eastern ASE, central Pine Island Trough, middle shelf	Glacial sediment sequences, mid Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Crossing MC seismics: penetrating major glacial Unconformities ASS-u4 (full glacial advance conditions) and ASS-u3 (erosional truncation?)
ASSW-02B (alternate)	Western ASE, Dotson-Getz Trough, middle shelf	Glacial sediment sequences, mid Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Single-line MC seismics: thick Pliocene/ Pleistocene sequences; penetration through major glacial unconformity ASS-u4
ASSE-06B (alternate)	Eastern ASE, Pine Island Trough East, mid to outer shelf	Glacial sediment sequences, mid Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Crossing MC seismics: thick Pliocene/ Pleistocene sequences; penetration into major glacial unconformity ASS-u4
ASSE-11A (primary)	Eastern ASE, central Pine Island Trough, mid to outer shelf	Glacial sediment sequences, mid/late Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Crossing SC/MC seismics: thick Pliocene/ Pleistocene sequences and penetration into major glacial unconformity ASS-u4
ASSE-05C (alternate)	Eastern ASE, central Pine Island Trough, mid to outer shelf	Glacial sediment sequences, late Miocene to Pliocene/Pleistocene	H 1, 2, 3; transition to full glacial conditions, CDW events; early Pliocene warm period, transition to cooling in late Pliocene	Single-line MC seismics (7 km south of cross-line): thick Pliocene/ Pleistocene sequences and penetration into major glacial unconformity ASS-u4
ASSE-07B (alternate)	Eastern ASE, Pine Island Trough East, outer shelf	Glacial sediment sequences, early Pliocene to Pleistocene	H 1, 2, 3; full glacial conditions, CDW events; late Pliocene cooling	Crossing SC/MC seismics: thick Pliocene and Pleistocene sequences, above prograding sequences
ASSE-12A (alternate)	Eastern ASE, Pine Island Trough East, outer shelf	Glacial sediment sequences, early Pliocene to Pleistocene	H 1, 2, 3; full glacial conditions, CDW events; late Pliocene cooling	Crossing SC/MC seismics: thick Pliocene and Pleistocene sequences, above prograding sequences
ASSE-08C (alternate)	Central ASE, Pine Island Trough West, outer shelf	Glacial sediment sequences, late Miocene to Pleistocene	H 1, 2, 3; full glacial conditions, CDW events; late Pliocene cooling	Crossing SC/MC seismics: thick Pliocene and Pleistocene sequences, above prograding sequences
ASSW-03B (alternate)	Western ASE, Dotson-Getz Trough, middle to outer shelf	Glacial sediment sequences, late Miocene to Pleistocene	H 1, 2, 3; full glacial conditions, CDW events; late Pliocene cooling	Single-line MC seismics: thick Pliocene and Pleistocene sequences
Continental rise				
ASRE-05B (primary)	Eastern ASE, continental rise	Deep-sea record of glacial sequences, early Miocene to Pliocene/Pleistocene, drift deposit	H 1, 2, 3; onset of major glaciation, mid-Miocene climate optimum, high-resolution record, correlation with paleo-current reconstruction	Crossing MC seismics: thick sequence down to early Miocene; avoiding structural complication and top of drift
ASRE-03B (alternate)	Eastern ASE, continental rise	Deep-sea record of glacial sequences, early Miocene to Pliocene/Pleistocene, drift deposit	H 1, 2, 3; onset of major glaciation, mid-Miocene climate optimum, high-resolution record, correlation with paleo-current reconstruction	Crossing MC seismics: thick sequence down to early Miocene; avoiding structural complication
ASRE-06A (alternate)	Central ASE, continental rise	Deep-sea record of glacial sequences, early Miocene to Pliocene/Pleistocene, drift deposit	H 1, 2, 3; onset of major glaciation, mid-Miocene climate optimum, high-resolution record, correlation with paleo-current reconstruction	Single-line MC: thick sequence Pliocene/Pleistocene and down to early Miocene; avoiding top of drift and structural complication

Table T1 (continued).

Site	Location	Drill targets	Scientific hypotheses (H) and objectives	Site selection criteria and seismic site data
ASRE-01B (primary)	Eastern ASE, continental rise	Deep-sea record of glacial sequences, mid Miocene to Pleistocene	H 1, 2, 3; major glacial and warm periods from mid-Miocene climate optimum to early Pliocene warm period to present, high-resolution record of Pliocene/Pleistocene	Crossing MC seismics: thick sequence Pliocene/Pleistocene and down to mid Miocene; avoiding structural complication
ASRE-02B (alternate)	Eastern ASE, continental rise	Deep-sea record of glacial sequences, mid Miocene to Pleistocene	H 1, 2, 3; major glacial and warm periods from mid-Miocene climate optimum to early Pliocene warm period to present, high-resolution record of Pliocene/Pleistocene	Single-line MC seismics: thick sequence Pliocene/Pleistocene and down to mid Miocene; avoiding structural complication
ASRE-04A (alternate)	Eastern ASE, continental rise	Deep-sea record of glacial sequences, late Miocene to Pleistocene, drift deposit	H 1, 2, 3; major glacial and warm periods from early Pliocene warm period to present, high-resolution record, correlation with paleo-current reconstruction	Single-line MC seismics (7 km west of cross-line): thick sequence Pleistocene and down to late Miocene; avoiding top of drift and structural complication
ASRW-01C (alternate)	Western ASE, continental rise	Deep-sea record of glacial sequences, late Miocene to Pleistocene	H 1, 2, 3; major glacial and warm periods from early Pliocene warm period to present, high-resolution record	Crossing MC seismics: thick sequence Pliocene/Pleistocene and down to late Miocene; avoiding structural complication

Table T2. Prioritization of drill sites. Highest priority level is 1, lowest is 3. Penetration depths differ in some cases from the maximum penetration depths of a particular site according to the overall objectives within a priority level. Hypothesis/objective numbers are according to descriptions in Scientific Objectives. NA = not applicable.

Ice cover scenario	Priority level	Primary site or first-choice alternate site	Alternate site(s)	Maximum penetration (m)	Hypothesis/ objective
Minimum ice cover on east and west ASE shelf (best case)	1.1	ASSE-11A	ASSE-05C, ASSE-07B, ASSE-12A, ASSE-08C	600–950	H 1, 2, 3
	1.2	ASSE-03C	ASSE-10A, ASSE-04B, ASSE-06B	850–950	H 1, 2, 3
	1.3	ASRE-05B	ASRE-03B, ASRE-06A	1200–1400	H 1, 2, 3
	1.4	ASSE-02C	ASSE-09A	900	H 4, 5
	1.5	ASRE-01B	ASRE-02B, ASRE-04A	900–950	H 1, 2, 3
	1.6	ASSE-01C	ASSE-09A	900	H 4, 5
Minimum ice cover on west ASE shelf and maximum ice cover on east ASE	2.1	ASSW-02B	NA	900	H 1, 2, 3
	2.2	ASSW-03B	ASSE-08C	850–950	H 1, 2, 3
	2.3	ASRW-01C	ASRE-06A, ASRE-05B, ASRE-01B	900–1200	H 1, 2, 3
	2.4	ASSW-01B	NA	600	H 4, 5
	2.5	ASRE-06A	ASRE-05B, ASRE-01B	950–1200	H 1, 2, 3
Maximum ice cover on east and west ASE shelves (worst case)	3.1	ASRE-01C	ASRE-02B, ASRE-04A	900–950	H 1, 2, 3
	3.2	ASRE-05B	ASRE-04A, ASRE-02B	900–1200	H 1, 2, 3
	3.3	ASRE-03B	ASRE-02B, ASRE-04A	900–1400	H 1, 2, 3
	3.4	ASRE-06A	NA	1200	H 1, 2, 3
	3.5	ASRW-01C	NA	900	H 1, 2, 3

Table T3. Operations and time estimates for primary sites, Expedition 379. This is the plan based on our scientific priorities, but we expect environmental conditions (ice, weather) to impact this plan. See Figure F9 for planned coring and logging operations.

Site	Location (latitude, longitude)	Seafloor depth (m)	Operations	Transit (days)	Drilling and coring (days)	Logging (days)
Punta Arenas			Begin expedition Days in port: 5.0			
			Transit ~1661 nmi to ASSE-02C @ 10.5 kt	6.6		
ASSE-02C	72.848°S	576	Hole A - APC/XCB core to 400 mbsf		1.9	
EPSP approved to 900 m	106.347°W		Hole B - RCB core to 900 mbsf; log with triple combo, FMS-sonic, and VSI		3.5	1.6
			Subtotal days on site: 7.0			
			Transit ~26 nmi to ASSE-01C @ 10.5 kt	0.1		
ASSE-01C	72.894°S	612	Hole A - APC/XCB core to 400 mbsf		1.8	
EPSP approved to 900 m	107.8143°W		Hole B - RCB core to 900 mbsf; log with triple combo, FMS-sonic, and VSI		3.5	1.6
			Subtotal days on site: 6.9			
			Transit ~19 nmi to ASSE-03B @ 10.5 kt	0.1		
ASSE-03B	72.582°S	578	Hole A - APC/XCB core to 400 mbsf		1.7	
EPSP approved to 850 m	108.002°W		Hole B - RCB core to 850 mbsf; log with triple combo, FMS-sonic, and VSI		4.1	1.5
			Subtotal days on site: 7.3			
			Transit ~34 nmi to ASSE-11A @ 10.5 kt	0.1		
ASSE-11A	72.022°S	585	Hole A - APC/XCB core to 400 mbsf		1.7	
EPSP approved to 700 m	107.588°W		Hole B - RCB core to 700 mbsf; log with triple combo, FMS-sonic, and VSI		2.5	1.4
			Subtotal days on site: 5.6			
			Transit ~118 nmi to ASRE-05B @ 10.5 kt	0.5		
ASRE-05B	70.0793°S	3720	Hole A - APC/XCB core to 400 mbsf		3.7	
EPSP approved to 1200 m	108.6122°W		Hole B - RCB core to 1200 mbsf; log with triple combo, FMS-sonic, and VSI		9.6	2.2
			Subtotal days on site: 15.5			
			Transit ~1601 nmi to Punta Arenas @ 10.5 kt	6.4		
Punta Arenas			End expedition	13.7	34.0	8.3

Port call:	5.0	Total operating days:	56.0
Subtotal on site:	42.3	Total expedition:	61.0

Table T4. Summarized operations and time estimates for alternate sites, Expedition 379.

Site No.	Latitude	Longitude	EPSP Depth (mbsf)	Seafloor Depth (mbrf)	Operations Description	Days on Site
ASRE-01B	70.242000°S	103.718000°W	950	3831	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 950 mbsf and log with triple combo, FMS-sonic, and VSI	12.2
ASRE-02B	70.528000°S	102.394000°W	950	3071	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 950 mbsf and log with triple combo, FMS-sonic, and VSI	11.2
ASRE-03B	69.773700°S	103.299000°W	1400	4051	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 1400 mbsf and log with triple combo, FMS-sonic, and VSI	18.6
ASRE-04A	70.242000°S	105.775000°W	900	3611	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASRE-06A	70.325000°S	114.223000°W	1200	3477	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 1200 mbsf and log with triple combo, FMS-sonic, and VSI	7.9
ASRW-01C	71.705200°S	120.668100°W	900	2654	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASSE-04B	72.558000°S	106.448000°W	900	549	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASSE-05C	72.149000°S	108.436000°W	800	593	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 800 mbsf and log with triple combo, FMS-sonic, and VSI	6.4
ASSE-06B	71.893000°S	105.552000°W	950	525	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 950 mbsf and log with triple combo, FMS-sonic, and VSI	6.3
ASSE-07B	71.287000°S	104.750000°W	600	551	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 600 mbsf and log with triple combo, FMS-sonic, and VSI	5.4
ASSE-08C	71.596600°S	113.255100°W	950	655	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 950 mbsf and log with triple combo, FMS-sonic, and VSI	6.3
ASSE-09A	72.910000°S	107.307000°W	900	701	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASSE-10A	72.572000°S	107.267000°W	900	744	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASSE-12A	71.332000°S	108.365000°W	600	506	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 600 mbsf and log with triple combo, FMS-sonic, and VSI	4.9
ASSW-02B	72.817000°S	116.583000°W	900	665	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 900 mbsf and log with triple combo, FMS-sonic, and VSI	5.9
ASSW-03B	72.502000°S	117.972000°W	850	549	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 850 mbsf and log with triple combo, FMS-sonic, and VSI	6.1
ASSW-01B	72.993000°S	115.792000°W	600	721	Hole A - APC/XCB to 400 mbsf	
					Hole B - RCB to 600 mbsf and log with triple combo, FMS-sonic, and VSI	4.9

Figure F1. Bathymetric map of the ASE off West Antarctica (adopted from Nitsche et al., 2007) with Expedition 379 primary (red) and alternate (yellow) drill sites. Thick gray lines mark existing marine multi- and single-channel seismic profiles collected during six ship expeditions from 1994 to 2010 (e.g., Gohl et al., 2013b). Orange line marks the boundary between the outcropping basement of the inner shelf and the sedimentary basin of the middle shelf (Graham et al., 2009; Gohl et al., 2013a, 2013b).

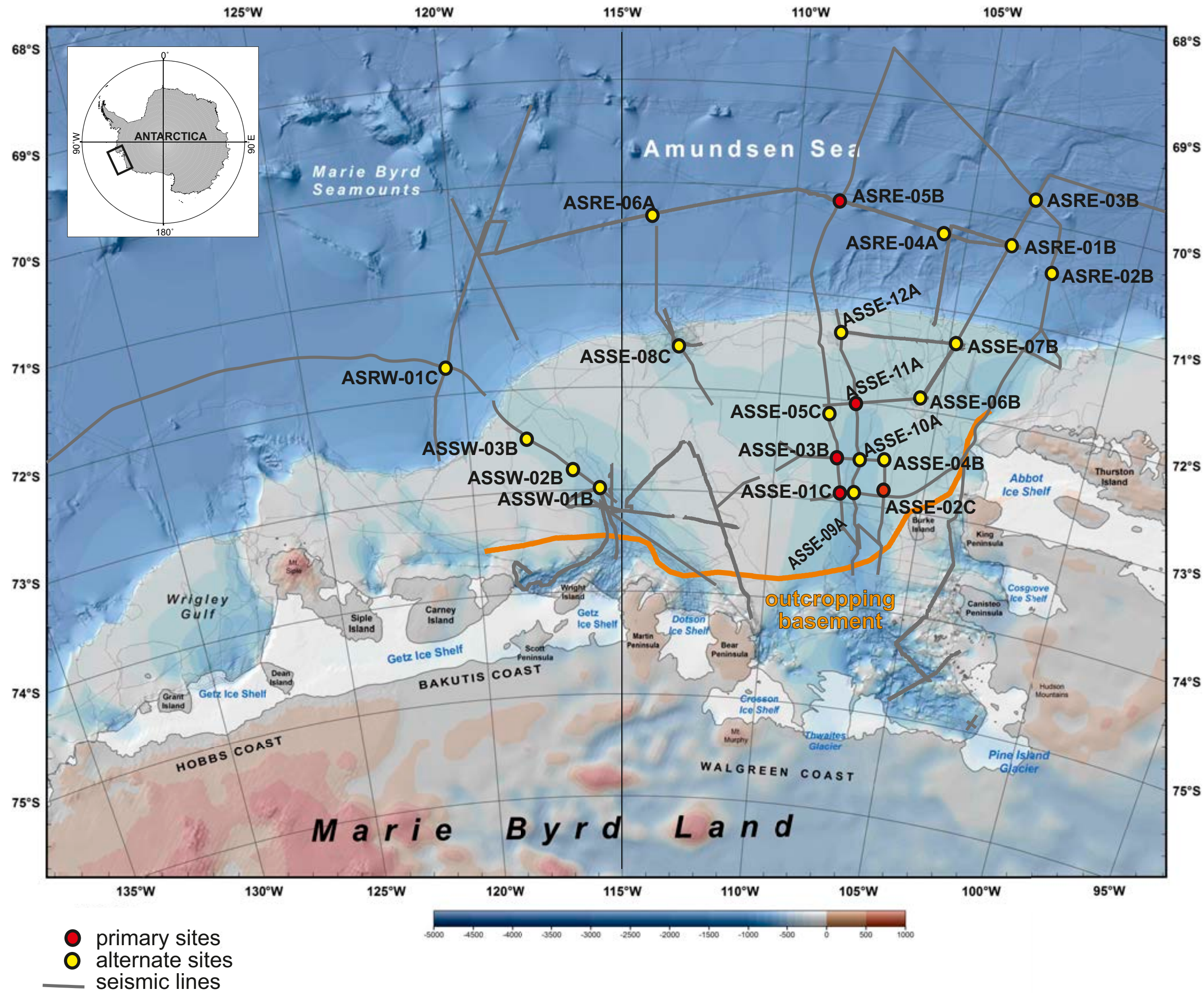


Figure F2. Antarctic ice sheet models for the Pliocene (modified from DeConto and Pollard, 2016) and the Last Interglacial (modified from Sutter et al., 2016) simulating the collapse of the WAIS in both warm times. Major ice retreat in the ASE seems to be a precursor for partial or total WAIS collapse.

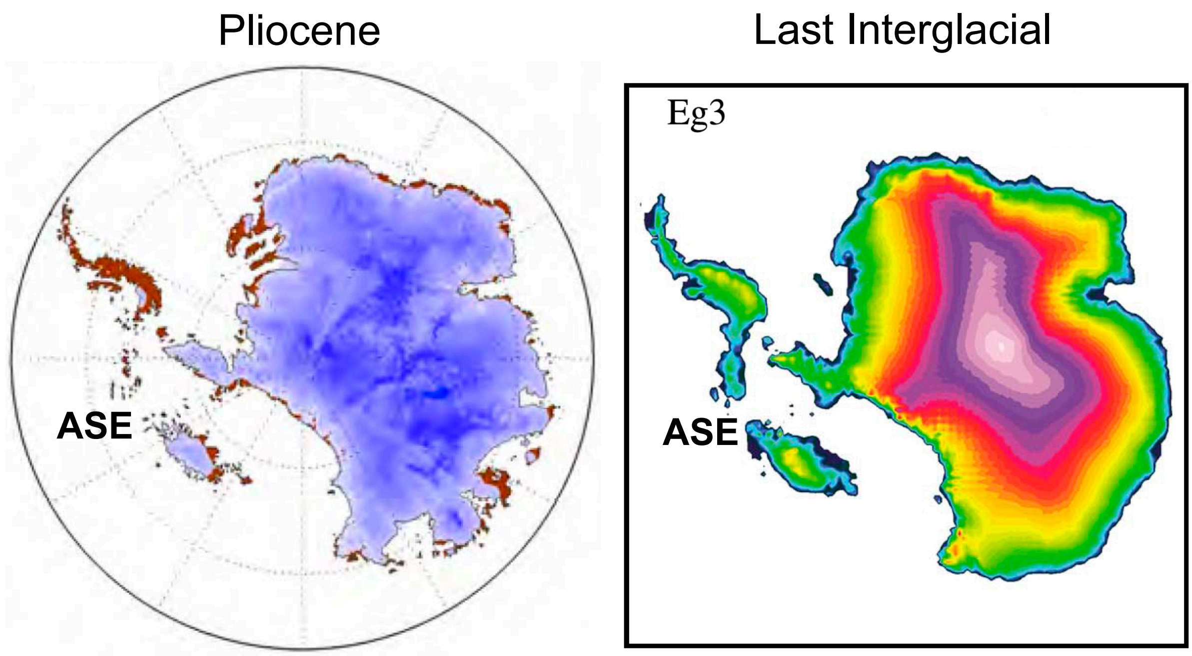


Figure F3. Seismic profile across continental rise of the eastern ASE with interpreted major sedimentary units and boundaries (modified from Uenzelmann-Neben and Gohl, 2014). Black arrow marks the location of a seismic crossing line. Proposed Site ASRE-05B is marked to a penetration depth of 1200 m.

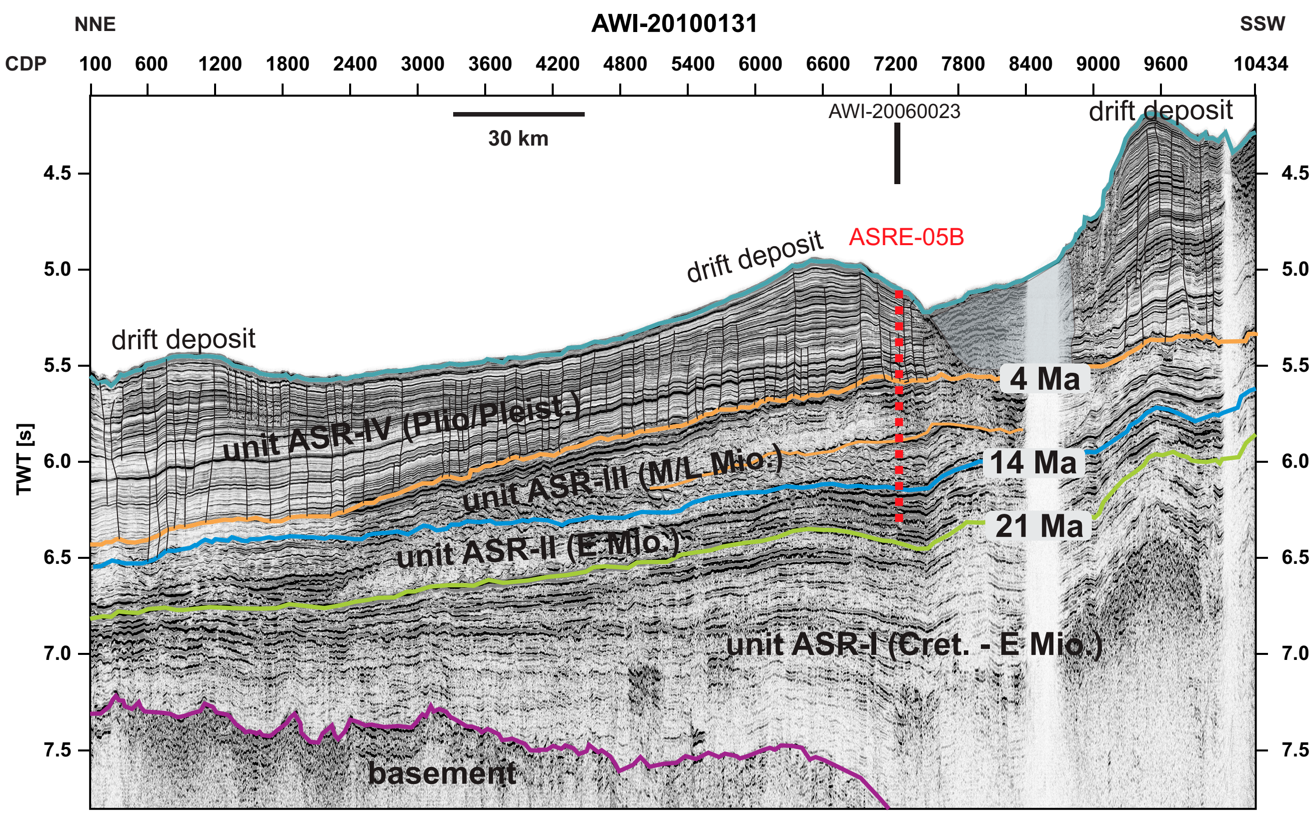


Figure F4. A. Composite of seismic profiles from the central Pine Island Trough across the outer shelf and slope of the eastern ASE shelf (adopted from Gohl et al., 2013b) with locations of three proposed drill sites. Main Unconformities ASS-u1 to ASS-u5 separate the main sedimentary Units ASS-1 to ASS-6 (blue) and are marked and annotated. Other dominant seismic horizons within the sediment units are line-drawn. Black arrows indicate seismic cross-lines. B. The seismic reflection pattern of the top segment of Profile AWI-20100134 across our Amundsen Sea drill sites has a large degree of similarity with that of (C) seismic Profile PD90-30 collected across the Eastern Basin of the Ross Sea shelf (Anderson and Bartek, 1992), which crosses DSDP Leg 28 Sites 270–272 (Hayes and Frakes, 1975). D. Composite of seismic profiles following the Dotson-Getz Trough of the western ASE shelf and across the upper slope (adopted from Gohl et al., 2013b) with three proposed drill sites. See Figure F1 for location of seismic profiles.

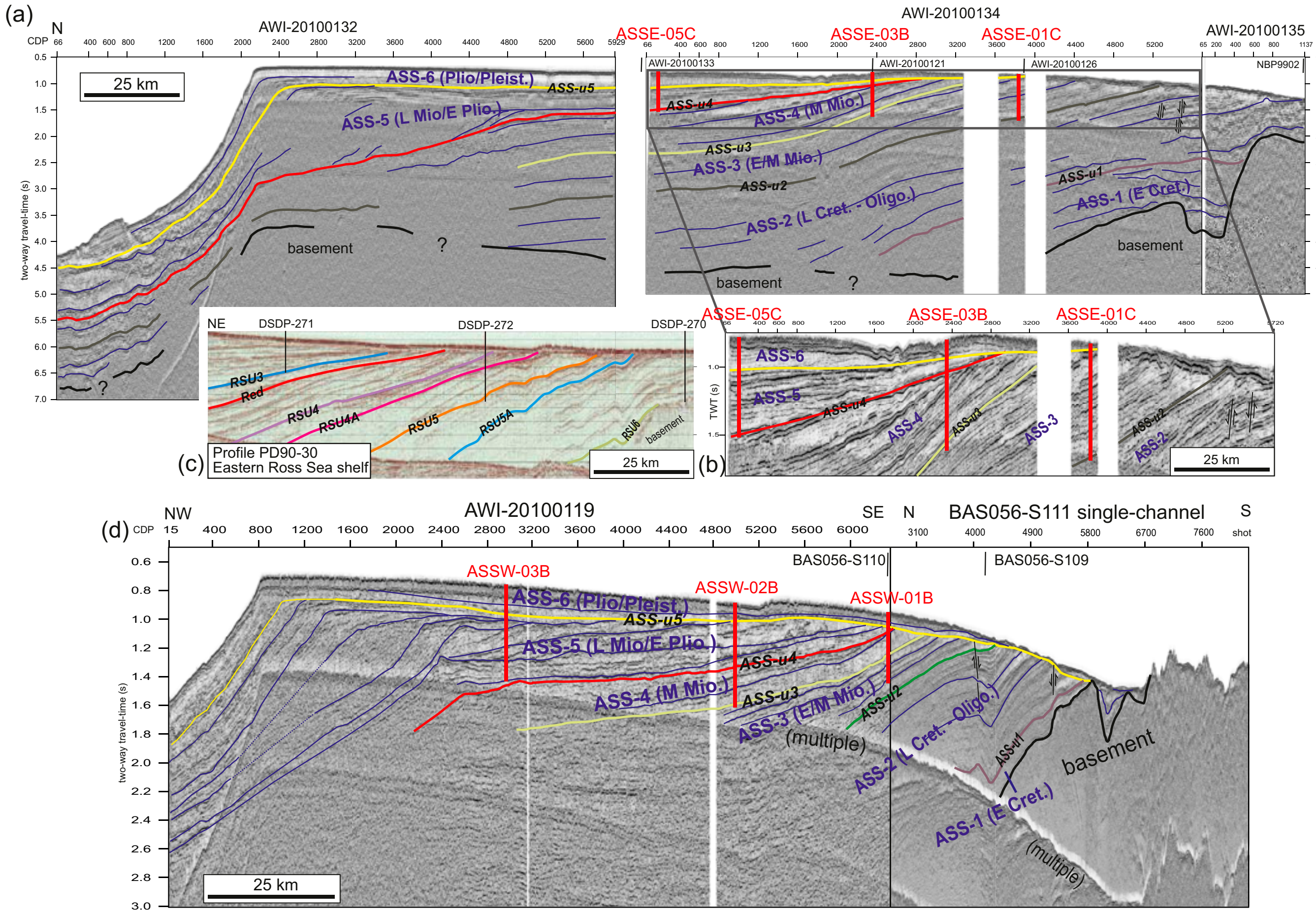


Figure F5. A. Seismic stratigraphic model of the eastern ASE shelf with sedimentary Units ASS-1 to ASS-6 and major Unconformities ASS-u1 to ASS-u5 (modified from Gohl et al., 2013a). Units ASS1–ASS4 correspond to sedimentary units of the ASE continental rise according to Uenzelmann-Neben and Gohl (2012). Units ASS-6 to ASS-1 are schematically backstripped to (B) the Pliocene, (C) the mid-late Miocene, (D) the middle Miocene, (E) the early Miocene and (F) the Cretaceous. NZ = New Zealand, MBL = Marie Byrd Land, WARS = West Antarctic Rift System.

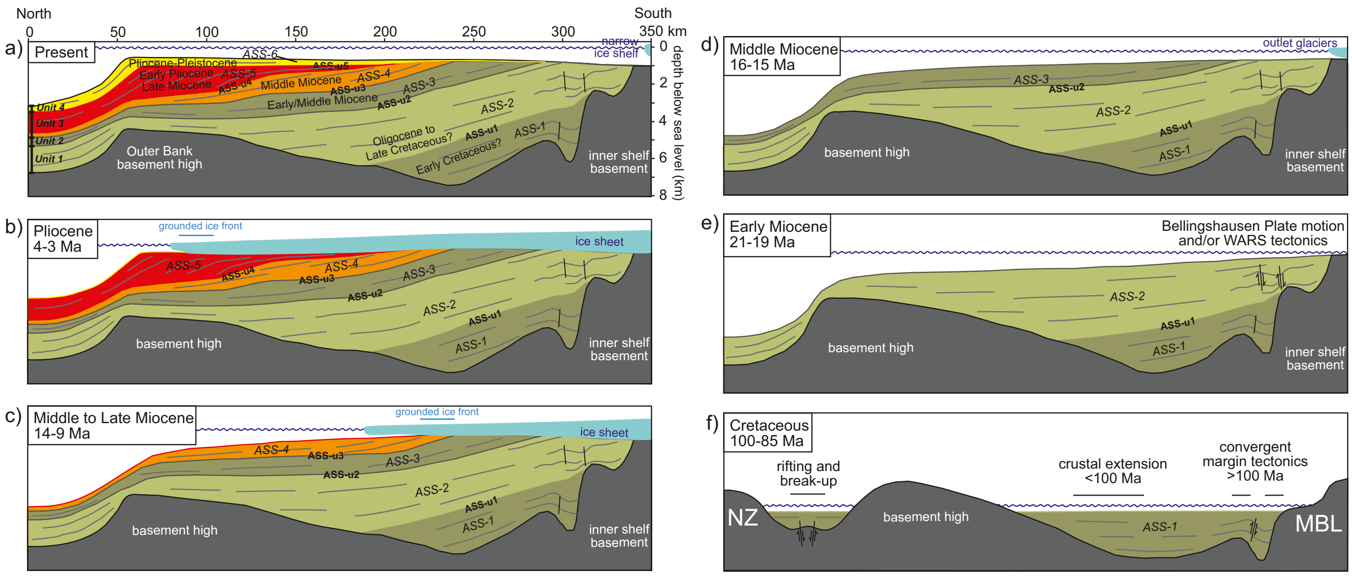


Figure F6. Planned coring and logging plans for the primary sites. See Table T3 for operations and time estimates.

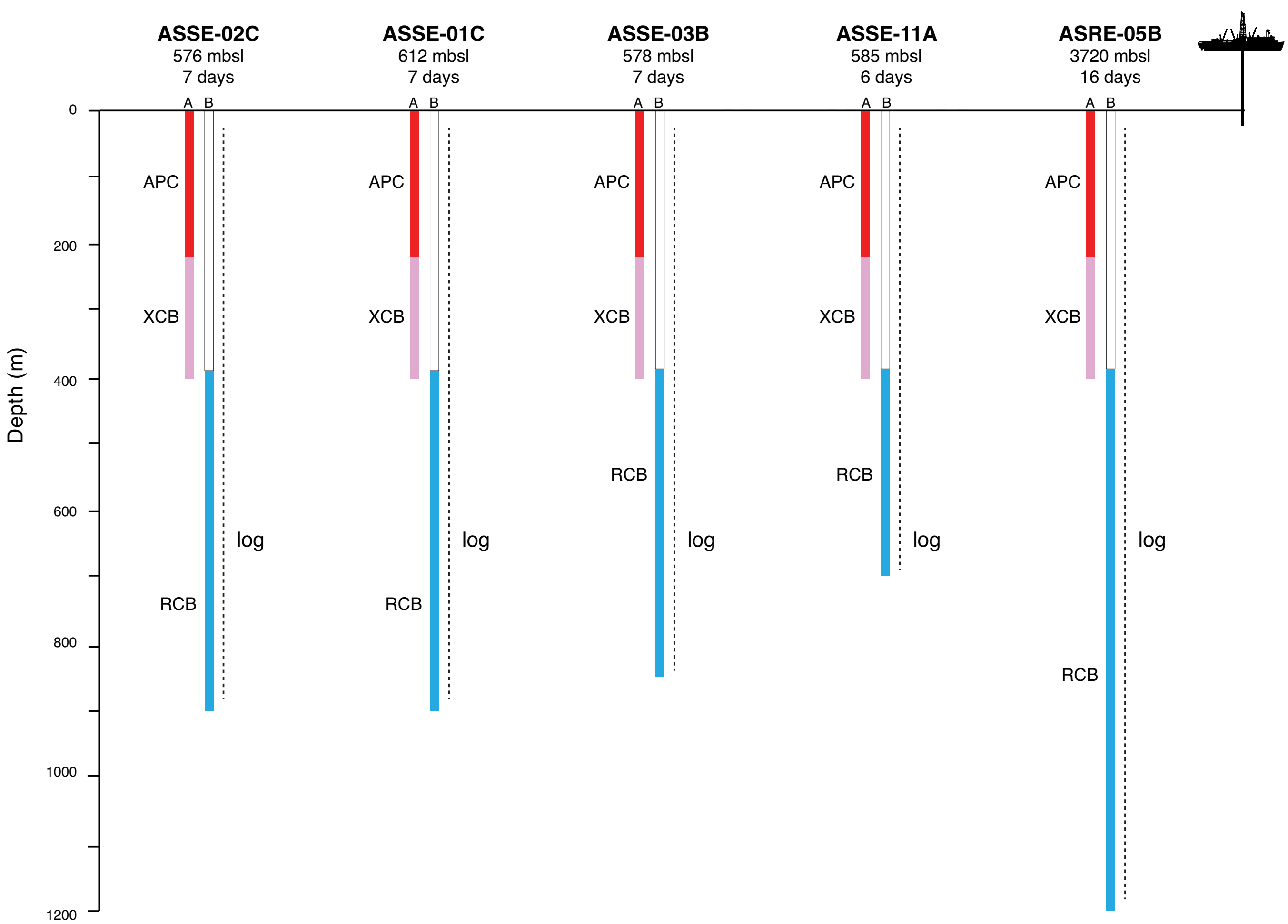
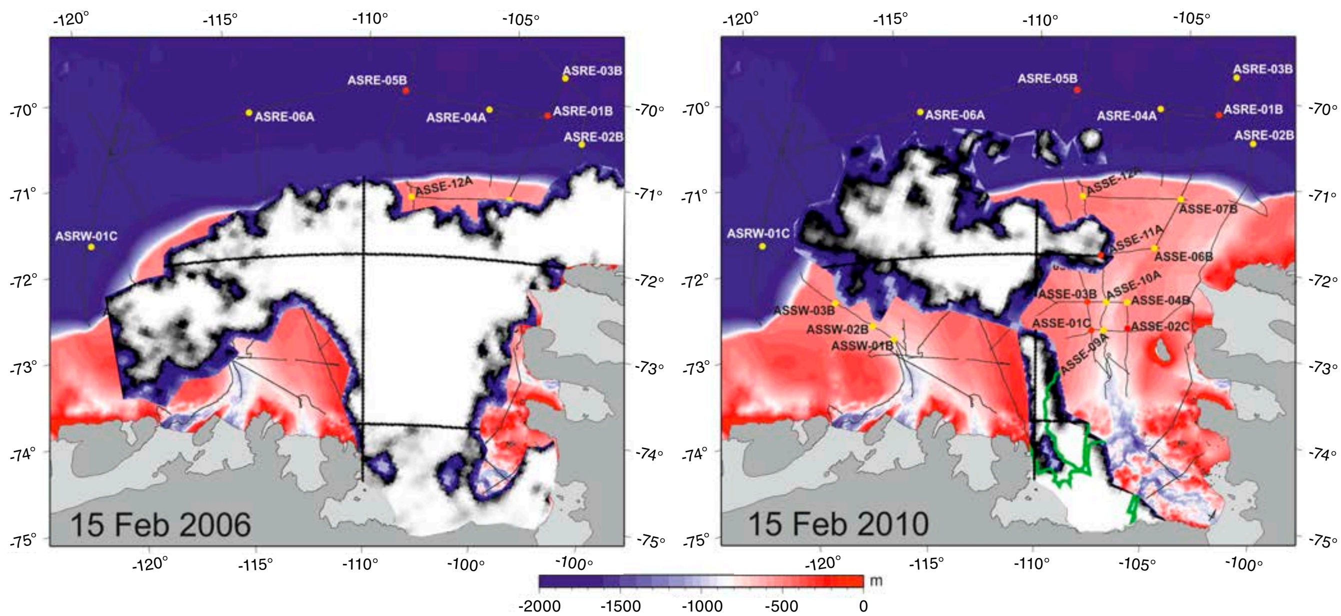


Figure F7. Maps illustrating the ASE with large ice cover in mid-February 2006 (worst case) and little ice cover in mid-February 2010 (best case). Both cases show the extremes within the past 12 y. Ice-cover data are from AMSR-E Sea Ice Maps produced by IUP, University of Bremen (**https://seaice.uni-bremen.de/sea-ice-concentration**).

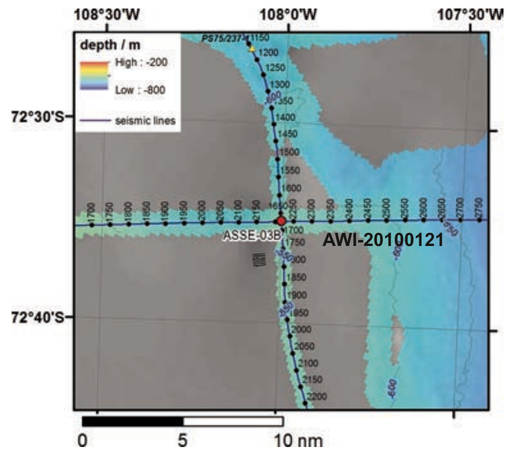


Site Summaries

Figure AF1. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-03B on seismic reflection (MCS) Lines AWI-20100134 and AWI-20100121. Bottom: MCS Line AWI-20100134 with location of proposed Site ASSE-03B and crossing MCS Line AWI-20100121 (SP 2220). Lines include shot point (SP) numbers.

Site ASSE-03B

Priority:	Primary
Position:	72.582°S, 108.002°W
Water depth (m):	578
Target drilling depth (mbsf):	850
Approved maximum penetration (mbsf):	850
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100134: SP 1674, CDP 2396 • AWI-20100121: SP 2220, CDP 3079
Objective(s):	• Recovery of glacial sediment sequences from mid-Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5, ASS-u4, and ASS-u3
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 850 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



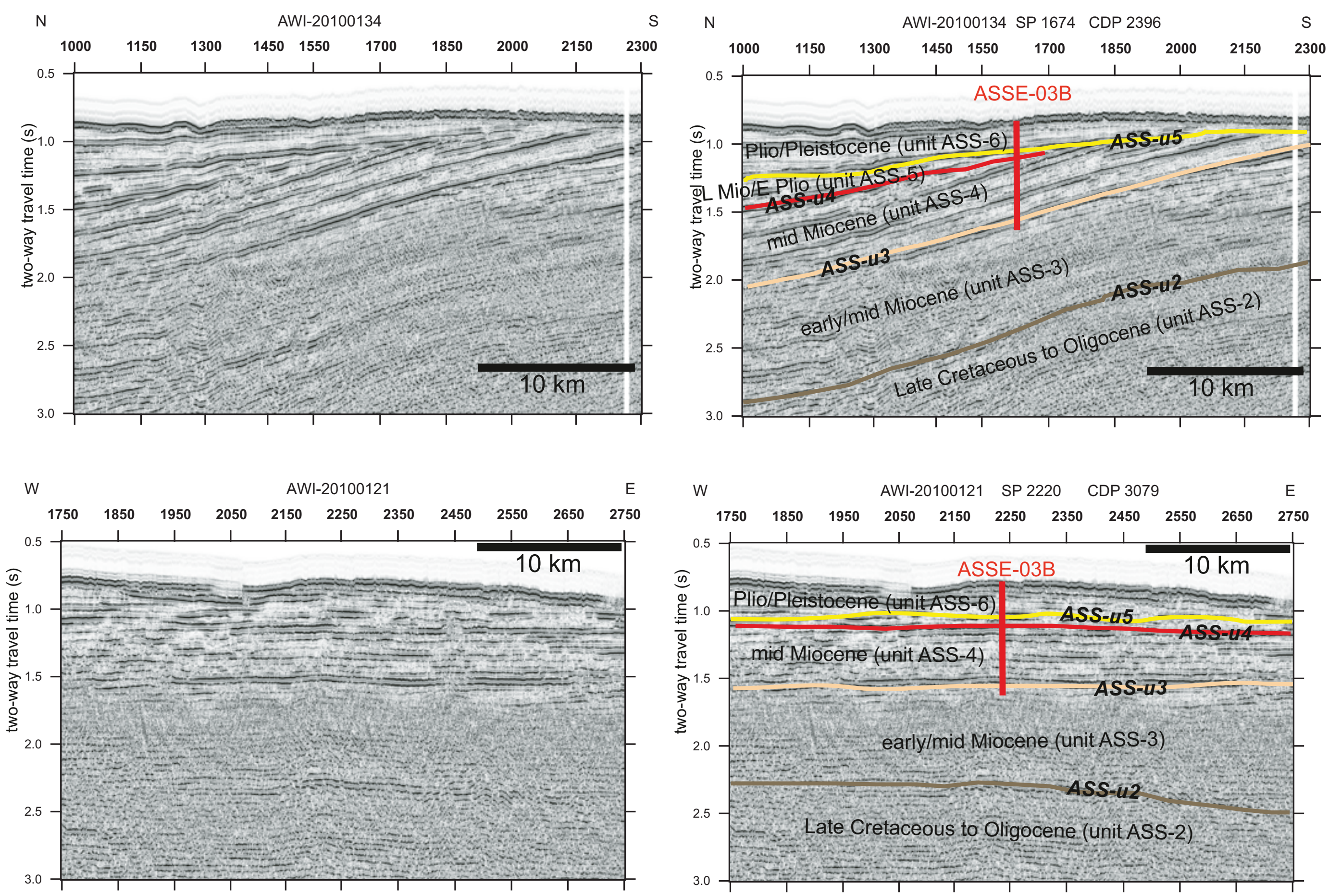
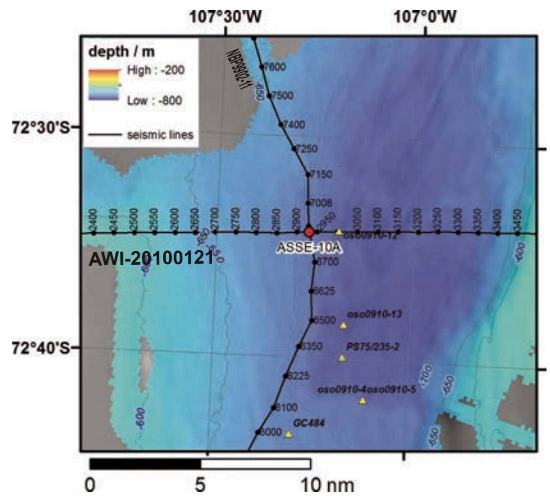


Figure AF2. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-10A on MCS Line AWI-20100121 and SCS Line NBP9902-11. Bottom: MCS Line AWI-20100121 with location of proposed Site ASSE-10A and crossing SCS Line NBP9902-11 (SP 6900).

Site ASSE-10A

Priority:	Alternate
Position:	72.572°S, 107.267°W
Water depth (m):	733
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100121: SP 2930, CDP 4062 SCS data: • NBP9902-11: SP 6900
Objective(s):	• Recovery of glacial sediment sequences from early/mid-Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5, ASS-u4, and ASS-u3
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



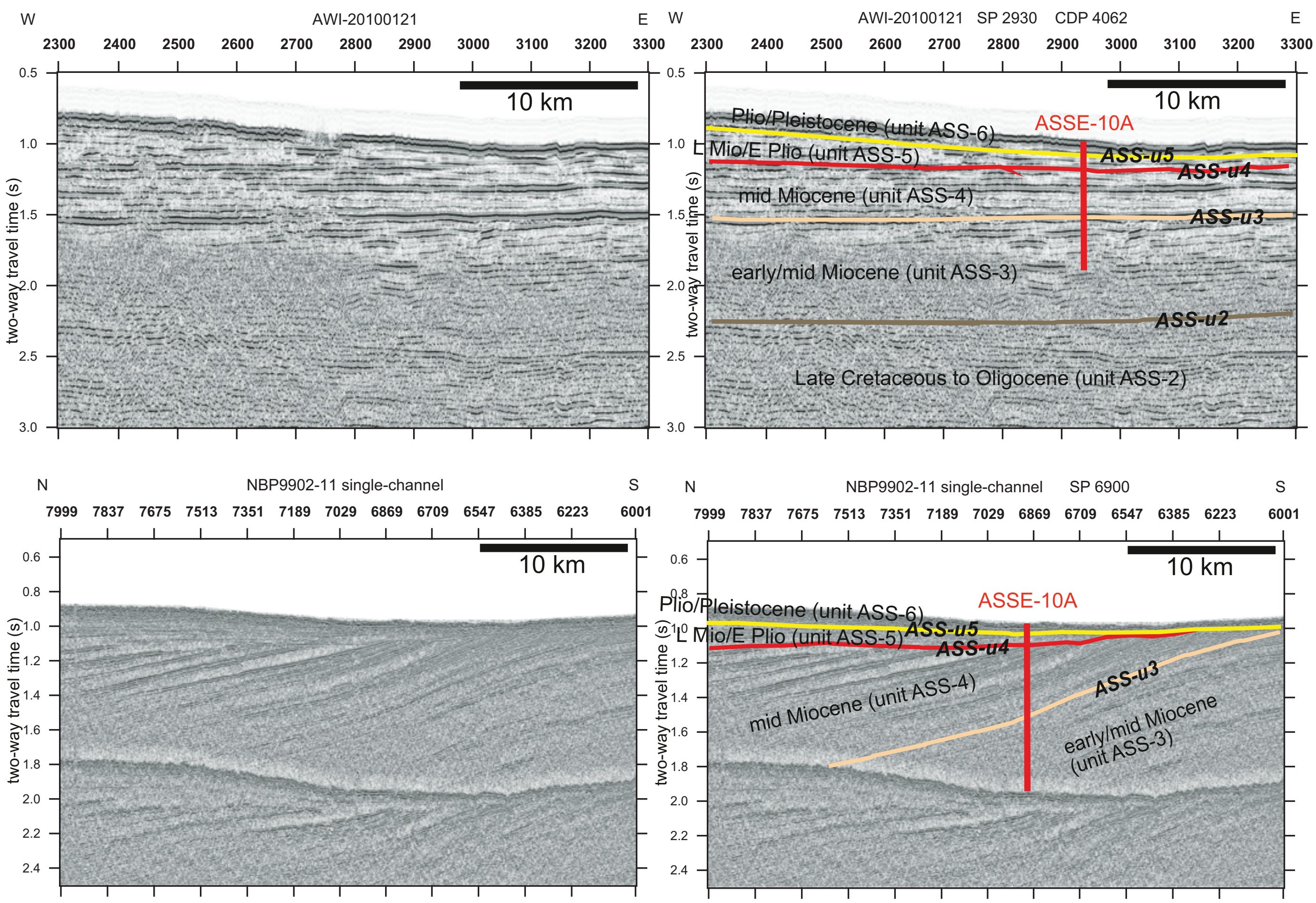
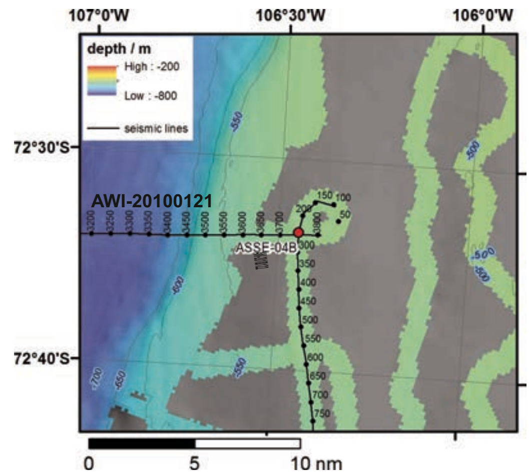


Figure AF3. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-04B on MCS Lines AWI-20100122 and AWI-20100121. Bottom: MCS Line AWI-20100122 with location of proposed Site ASSE-04B and MCS Line AWI-20100121 (SP 3748).

Site ASSE-04B

Priority:	Alternate
Position:	72.558°S, 106.448°W
Water depth (m):	538
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100122: SP 250, CDP 456 • AWI-20100121: SP 3748, CDP 5163
Objective(s):	• Recovery of glacial sediment sequences from mid-Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5, ASS-u4, and ASS-u3
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



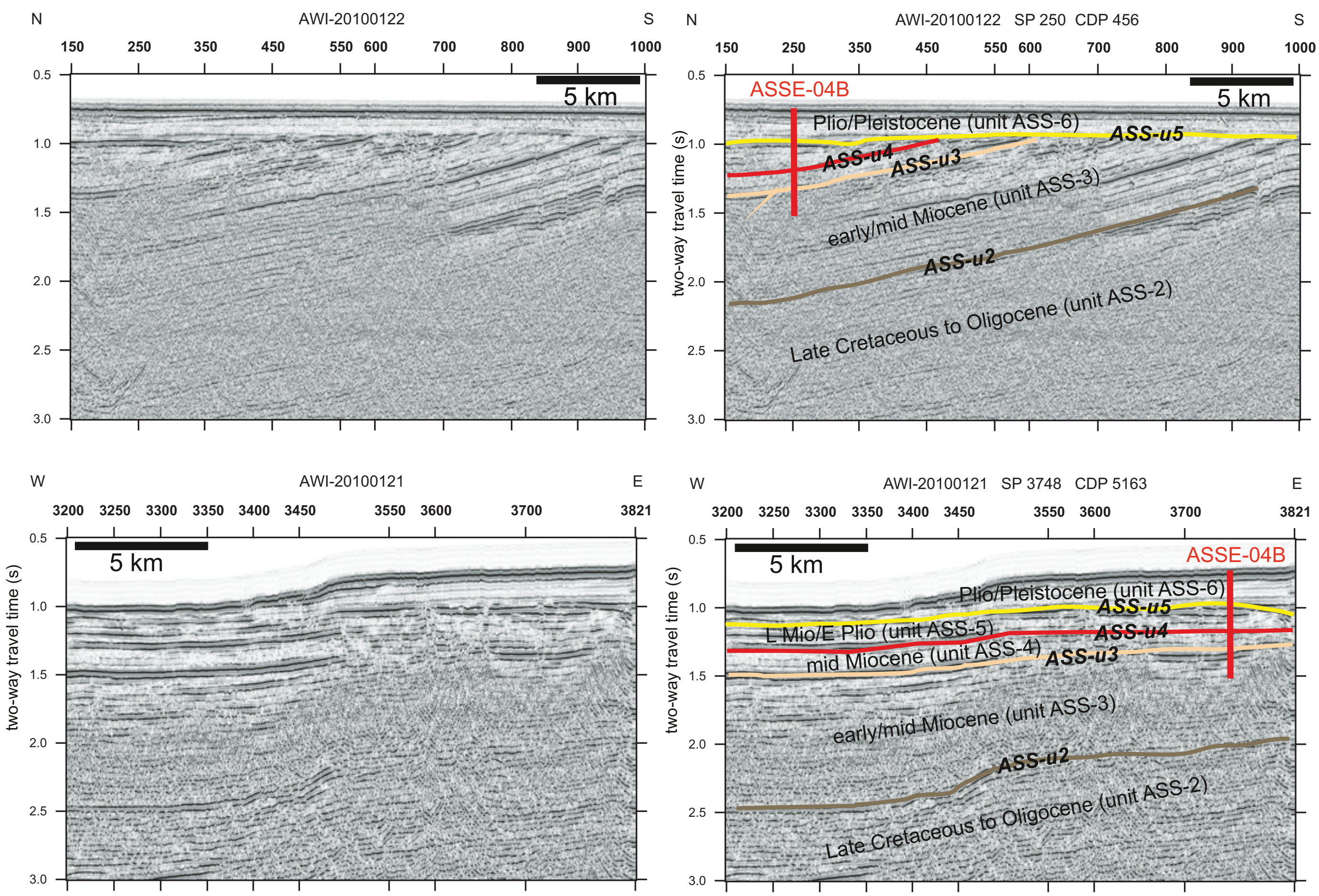
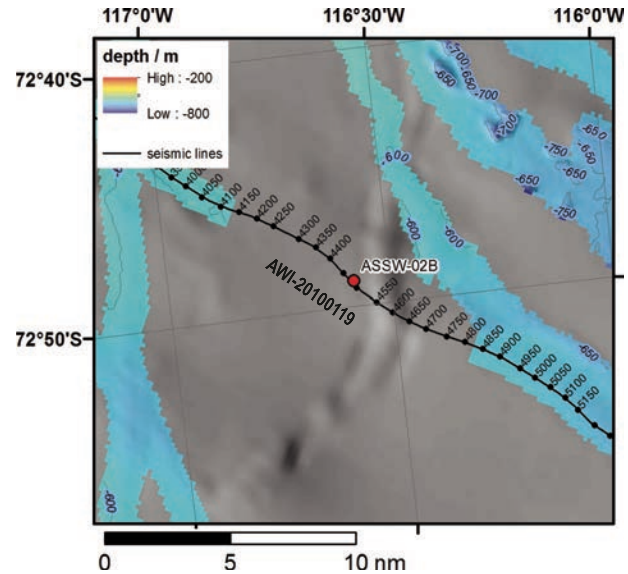


Figure AF4. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSW-02B on MCS Line AWI-20100119. Bottom: MCS Line AWI-20100119 with location of proposed Site ASSW-02B.

Site ASSW-02B

Priority:	Alternate
Position:	72.817°S, 116.583°W
Water depth (m):	654
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100119: SP 4490, CDP 5000
Objective(s):	• Recovery of glacial sediment sequences from mid-Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5, ASS-u4, and ASS-u3
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



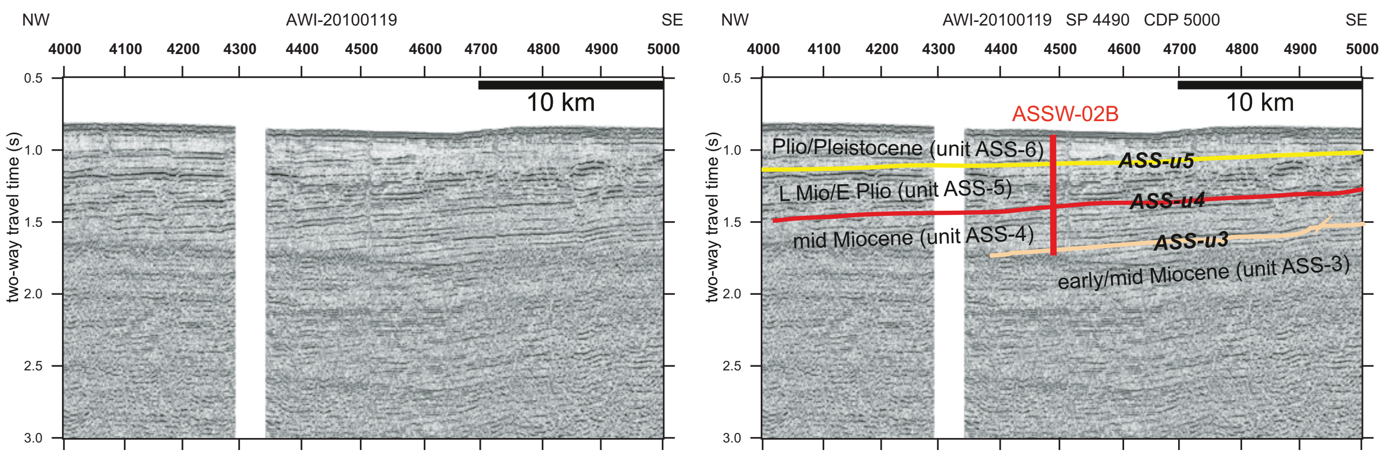
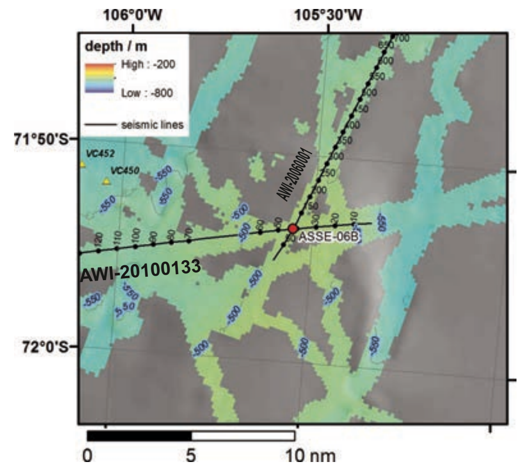


Figure AF5. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-06B on MCS Lines AWI-20060001 and AWI-20100133. Bottom: MCS Line AWI-20060001 with location of proposed Site ASSE-06B and MCS Line AWI-20100133 (SP 42).

Site ASSE-06B

Priority:	Alternate
Position:	71.893°S, 105.552°W
Water depth (m):	514
Target drilling depth (mbsf):	950
Approved maximum penetration (mbsf):	950
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060001: SP 100, CDP 157 • AWI-20100133: SP 42, CDP 203
Objective(s):	• Recovery of glacial sediment sequences from mid-/late Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5 and ASS-u4
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 950 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



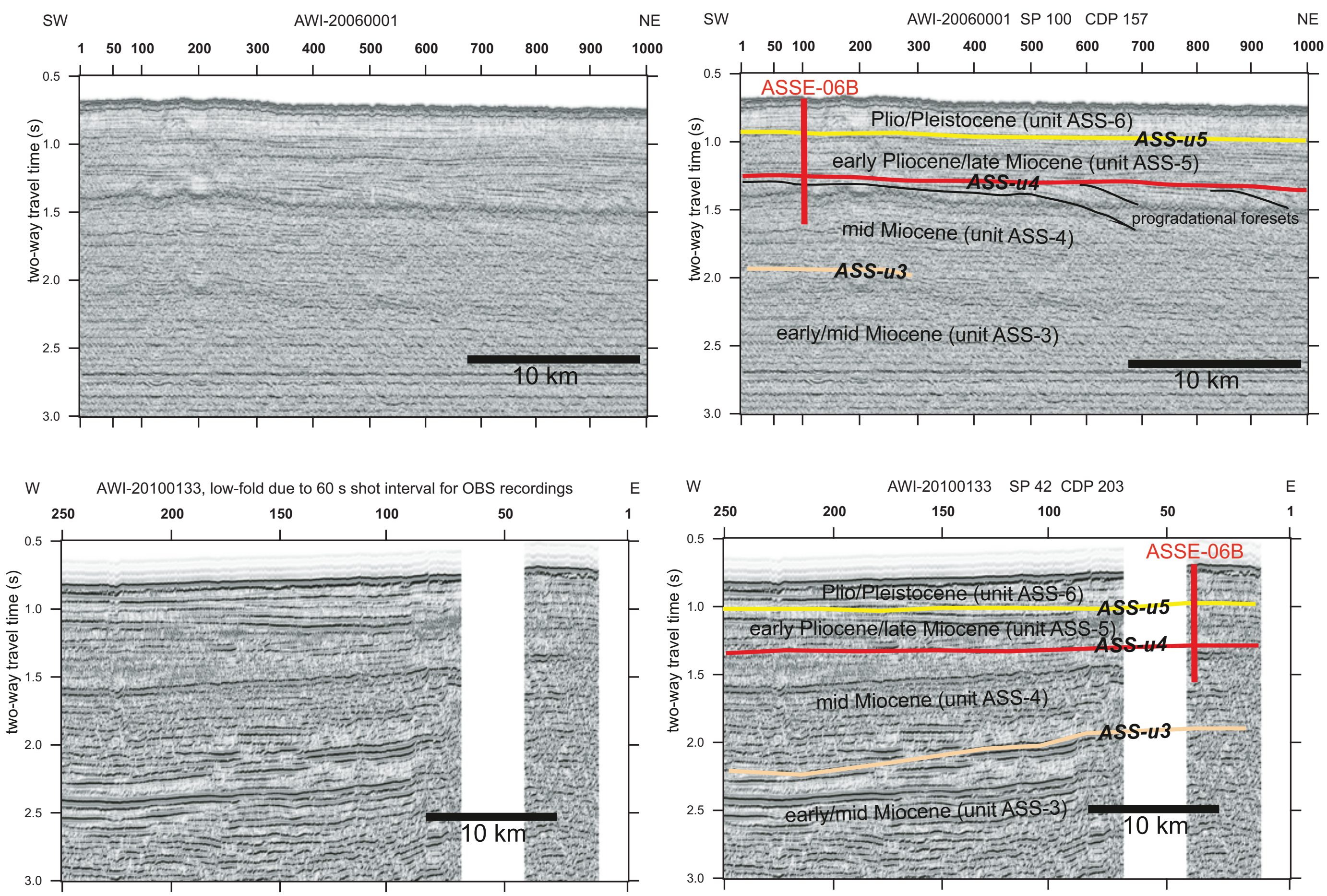
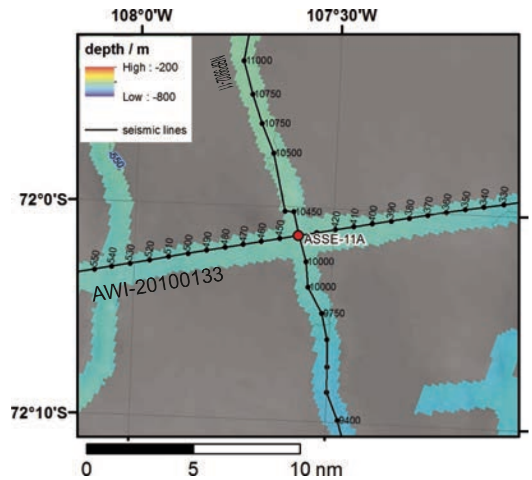


Figure AF6. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-11A on MCS Line AWI-20100133 and SCS Line NBP9902-11. Bottom: MCS Line AWI-20100133 with location of proposed Site ASSE-11A and SCS Line NBP9902-11 (SP 10150).

Site ASSE-11A

Priority:	Primary
Position:	72.022°S, 107.588°W
Water depth (m):	585
Target drilling depth (mbsf):	700
Approved maximum penetration (mbsf):	700
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060133: SP 440, CDP 1650 SCS data: • NBP9902-11: SP 10150
Objective(s):	• Recovery of glacial sediment sequences from mid-/late Miocene to Plio/Pleistocene • Transitions to full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformities ASS-u5 and ASS-u4
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 700 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



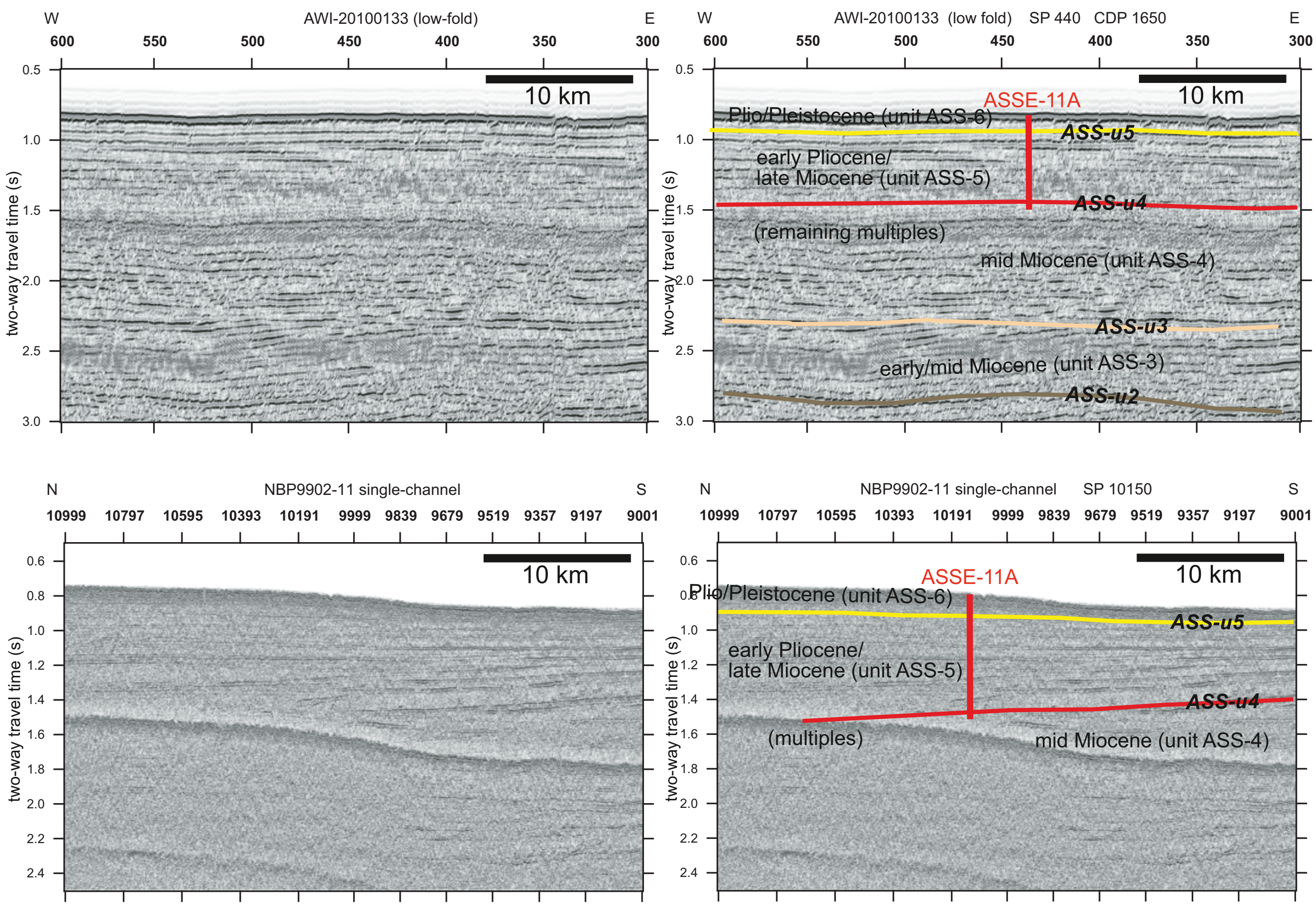
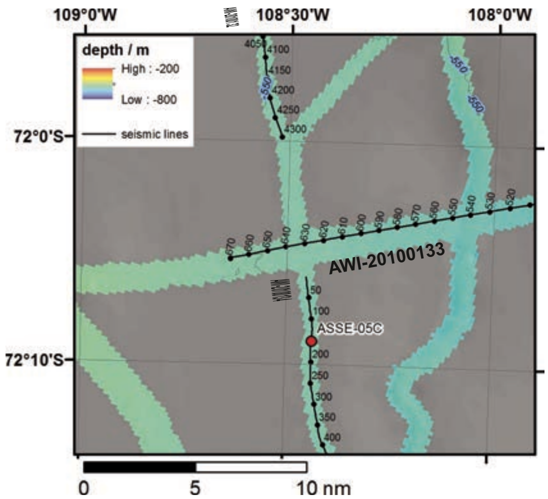


Figure AF7. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-05C on MCS Line AWI-20100134. Crossing MCS Line AWI-20100133 (projected to SP 630) is 10 km north of the site. Bottom: MCS Line AWI-20100134 with location of proposed Site ASSE-05C.

Site ASSE-05C

Priority:	Alternate
Position:	72.149°S, 108.436°W
Water depth (m):	582
Target drilling depth (mbsf):	800
Approved maximum penetration (mbsf):	800
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060134: SP 150, CDP 340 • AWI-20100133: crosses 10 km north of drill site, projected to SP 630, CDP 2262
Objective(s):	• Recovery of glacial sediment sequences from late Miocene to Plio/Pleistocene • Records of full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformity ASS-u5 (and perhaps ASS-u4)
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 800 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



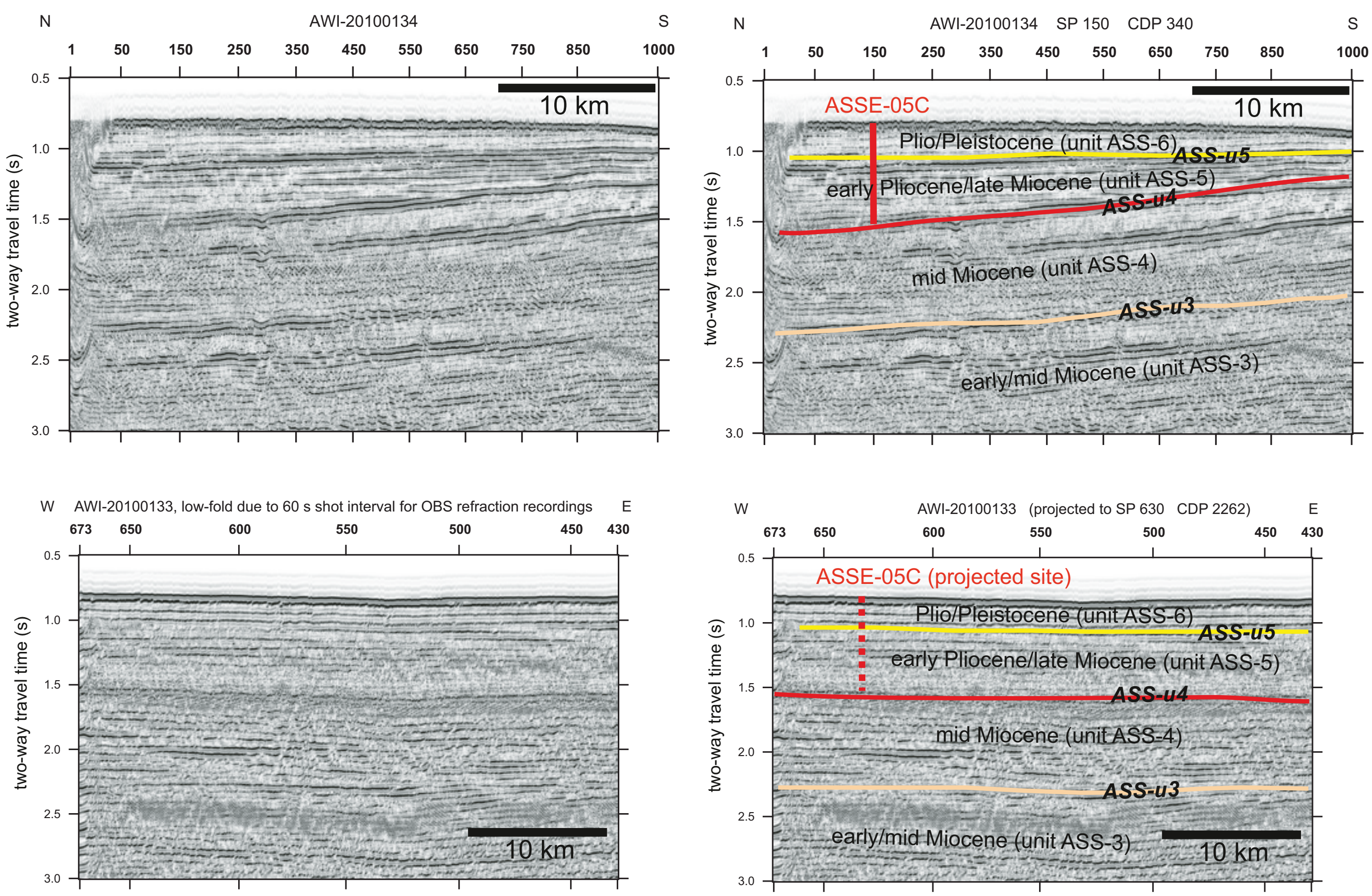
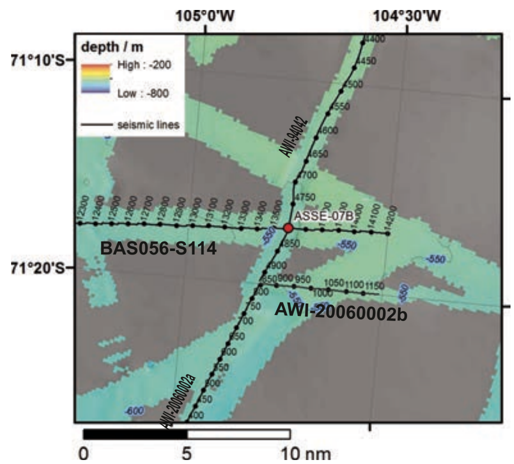


Figure AF8. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-07B on MCS Line AWI-94042 and SCS Line BAS056-S114. Bottom: MCS Line AWI-94042 with location of proposed Site ASSE-07B and SCS Line BAS056-S114 (SP 13600).

Site ASSE-07B

Priority:	Alternate
Position:	71.287°S, 104.750°W
Water depth (m):	540
Target drilling depth (mbsf):	600
Approved maximum penetration (mbsf):	600
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-94042: SP 4800, CDP 8481 SCS data: • BAS056-S114: SP 13600
Objective(s):	• Recovery of glacial sediment sequences from early Pliocene to Pleistocene • Records of full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformity ASS-u5
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 600 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



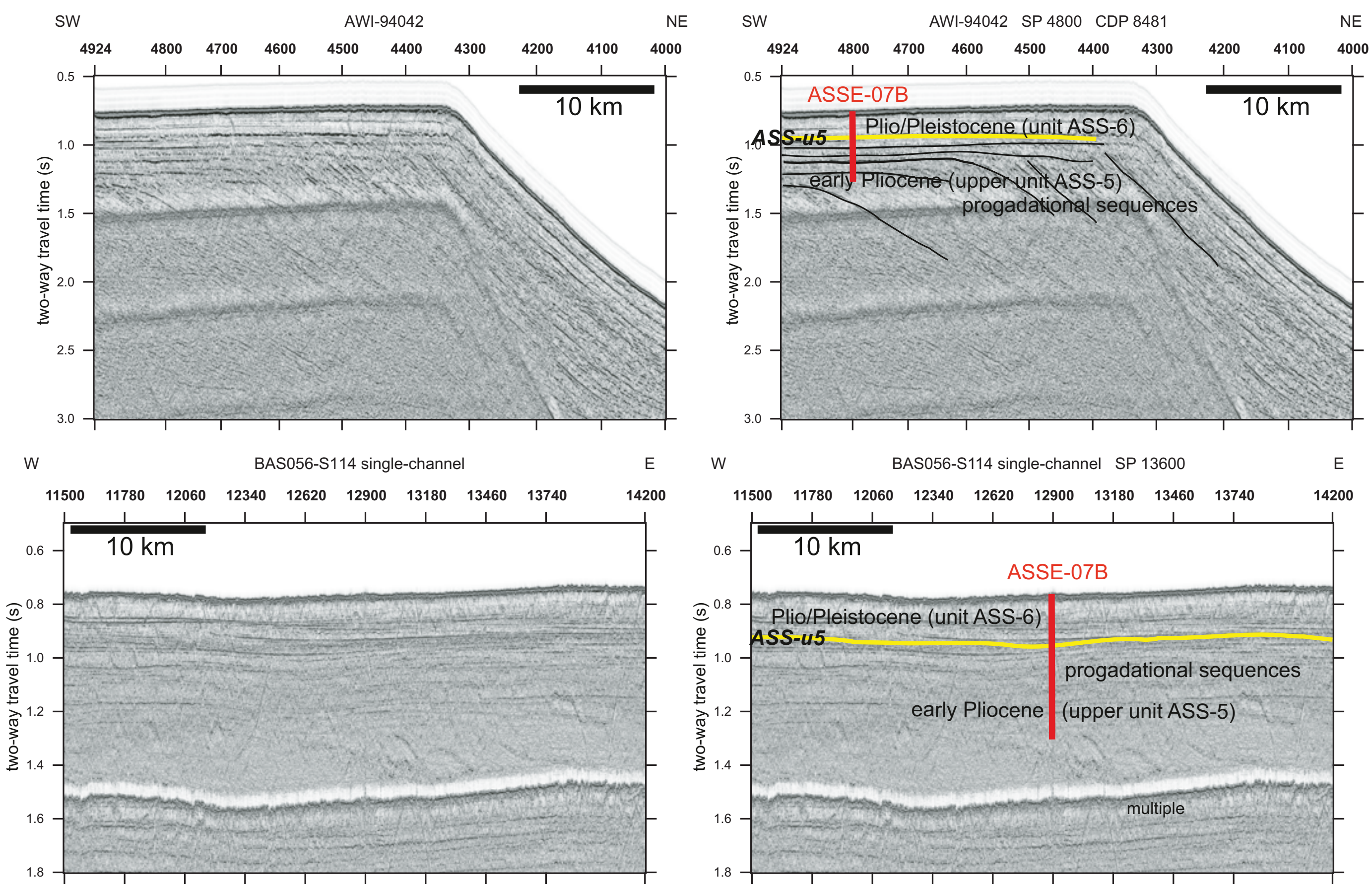
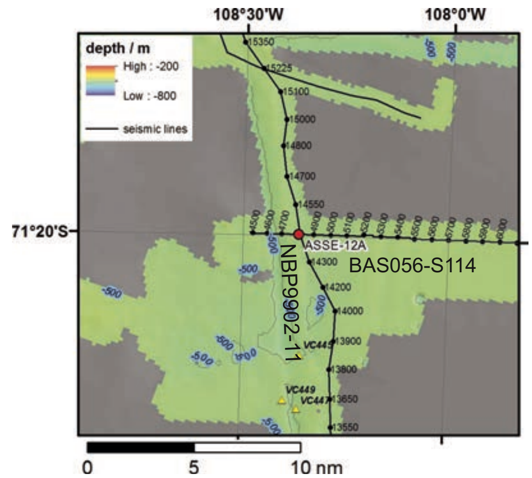


Figure AF9. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-12A on SCS Lines BAS056-S114 and NBP9902-11. Bottom: SCS Line BAS056-S114 with location of proposed Site ASSE-12A and SCS Line NBP9902-11 (SP 14400).

Site ASSE-12A

Priority:	Alternate
Position:	71.332°S, 108.365°W
Water depth (m):	495
Target drilling depth (mbsf):	600
Approved maximum penetration (mbsf):	600
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map SCS data: • BAS056-S114: SP 4806 • NBP9902-11: SP 14400
Objective(s):	• Recovery of glacial sediment sequences of Pliocene and Pleistocene • Records of early Pliocene warm period and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformity ASS-u5
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 600 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



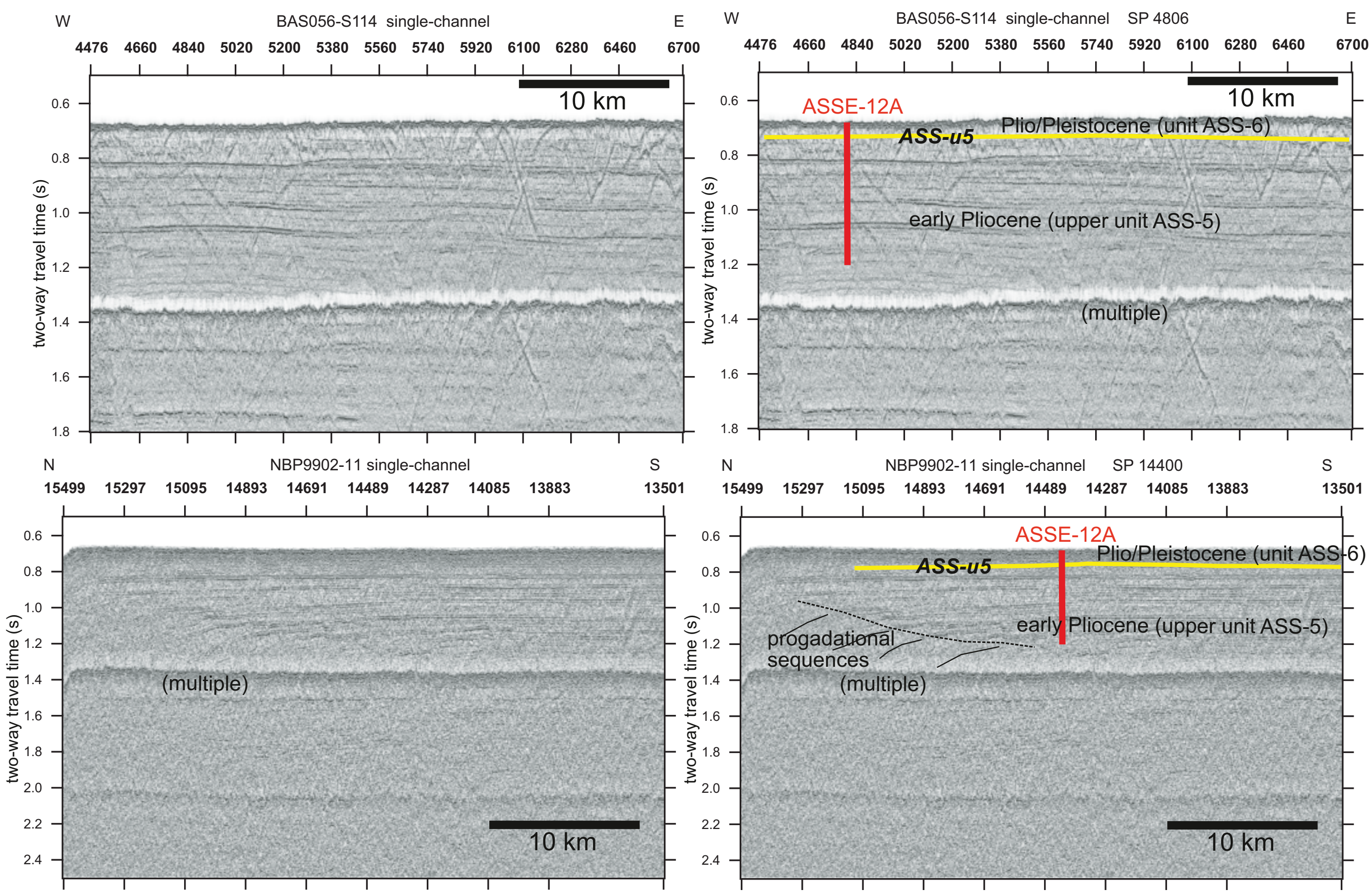
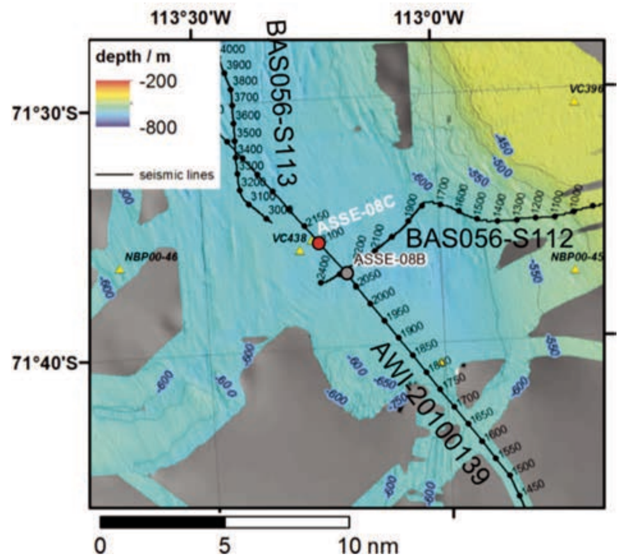


Figure AF10. Top: Map with multibeam bathymetry swaths showing location of proposed Site ASSE-08C on MCS Line AWI-20100139. SCS Line BAS056-S112 (SP 2297) crosses 3.1 km southeast of the site. Bottom: MCS Line AWI-20100139 with location of proposed Site ASSE-08C.

Site ASSE-08C

Priority:	Alternate
Position:	71.597°S, 113.255°W
Water depth (m):	644
Target drilling depth (mbsf):	950
Approved maximum penetration (mbsf):	950
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100139: SP 2100, CDP 3078 SCS data: • BAS56-S112: crosses AWI-20100139 3.1 km southeast of drill site, projected to SP 2297
Objective(s):	• Recovery of glacial sediment sequences from late Miocene to Plio/Pleistocene • Records of full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformity ASS-u5
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 950 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



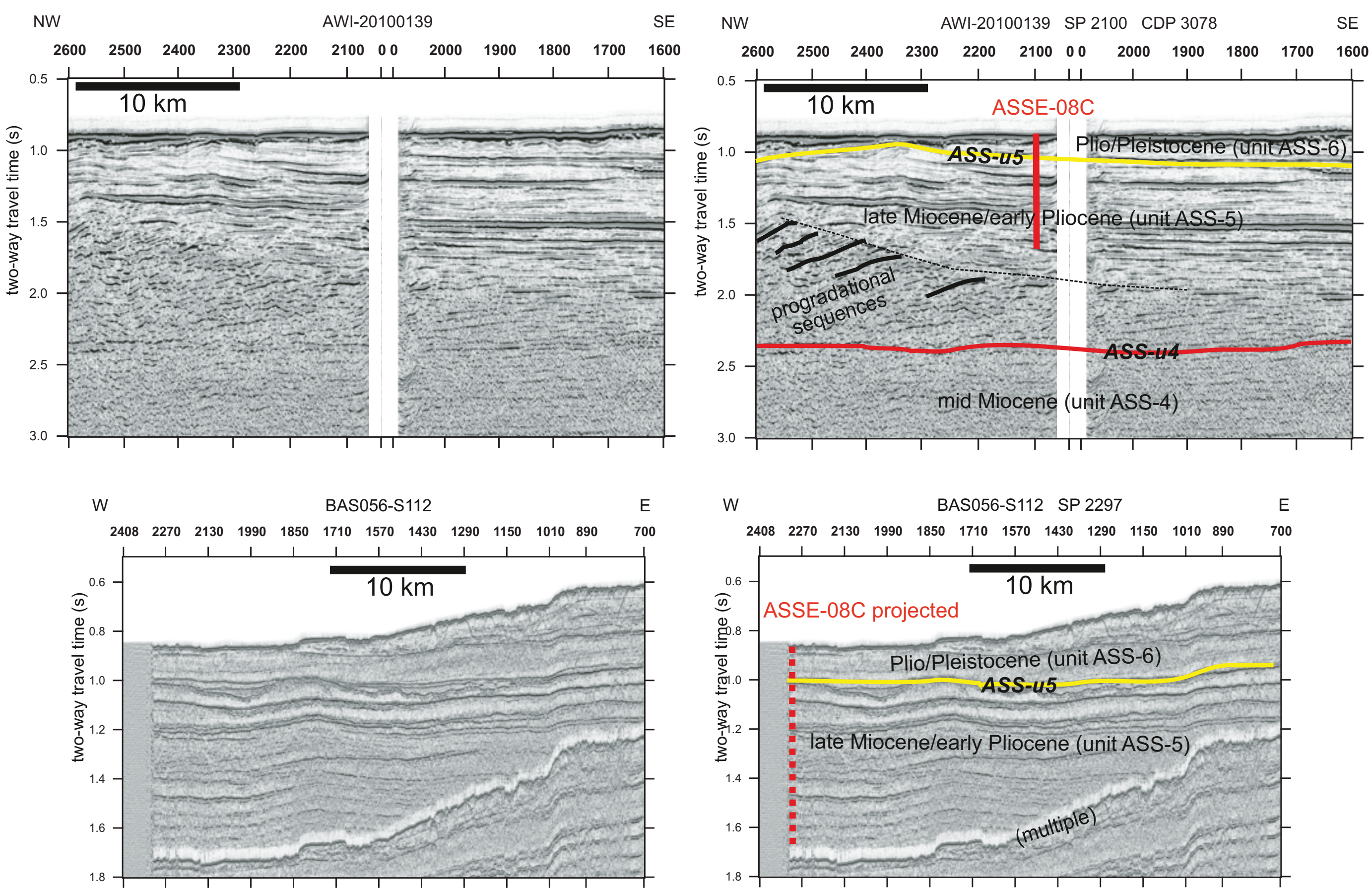
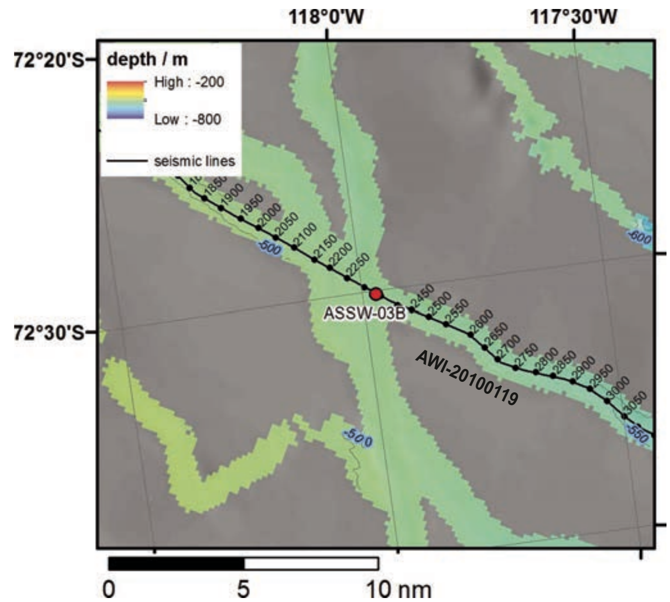


Figure AF11. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSW-03B on MCS Line AWI-20100119. Bottom: MCS Line AWI-20100119 with location of proposed Site ASSW-03B.

Site ASSW-03B

Priority:	Alternate
Position:	72.502°S, 117.972°W
Water depth (m):	538
Target drilling depth (mbsf):	850
Approved maximum penetration (mbsf):	850
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100119: SP 2330, CDP 2602
Objective(s):	• Recovery of glacial sediment sequences from late Miocene to Plio/Pleistocene • Records of full glacial conditions, early Pliocene warm period, and cooling in the late Pliocene • CDW events • Penetrating truncational Unconformity ASS-u5 (and perhaps ASS-u4)
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 850 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences



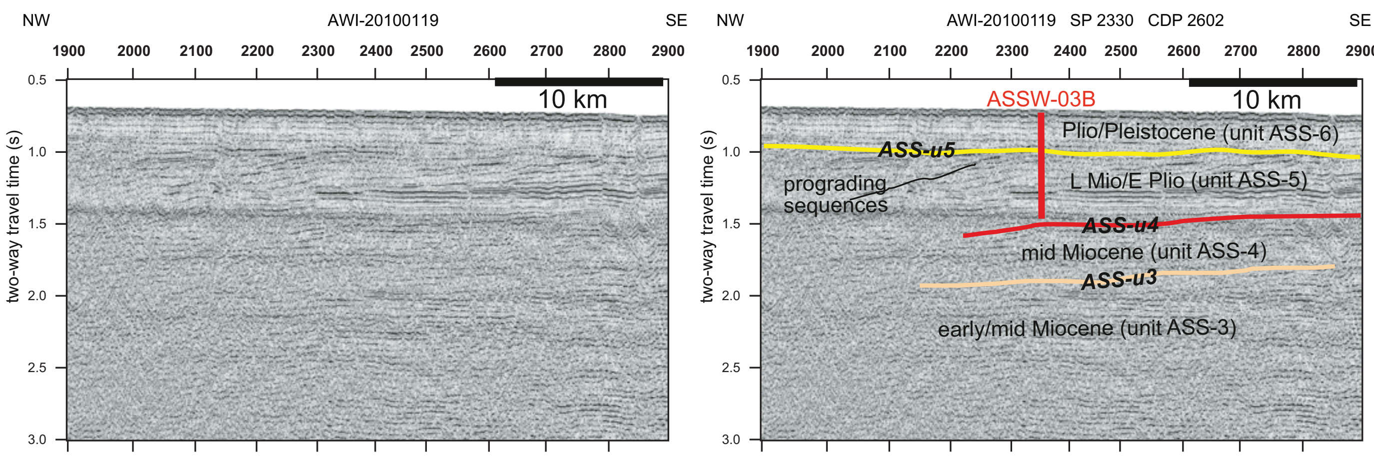
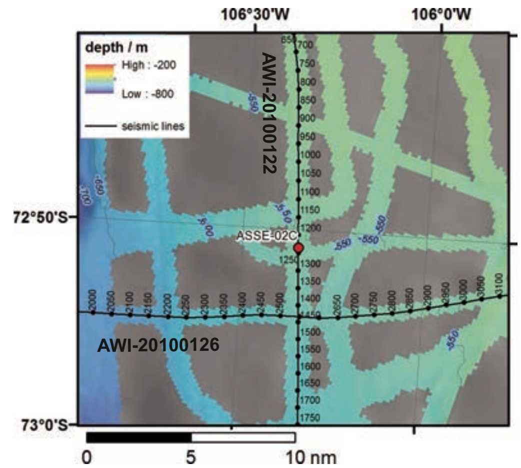


Figure AF12. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-02C on MCS Line AWI-20100122. Crossing MCS line AWI-20100126 (projected to SP 2549) is 7 km south of the site. Bottom: MCS Line AWI-20100122 with location of proposed Site ASSE-02C.

Site ASSE-02C

Priority:	Primary
Position:	72.848°S, 106.347°W
Water depth (m):	576
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100122: SP 1235, CDP 1759 • AWI-20100126: crosses AWI-20100122 7 km south of drill site, projected to SP 2549, CDP 3504
Objective(s):	• Recovery of records from preglacial times (back to Cretaceous–Paleocene) to preglacial to glacial transition (E/O boundary) • Onset of first glacial period of West Antarctica • Penetrating truncational Unconformities ASS-u5 and ASS-u2 • Records of Marie Byrd Land dome uplift in relation to early glacial phases
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences; preglacial mudstone and/or sandstone



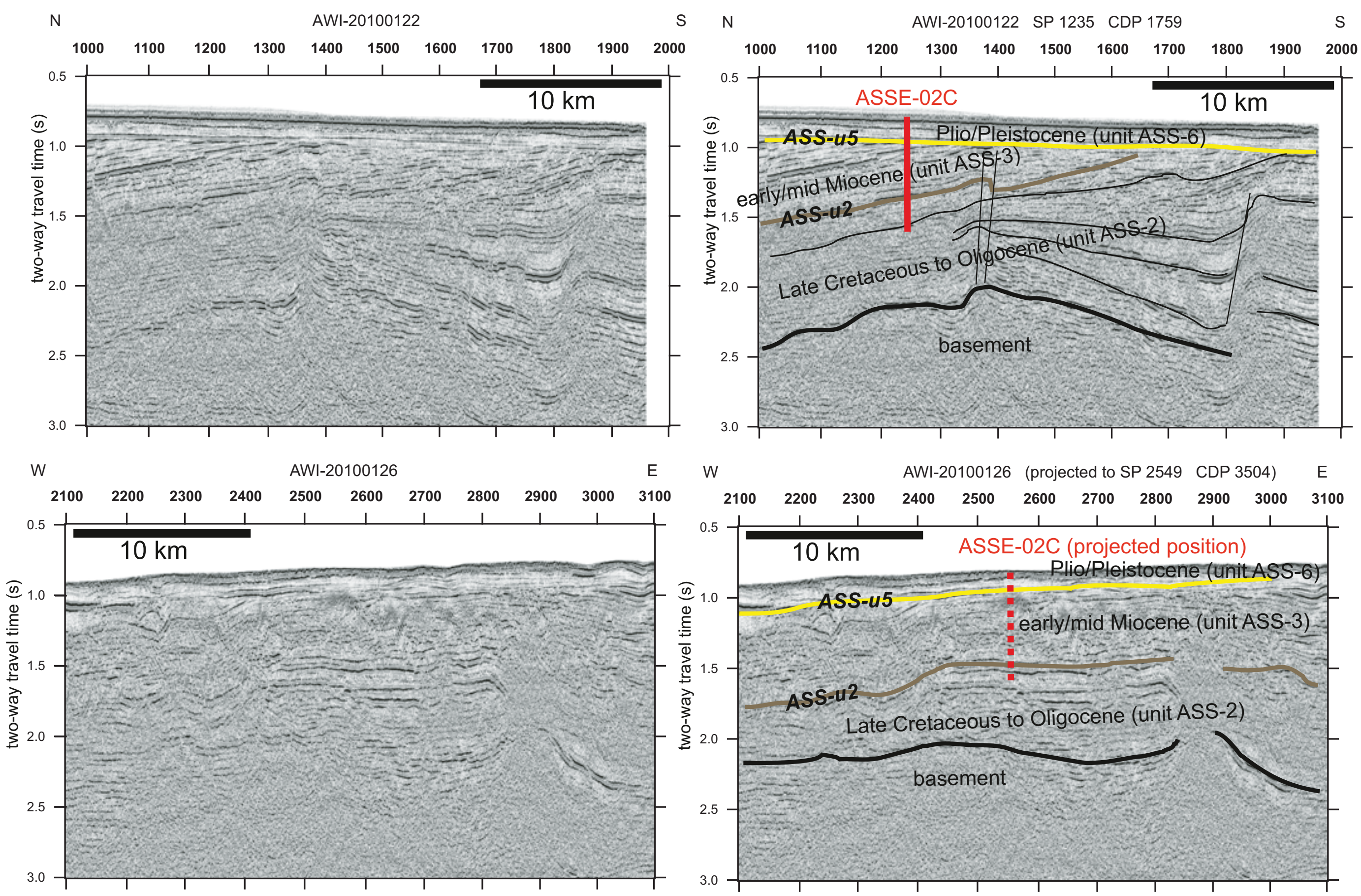
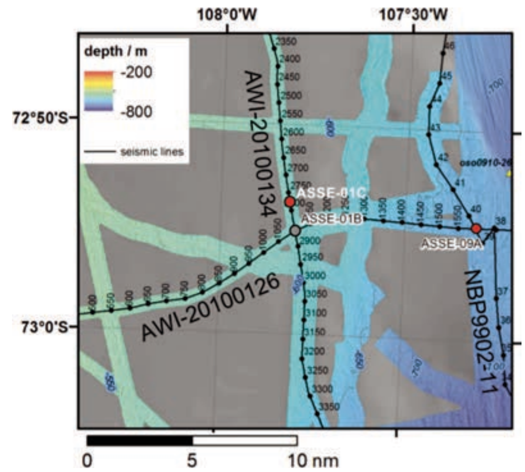


Figure AF13. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSE-01C on MCS Line AWI-20100134. Crossing MCS Line AWI-20100126 (projected to SP 1103) is 2.7 km south of the site. Bottom: MCS Line AWI-20100134 with location of proposed Site ASSE-01C.

Site ASSE-01C

Priority:	Primary
Position:	72.895°S, 107.814°W
Water depth (m):	612
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100134: SP 2775, CDP 3823 • AWI-20100126: crosses 2.7 km south of drill site, projected to SP 1103, CDP 1563
Objective(s):	• Recovery of records from preglacial times (back to Cretaceous–Paleocene) to preglacial to glacial transition (E/O boundary) • Onset of first glacial period of West Antarctica • Penetrating truncational Unconformities ASS-u5 and ASS-u2 • Records of Marie Byrd Land dome uplift in relation to early glacial phases
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences; preglacial mudstone and/or sandstone



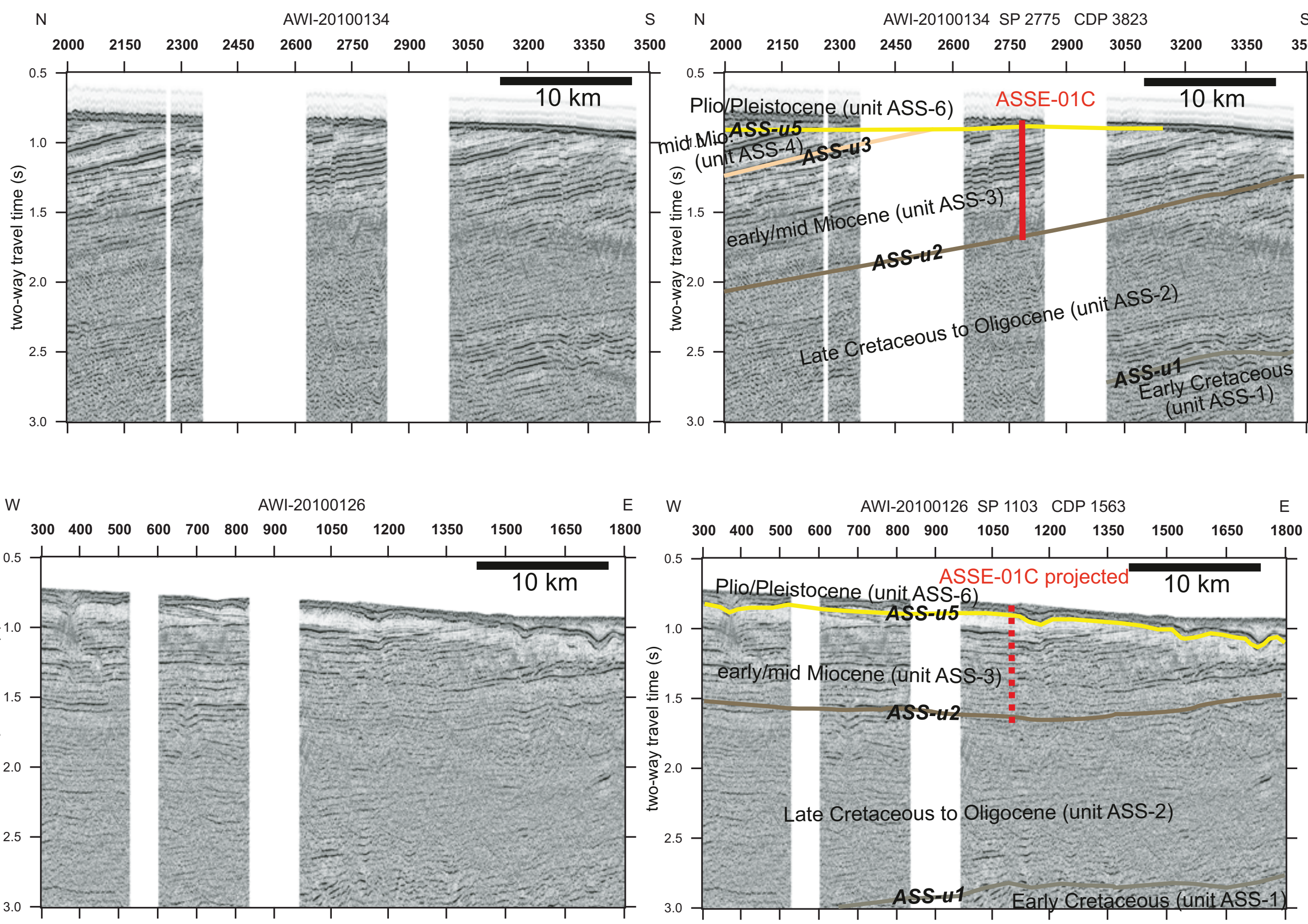
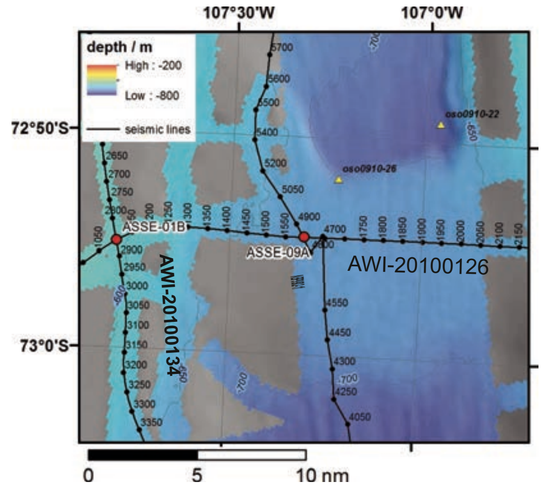


Figure AF14. Map with multibeam bathymetry swaths showing location of proposed Site ASSE-09A on MCS Line AWI-20100126 and SCS Line NBP9902-11. Bottom: MCS Line AWI-20100126 with location of proposed Site ASSE-09A and SCS Line NBP9902-11 (SP 4850).

Site ASSE-09A

Priority:	Alternate
Position:	72.910°S, 107.307°W
Water depth (m):	690
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100126: SP 1596, CDP 2220 SCS data: • NBP9902-11: SP 4850
Objective(s):	• Recovery of records from preglacial times (back to Cretaceous–Paleocene) to preglacial to glacial transition (E/O boundary) • Onset of first glacial period of West Antarctica • Penetrating truncational Unconformities ASS-u5 and ASS-u2 • Records of Marie Byrd Land dome uplift in relation to early glacial phases
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences; preglacial mudstone and/or sandstone



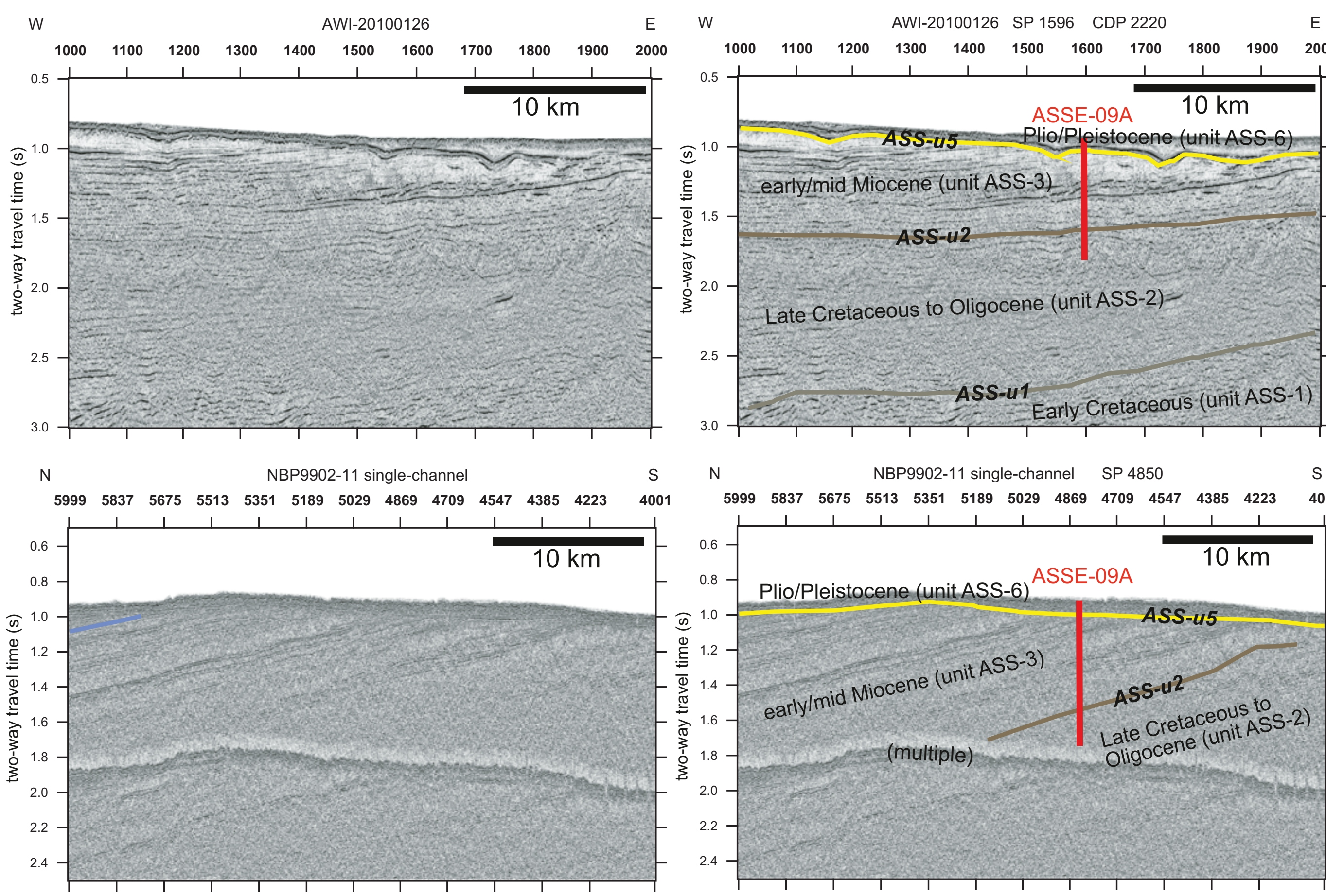
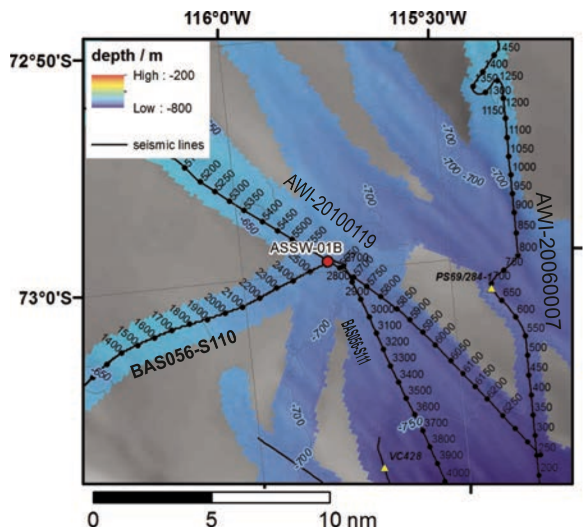


Figure AF15. Top: map with multibeam bathymetry swaths showing location of proposed Site ASSW-01B on MCS Line AWI-20100119 (Figure A15b) and SCS Line BAS056-S110. Bottom: MCS Line AWI-20100119 with location of proposed Site ASSW-01B and SCS Line BAS056-S110 (SP 2605).

Site ASSW-01B

Priority:	Alternate
Position:	72.993°S, 115.792°W
Water depth (m):	710
Target drilling depth (mbsf):	600
Approved maximum penetration (mbsf):	600
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100119: SP 5610, CDP 6309 SCS data: • BAS056-S110: SP 2605
Objective(s):	• Recovery of records from preglacial to glacial transition (E/O boundary), Miocene, and Plio/Pleistocene • Onset of first glacial period of West Antarctica • Penetrating truncational Unconformities ASS-u5 and ASS-u3 • Records of Marie Byrd Land dome uplift in relation to early glacial phases
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 600 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Alternating diamicton and thin diatomaceous ooze sequences; preglacial mudstone and/or sandstone



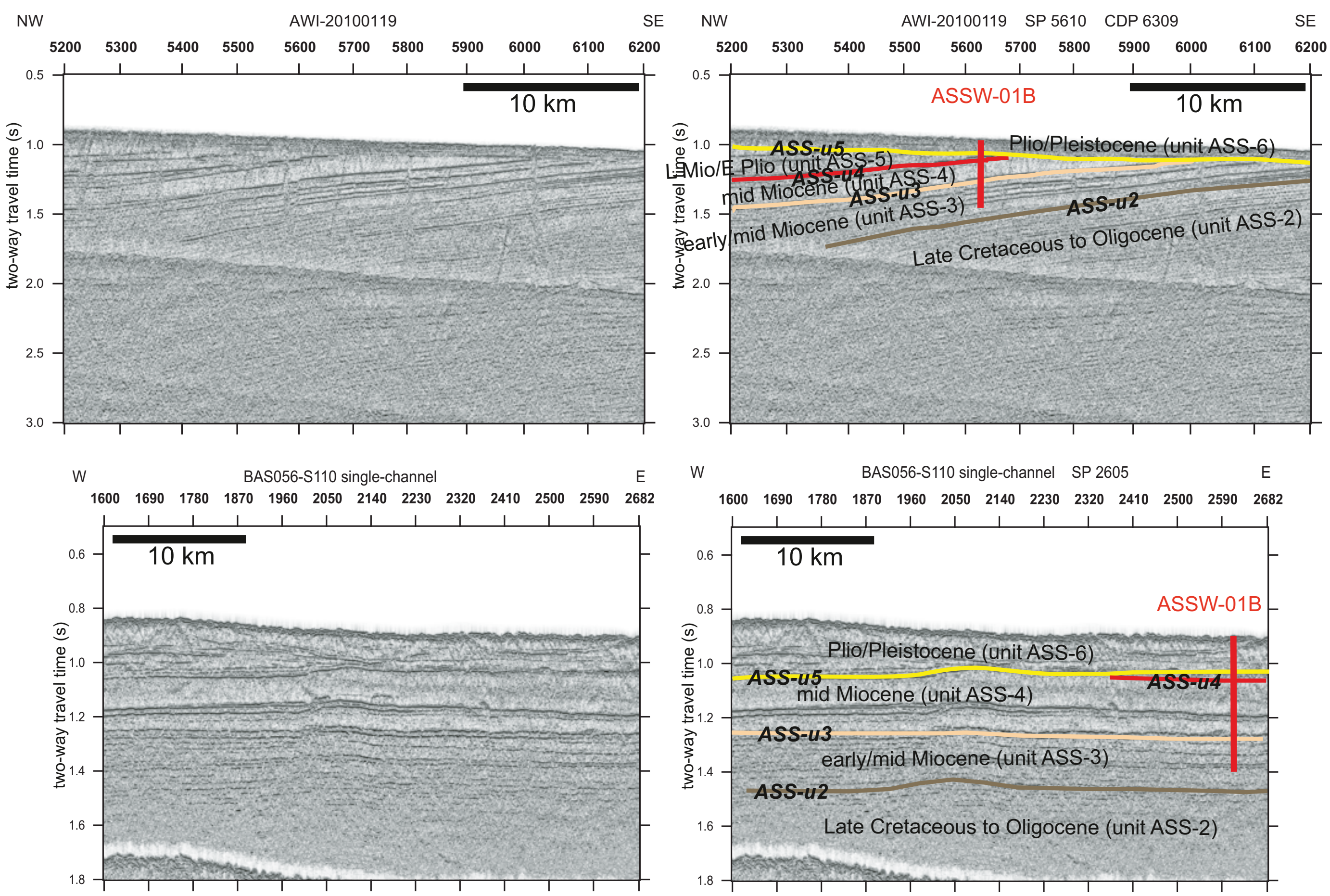
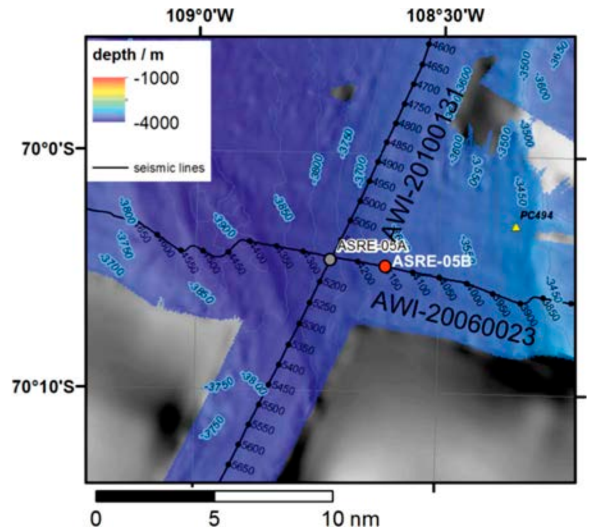


Figure AF16. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-05B on MCS Line AWI-20060023. MCS Line AWI-20100131 (projected SP 5150) crosses 4.3 km west of the site. Bottom: MCS Line AWI-20060023 with location of proposed Site ASRE-05B.

Site ASRE-05B

Priority:	Primary
Position:	70.079°S, 108.612°W
Water depth (m):	3720
Target drilling depth (mbsf):	1200
Approved maximum penetration (mbsf):	1200
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060023: SP 1200, CDP 1812 • AWI-20100131: crosses AWI-20060023 4.3 km west of drill site, projected to SP 5150, CDP 7233
Objective(s):	• Recovery of continuous high-resolution drift records from early/mid-Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica • Correlation with paleo-ocean current reconstruction
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 1200 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites



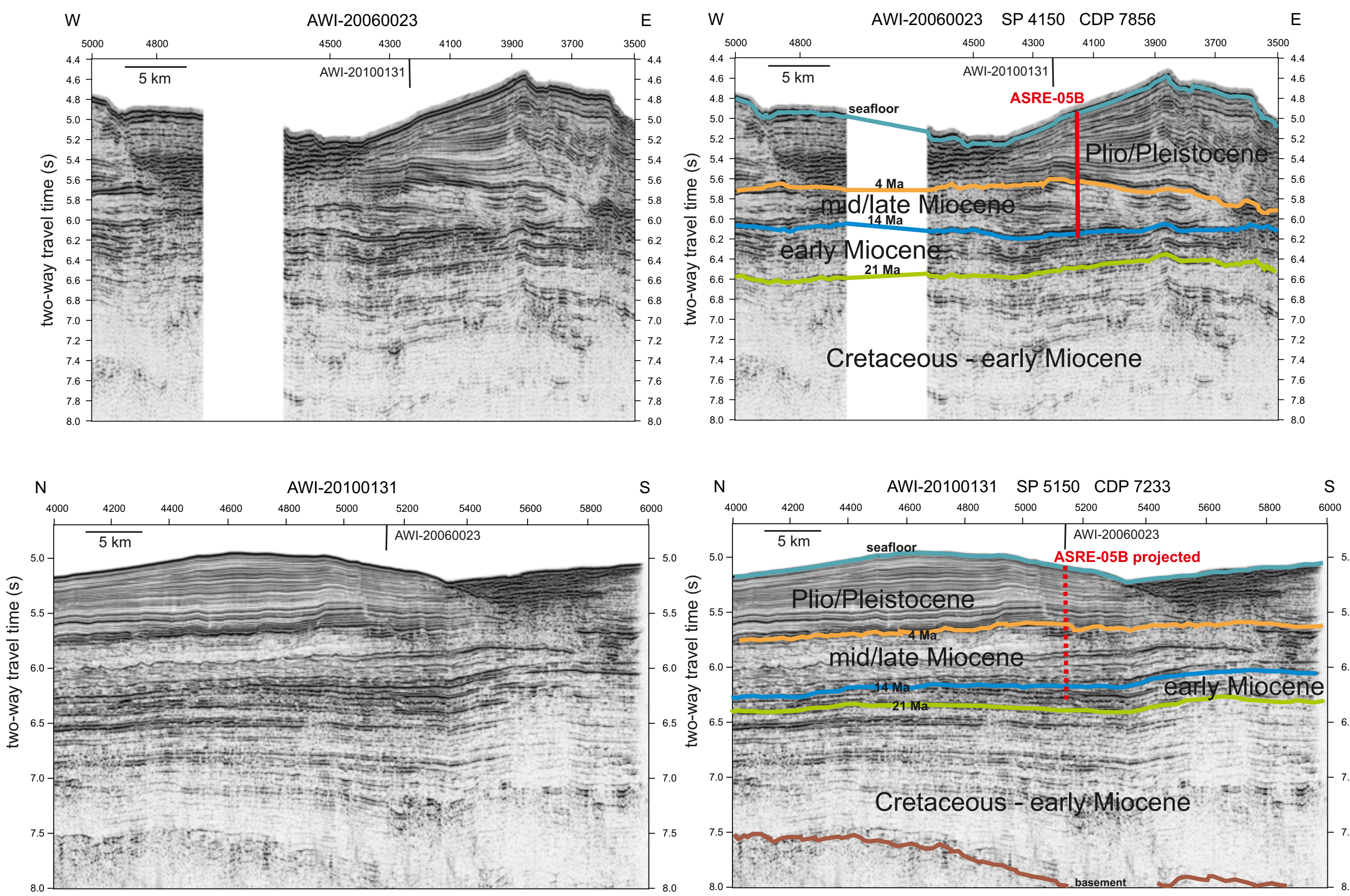
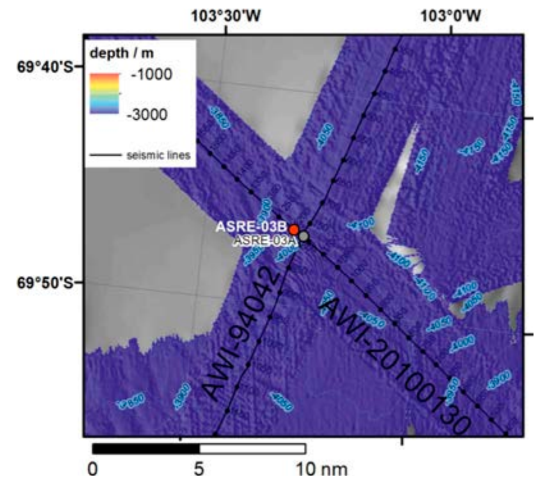


Figure AF17. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-03B on MCS Line AWI-20100130. MCS Line AWI-94042 (projected SP 788) crosses 825 m southeast of the site. Bottom: MCS Line AWI-20100130 with location of proposed Site ASRE-03B.

Site ASRE-03B

Priority:	Alternate
Position:	69.774°S, 103.299°W
Water depth (m):	4040
Target drilling depth (mbsf):	1400
Approved maximum penetration (mbsf):	1400
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100130: SP 1200, CDP 1812 • AWI-94042: crosses AWI-20100130 825 m southeast of drill site, projected to SP 788, CDP 1353
Objective(s):	• Recovery of continuous high-resolution drift records from early/mid-Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica • Correlation with paleo-ocean current reconstruction
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 1400 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites



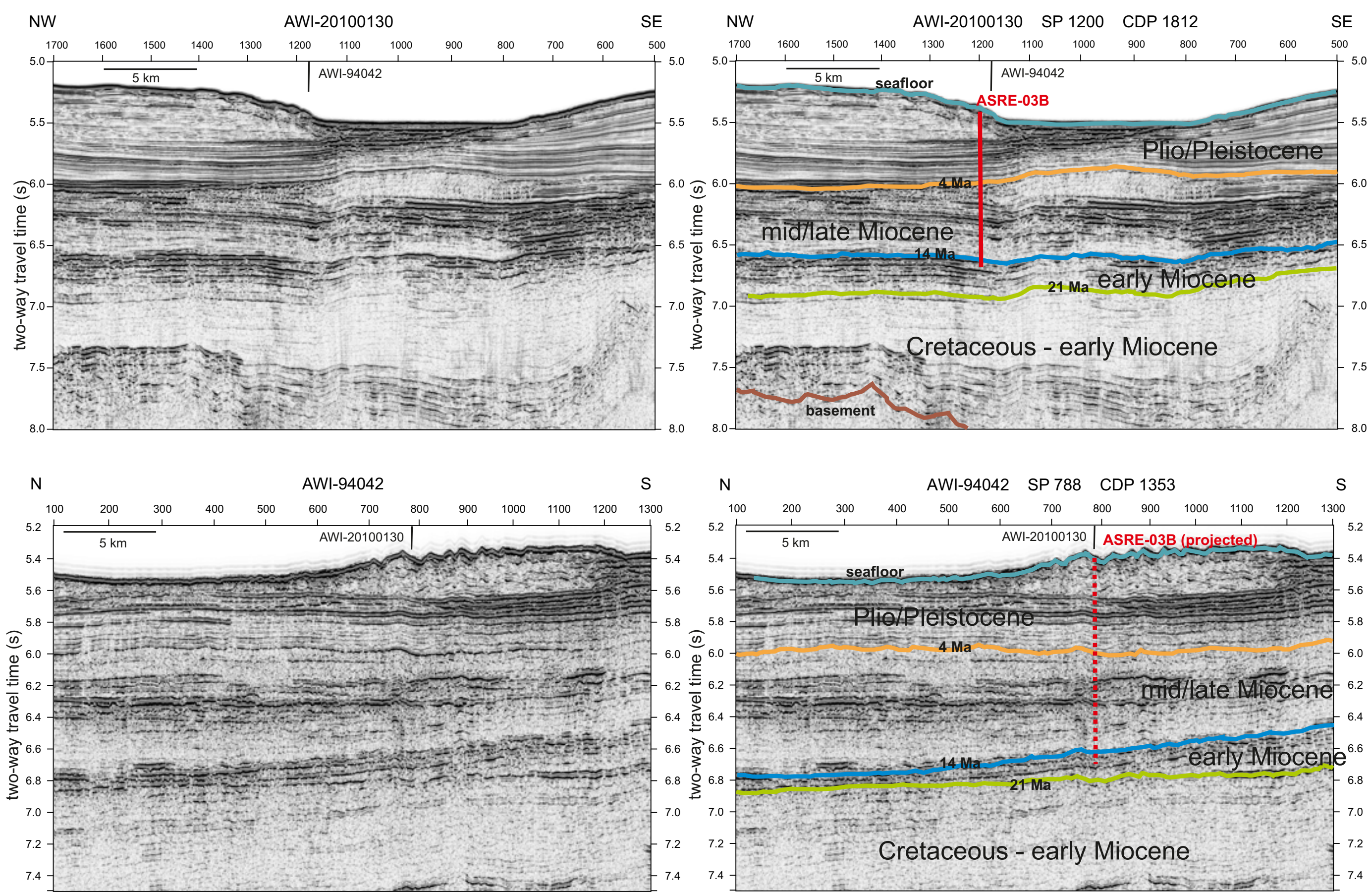
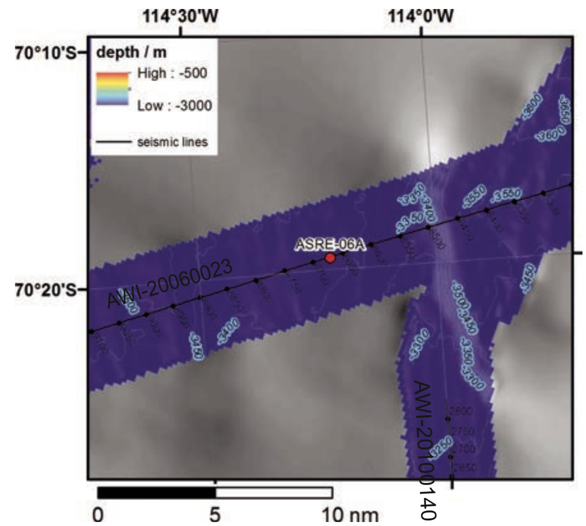


Figure AF18. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-06A on MCS Line AWI-20060023. Bottom: MCS Line AWI-20060023 with location of proposed Site ASRE-06A.

Site ASRE-06A

Priority:	Alternate
Position:	70.325°S, 114.223°W
Water depth (m):	3466
Target drilling depth (mbsf):	1200
Approved maximum penetration (mbsf):	1200
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060023: SP 8670, CDP 16706
Objective(s):	• Recovery of continuous high-resolution drift records from early/mid-Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica • Correlation with paleo-ocean current reconstruction
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 1200 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites

Site ASRE-06A



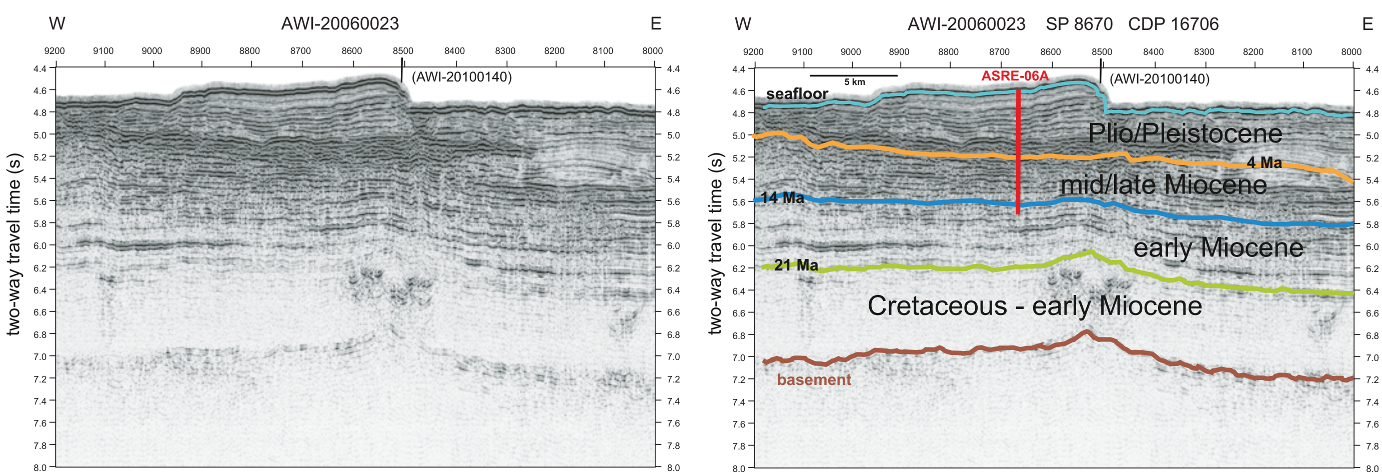
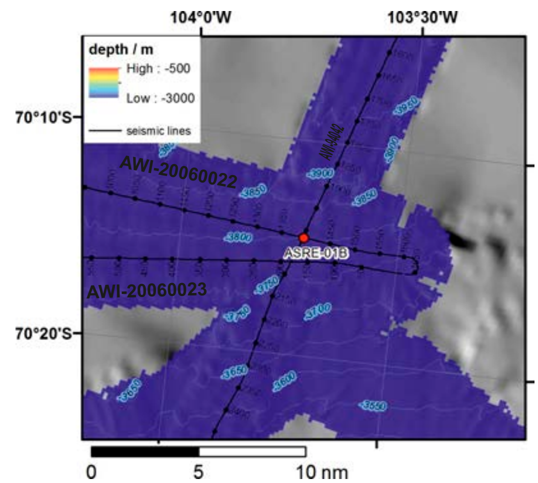


Figure AF19. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-01B on MCS Lines AWI-94042 and AWI-20060022. Bottom: MCS Line AWI-94042 with location of proposed Site ASRE-01B and MCS Line AWI-20060022 (SP 1395).

Site ASRE-01B

Priority:	Primary
Position:	70.242°S, 103.718°W
Water depth (m):	3820
Target drilling depth (mbsf):	950
Approved maximum penetration (mbsf):	950
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-94042: SP 2016, CDP 3524 • AWI-20060022: SP 1395, CDP 2750
Objective(s):	• Recovery of continuous high-resolution lower slope records from mid-/late Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 950 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites



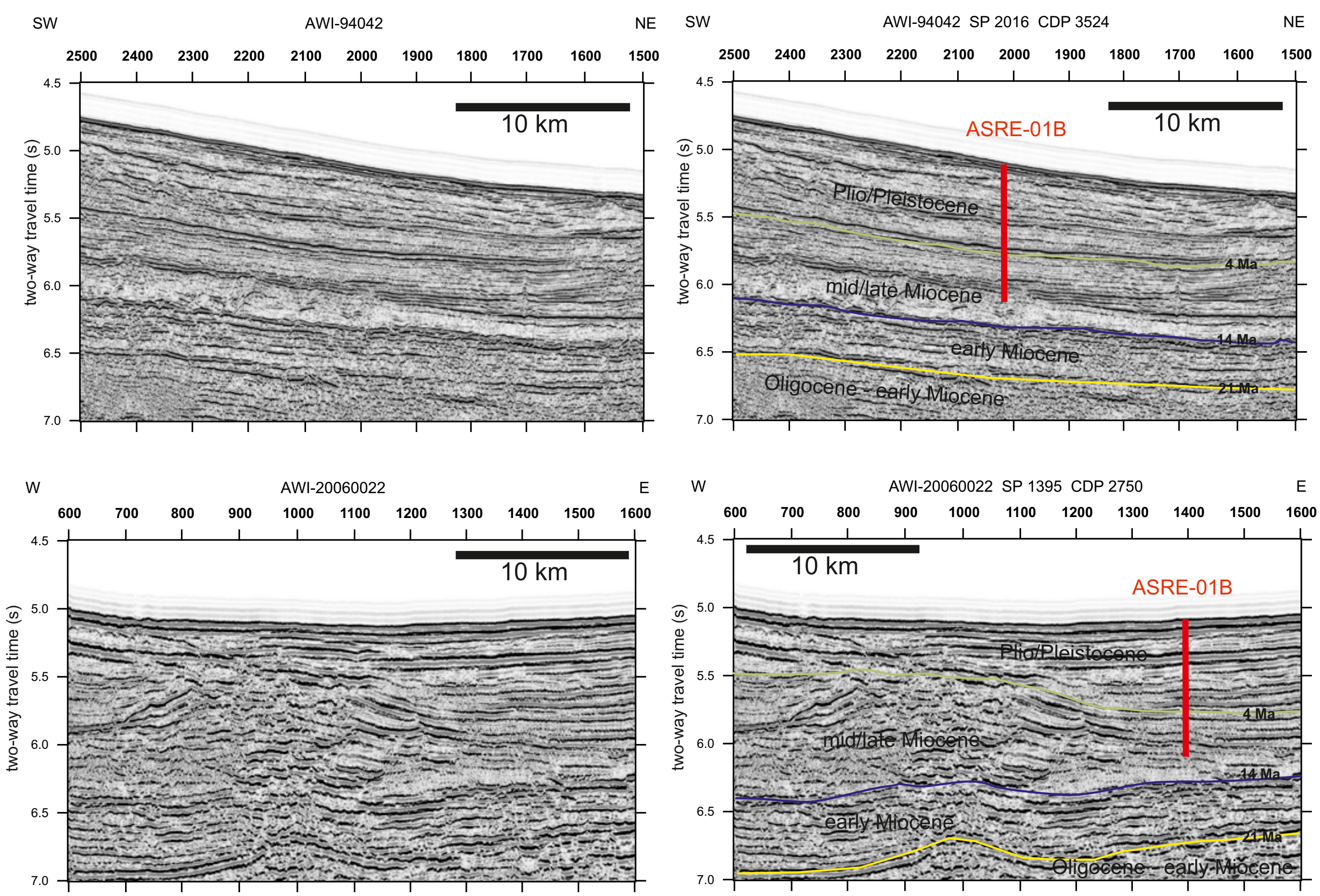
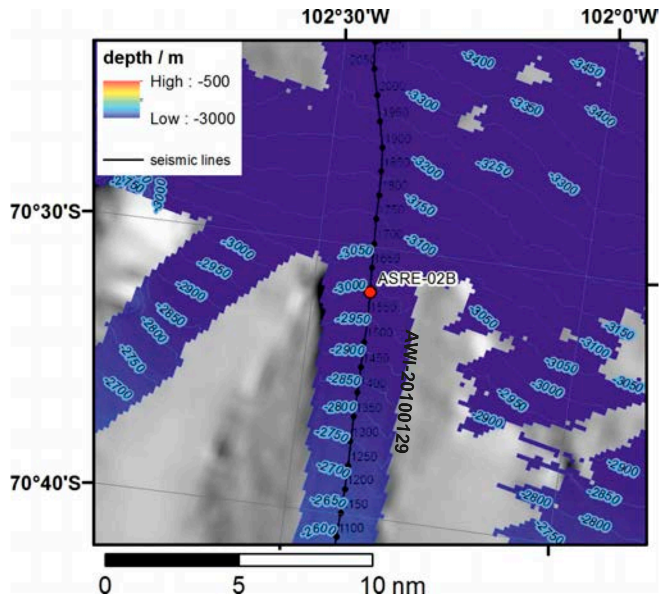
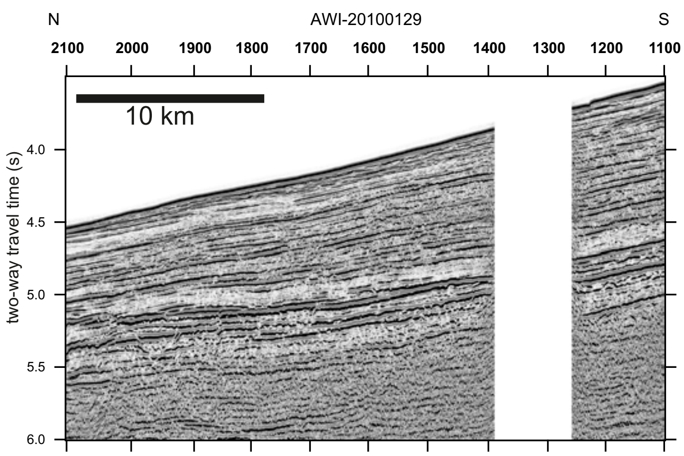


Figure AF20. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-02B on MCS Line AWI-20100129. Bottom: MCS Line AWI-20100129 with location of proposed Site ASRE-02B.

Site ASRE-02B

Priority:	Alternate
Position:	70.528°S, 102.394°W
Water depth (m):	3060
Target drilling depth (mbsf):	950
Approved maximum penetration (mbsf):	950
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100129: SP 1600, CDP 2251
Objective(s):	• Recovery of continuous high-resolution lower slope records from mid-/late Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 950 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites





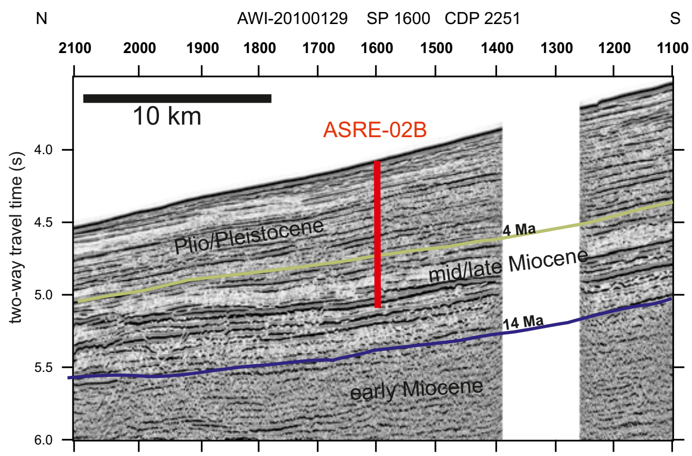
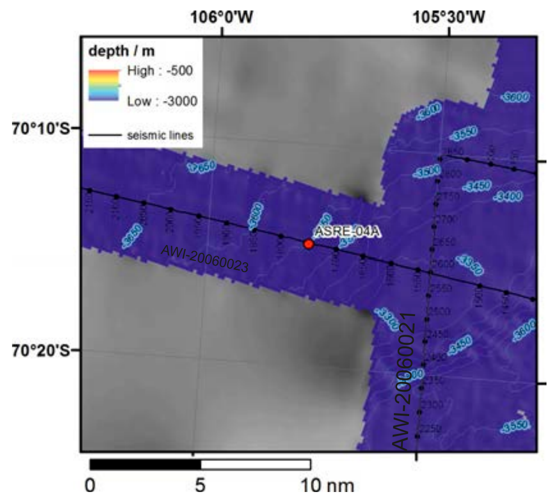


Figure AF21. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRE-04A on MCS Lines AWI-20060023. MCS Line AWI-20060021 (projected SP 2596) crosses 10 km east of the site. Bottom: MCS Line AWI-20060023 with location of proposed Site ASRE-04A.

Site ASRE-04A

Priority:	Alternate
Position:	70.242°S, 105.775°W
Water depth (m):	3600
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20060023: SP 1750, CDP 3467 • AWI-20060021: crosses AWI-20060023 10 km east of drill site, projected to SP 2596, CDP 4062
Objective(s):	• Recovery of continuous high-resolution drift records from mid-/late Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica • Correlation with paleo-ocean current reconstruction
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites



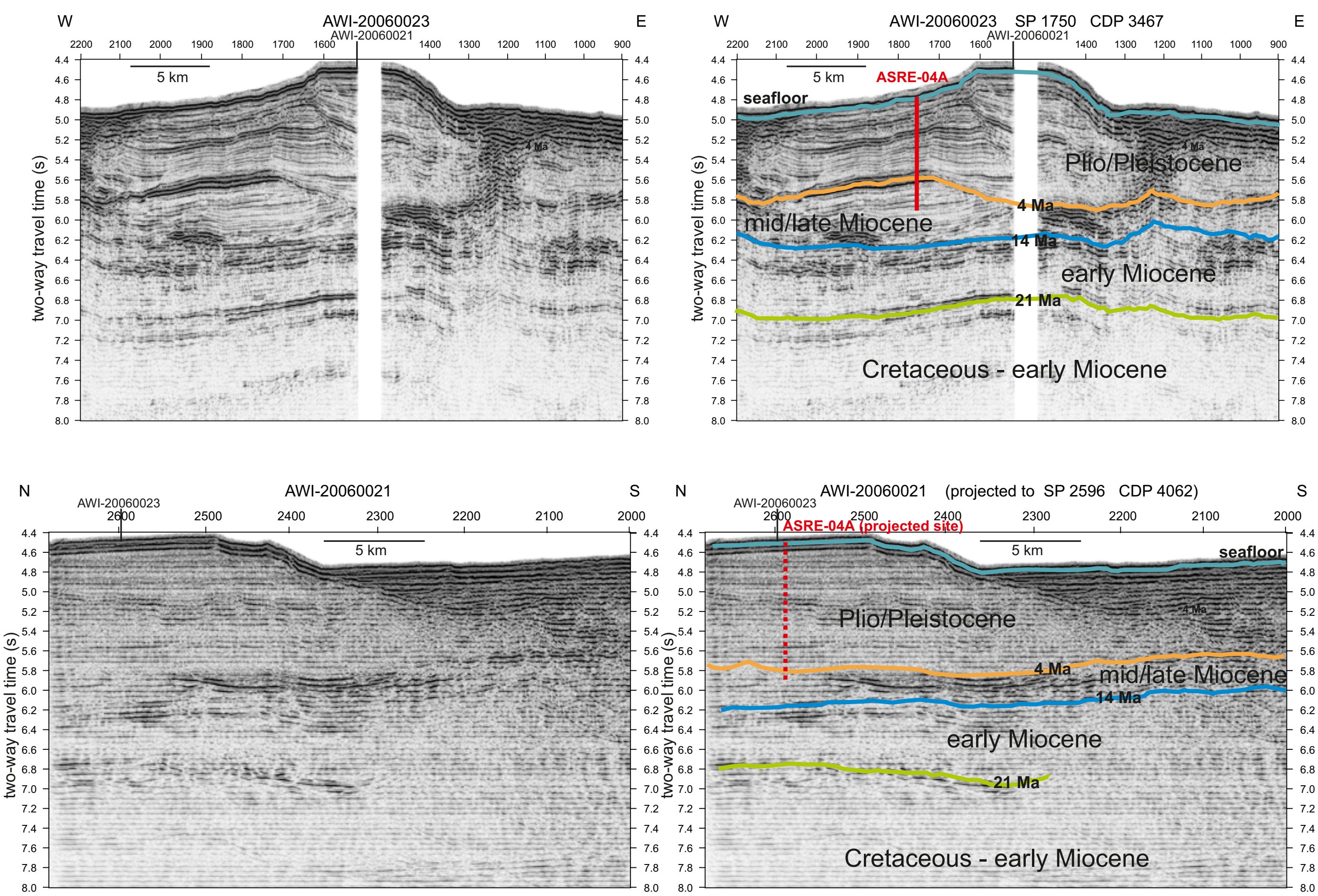


Figure AF22. Top: map with multibeam bathymetry swaths showing location of proposed Site ASRW-01C on MCS Line AWI-20100117. MCS Line AWI-94054 (projected SP 4053) crosses 7.8 km east of the site. Bottom: MCS Line AWI-20100117 with location of proposed Site ASRW-01C.

Site ASRW-01C

Priority:	Alternate
Position:	71.705°S, 120.668°W
Water depth (m):	2643
Target drilling depth (mbsf):	900
Approved maximum penetration (mbsf):	900
Survey coverage (track map; seismic profile):	Bathymetric and seismic track map MCS data: • AWI-20100117: SP 17050, CDP 22440 • AWI-94054: crosses AWI-20100117 7.8 km east of drill site, projected to SP 4053, CDP 6912
Objective(s):	• Recovery of continuous high-resolution lower slope records from mid-/late Miocene to Plio/Pleistocene and Quaternary • Records of Mid-Miocene Climate Optimum, late Miocene cooling, and Pliocene warm period • Onset of first glacial period of West Antarctica • Correlation with paleo-ocean current reconstruction
Drilling program:	Hole A: APC/XCB to 400 mbsf with nonmagnetic core barrels Hole B: RCB to 900 mbsf with nonmagnetic core barrels
Logging/downhole measurements program:	Hole B: • Triple combo • FMS-sonic • VSI
Nature of rock anticipated:	Fine-grained hemipelagic biogeneous mud/silt; fine-grained turbidites