International Ocean Discovery Program Expedition 395 Scientific Prospectus

Reykjanes Mantle Convection and Climate: Mantle Dynamics, Paleoceanography and Climate Evolution in the North Atlantic Ocean

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Abstract

The intersection between the Mid-Atlantic Ridge and Iceland hotspot provides a natural laboratory where the composition and dynamics of Earth's upper mantle can be observed. Plume-ridge interaction drives variations in the melting regime, which result in a range of crustal types, including a series of V-shaped ridges (VSRs) and V-shaped troughs (VSTs) south of Iceland. Time-dependent mantle upwelling beneath Iceland dynamically supports regional bathymetry and leads to changes in the height of oceanic gateways, which in turn control the flow of deep water on geologic timescales. Expedition 395 has three objectives: (1) to test contrasting hypotheses for the formation of VSRs, (2) to understand temporal changes in ocean circulation and explore connections with plume activity, and (3) to reconstruct the evolving chemistry of hydrothermal fluids with increasing crustal age and varying sediment thickness and crustal architecture. This expedition will recover basaltic samples from crust that is blanketed by thick sediments and is thus inaccessible when using dredging. Major, trace, and isotope geochemistry of basalts will allow us to observe spatial and temporal variations in mantle melting processes. We will test the hypothesis that the Iceland plume thermally pulses on two timescales (5–10 and ~30 Ma), leading to fundamental changes in crustal architecture. This idea will be tested against alternative hypotheses involving propagating rifts and buoyant mantle upwelling. Millennial-scale paleoclimate records are contained in rapidly accumulated sediments of contourite drifts in this region. The accumulation rate of these sediments is a proxy for current strength, which is moderated by dynamic support of oceanic gateways such as the Greenland-Scotland Ridge. These sediments also provide constraints for climatic events including Pliocene warmth, the onset of Northern Hemisphere glaciation, and abrupt Late Pleistocene climate change. Our combined approach will explore relationships between deep Earth processes, ocean circulation, and climate. Our objectives will be addressed by recovering sedimentary and basaltic cores, and we plan to penetrate ~130 m into igneous basement at five sites east of Reykjanes Ridge. Four sites intersect VSR/VST pairs, one of which coincides with Björn drift. A fifth site is located over 32.4 My old oceanic crust that is devoid of V-shaped features. This site was chosen because it intersects Oligocene–Miocene sediments of Gardar drift. Recovered sediments and basalts will provide a major advance in our understanding of mantle dynamics and the linked nature of Earth's interior, oceans, and climate.

Expedition 395 Schedule

International Ocean Discovery Program (IODP) Expedition 395 is based on IODP drilling Proposal 892-Full2 and Addendum 892-Add (available at **https://iodp.tamu.edu/scienceops/expeditions/reykjanes_mantle_convection_and_climate.html**). Following evaluation by the IODP Scientific Advisory Structure, the expedition was scheduled for the research vessel (R/V) *JOIDES Resolution*, operating under contract with the *JOIDES Resolution* Science Operator (JRSO). A total of 56 days will be available for the transit, drilling, coring, and downhole measurements described in this report. At the time of publication of this *Scientific Prospectus*, the expedition was postponed due to the COVID-19 pandemic and is pending rescheduling by the *JOIDES Resolution* Facility Board (for the updated schedule, see **http://iodp.tamu.edu/scienceops**). Further details about the facilities aboard *JOIDES Resolution* can be found at **http://iodp.tamu.edu/labs/index.html**.

Introduction

Scientific ocean drilling has transformed our understanding of Earth over the past five decades, from insights into past climates to the confirmation of plate tectonic theory. However, the convecting behavior of Earth's mantle and its effects on surface processes such as ocean circulation and climate remains poorly understood. Basaltic rocks erupted at mid-ocean ridges (MORs) provide a window into the mantle, and where ridges intersect large upwellings called mantle plumes, they record mantle composition and dynamics through time. Although mantle plumes (e.g., beneath Hawaii) are fairly common, intersecting plume-ridge systems are unusual. One such intersecting system is located in the North Atlantic Ocean, where the Iceland mantle plume is bisected by the Mid-Atlantic Ridge (Figure **F1**). Pulsing behavior of the Iceland plume on geologic timescales is thought to have caused the North Atlantic region to go up and down by hundreds of meters, with major implications for oceanic gateways from the Greenland and Norwegian Seas into the North Atlantic Ocean and hence for deepwater circulation.

The flanks of Reykjanes Ridge south of Iceland lie above one of Earth's largest plume-ridge systems and are blanketed by rapidly accumulating sediments that record the oceanographic conditions under the influence of nearby deepwater gateways. This configuration provides an ideal natural laboratory to test a diverse range of hypotheses about mantle dynamics, crustal accretion, paleoceanography, and climate. Although the rich scientific potential in this region was demonstrated during Deep Sea Drilling Project (DSDP) Leg 49 and Ocean Drilling Program (ODP) Leg 162 (Luyendyk et al., 1979; Jansen and Raymo, 1996), comprehensive sampling of both the sediment and underlying basaltic crust is still lacking. A transect of holes will be drilled during Expedition 395 to address three major objectives: (1) to unravel the time-dependent behavior of the Iceland mantle plume; (2) to obtain high-resolution records of climate and ocean circulation near major North Atlantic oceanic gateways; and (3) to track the accretion, aging, and hydrothermal exchange of oceanic crust over 32 My.

Scientific background and geological setting

The accretion of new oceanic crust records small fluctuations in underlying mantle properties, so rocks sampled from MORs have long been used as tracers of Earth's mantle (e.g., Hart et al., 1973; Krause and Schilling, 1969). Where MORs intersect mantle plumes, such as along Reykjanes and Kolbeinsey Ridges near Iceland, the accretion of oceanic crust is thought to be influenced by plume activity. Close agreement of models of dynamic topography and seismic tomography supports the idea that mantle upwelling beneath Iceland influences the entire North Atlantic region today (Figure **F1**). A possible sign of time-dependent plume behavior is the set of diachronous V-shaped ridges (VSRs) and V-shaped troughs (VSTs) that straddle Reykjanes Ridge south of Iceland (Figure **F2**). Vogt (1971) first suggested that the VSRs reflect variations in crustal thickness caused by pulses of hotter asthenosphere advecting horizontally away from the Iceland plume that episodically increase the thickness of crust formed at the axis. Since Vogt's early thermal pulsing hypothesis, the origin of the VSRs has been debated (Figure **F3**) (e.g., Parnell-Turner et al., 2014). One alternative idea is that the VSRs may be tectonic in origin and have no requirement for hotspot melt anomalies (Benediktsdóttir et al., 2012; Briais and Rabinowicz, 2002; Rabinowicz and Briais, 2002). In this scenario, a sequence of propagating rifts and southward migrating discontinuities, suggested by the observed asymmetric accretion at the ridge axis, explains the formation of VSRs and VSTs, which are thought to represent ridge segments and pseudofault scarps, respectively (Figure **F3B**). A third hypothesis, in which shallow buoyant mantle upwelling instabilities propagate along axis to form the observed crustal structure, has also been suggested; it avoids the requirement for rapid mantle plume flow (Martinez and Hey, 2017) (Figure **F3C**). Two VSR/VST pairs will be targeted at four sites during Expedition 395 so that these alternative hypotheses can be tested by comparison of the geochemistry of recovered basalts (Figure **F4**). A fifth site, on 32 My old crust, will sample rocks from oceanic crust apparently unaffected by the Iceland plume and VSR-forming processes and will deliver the first reference baseline for North Atlantic crustal composition. Together, these five sites will provide a transect through progressively altered crust and record the time-integrated effects of fluid–rock reaction, including hydrothermal and low-temperature alteration (Figure **F5**).

The North Atlantic Ocean is separated from the colder, more dense waters of the Arctic Ocean and Norwegian-Greenland Sea by the Greenland-Scotland Ridge (GSR), which represents a critical gateway affecting Cenozoic deepwater circulation patterns and climate. The GSR is generally less than 500 meters below sea level (mbsl) and is only ~1000 mbsl at its deepest point, making the overflow flux sensitive to small variations in the ridge depth. Reconstructions of Neogene mantle plume activity correlate with deepwater circulation patterns in the North Atlantic (Wright and Miller, 1996). Times of high mantle plume activity are linked to low Northern Component Water productivity, increased current strength, and sedimentary deposition rates (Parnell-Turner et al., 2015; Poore et al., 2006; Wright and Miller, 1996). Southward-flowing deepwater currents in the North Atlantic Ocean deposit fine-grained sediments called contourite drifts, which accumulate at rates of hundreds of meters per million years. Two major drifts, Gardar and Björn, were successfully drilled during Leg 162 (Jansen and Raymo, 1996), providing a record of drift sedimentation back to early Pleistocene times (1.7 Ma). Expedition 395 will extend this record to Oligocene times (~32 Ma) with sites located to drill to the base of the thickest parts of the Gardar and Björn drifts.

High sedimentation rate combined with near 100% core recovery rates means that previous scientific holes drilled into contourites contain some of the highest resolution records of ocean circulation and climate to date (e.g., ODP Sites 983 and 984; Kleiven et al., 2011; Thornalley et al., 2013). These records can be directly compared to atmospheric records from ice cores and provide a unique, high-resolution insight into the Earth's climatic past (Barker et al., 2019). The locations of the five Expedition 395 sites have been optimized to obtain undisturbed sedimentary cores, which will support millennial-scale reconstructions of surface and deepwater properties.

Depth of basement drilling

Our basement objectives require recovery of samples from ~15 lava flow units to obtain a space- and time-averaged geochemical record of basalt composition, which we estimate will require ~130 m of basement penetration. This approach will also allow us to characterize the age- and depth-dependent chemical exchanges between seawater, sediment, and oceanic crust. Our estimate of 130 m is based upon results from Leg 49; however, the operations plan is flexible to account for flow unit thicknesses that differ from those encountered during Leg 49.

Seismic studies and site survey data

The supporting site survey data for Expedition 395 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select proposal number P892).

In January–February 2010, RRS *James Cook* Cruise JC50 conducted a detailed geophysical survey of Reykjanes Ridge and its flanks, collecting more than ~2400 km of high-resolution (2-D) multichannel reflection seismic data (Parnell-Turner et al., 2017). The survey consisted of two basin-spanning regional profiles, oriented parallel to plate-spreading flowlines, and a series of 19 shorter perpendicular crossing lines. 2-D seismic reflection data were recorded on a 132-channel hydrophone streamer with 12.5 m group spacing. The seismic source comprised a single generator-injector air gun (250 in^3 primary pulse; 105 in^3 injector pulse) fired at a pressure of 3000 psi at 15 s intervals. Nominal ship speed of 5.0 kt (~9.3 km/h) yielded a shot spacing of ~40 m and a nominal fold of ~21. These multichannel data are of sufficient quality to identify the sediment/basement interface as well as potential drilling hazards such as faults, gas accumulations, and stratigraphic discontinuities.

Multibeam bathymetric data were acquired during Cruise JC50 at each site using a hull-mounted Kongsberg EM120 multibeam echosounder. At a depth of 1 km (typical at Reykjanes Ridge), resolution is ~30 m. Additional legacy bathymetric surveys, carried out during R/V *Maurice Ewing* Cruise EW9008 and RRS *Charles Darwin* Cruises CD81 and CD87, provide coverage near Reykjanes Ridge.

Four primary sites are chosen to target VSRs and VSTs, and a fifth primary site is located to sample segmented oceanic crust devoid of V-shaped features. These five primary and seven alternate sites are positioned on thick sediment or in localized sedimentary basins that are imaged on seismic reflection profiles so that holes can easily be established. Sites were chosen as close to crossing seismic profiles as possible while avoiding sedimentary disturbances, faults, and basement discontinuities. Sediment thicknesses are estimated using interval sediment velocities from Leg 162 where possible, and stacking velocities are used for deeper levels. Expected sediment thickness ranges from 210 m at proposed Site REYK-13A to 970 m at proposed Site REYK-2A.

Scientific objectives

1. *Objective 1: crustal accretion and mantle plume behavior*

Scientific justification

We will use the composition of basaltic samples to understand crustal formation south of Iceland at two temporal scales. First, on ~5–10 My timescales, we seek to test three alternative hypotheses for the formation of VSRs: (1) thermal pulsing, (2) propagating rifts, and (3) buoyant mantle upwelling. Drilling will allow us to test these hypotheses, which predict differing depths, temperatures, and degrees of melting between VSRs and VSTs recorded in basalt composition. Dredged samples are restricted to the ridge axis because deep-sea corals and sediments cover off-axis areas (Jones et al., 2014; Murton et al., 2002). Hence, off-axis VSRs and VSTs can only be sampled by drilling. Second, we aim to test the controls on crustal architecture over longer, ~30–40 My timescales. Oceanic crust south of Iceland can be divided into two distinct structural types (smooth and segmented) using gravity and magnetic and bathymetric data sets (e.g., White, 1997). Smooth oceanic crust contains VSRs and VSTs but also exhibits seafloor magnetic anomalies largely unbroken by fracture zone offsets that are similar to those more typical at fast-spreading ridges. Segmented oceanic crust exhibits traces of ridge axis discontinuities that are more typical of slow-spreading ridges; hence, the seafloor here represents a microcosm of global variability in crustal structure. The shape of the boundary between smooth and segmented crustal styles has shifted through time (Jones et al., 2002). This transgressive character may record expansion and contraction of the Iceland plume head over ~35 My. It may also result from changes in the Reykjanes Ridge spreading rate. Segmented oceanic crust usually forms above cooler asthenosphere or at slow-spreading ridges, whereas smooth crust usually forms above relatively hot asthenosphere close to plume heads or at intermediate to fast-spreading ridges. Therefore, in the North Atlantic Ocean, small changes in melt flux, temperature, and/or spreading rate may drive regime changes in crustal architecture. Our objective of understanding how crustal formation responds to mantle temperature, degree of melting, and plume activity will be achieved by comparing the geochemistry of basalts from smooth and segmented crustal domains.

Basalt geochemistry

The accretion of oceanic crust is sensitive to small temperature perturbations, which can change the thickness of newly formed material by hundreds of meters to kilometers (White et al., 1995). The basalt trace element ratio, Nb/Y, is largely insensitive to crustal processes such as fractional crystallization and reflects the depth and degree of melting. A southward decrease of Nb/Y between 63°N and 61°N on Reykjanes Ridge correlates with deepening of the axis, a decrease in crustal thickness, and decreasing source enrichment estimated by isotopic indicators such as $^{87}Sr/^{86}Sr$ (Figure **F6**; Jones et al., 2014; Murton et al., 2002). Two complete cycles of variation in incompatible trace element ratios can be observed along axis (Figure **F6**); they correlate with patterns in gravity anomaly, bathymetry, and earthquake seismicity (Parnell-Turner et al., 2013). Compositional variations associated with VSRs cannot be explained by fractional crystallization alone because a corresponding variation in Mg number is absent (Figure **F6C**). Because enrichment in incompatible trace elements is inversely correlated with crustal thickness over the past 12 My, mantle temperature variation is thought to play an important role in controlling crustal thickness, in addition to changes in mantle source fusibility (Jones et al., 2014).

Leg 49 yielded major advances in understanding of mantle heterogeneity (e.g., Wood et al., 1979), plume structure (e.g., Fitton et al., 1997), and melting processes (e.g., Kempton et al., 2000). However, the location of these sites precludes their use to address the temporal and spatial variability of plume dynamics. Expedition 395 sites, located along a spreading-parallel flowline, avoid the issue of variable distance from the plume. Incompatible trace element concentrations and ratios (e.g., Nb/Y and La/Sm) will be used to constrain melting models, building upon previous work on the axis. Major and trace element concentrations will be measured to constrain differences in the composition, depth, and extent of melting between VSR/VST pairs and segmented crust unaffected by VSRs. Indirect reconstruction of axial depth is possible using volatile elements such as carbon, water, and sulfur, which de-gas when erupted at the seafloor. For example, advances in understanding the CO_2 concentration in ridge basalts enable quantification of eruption pressure (Le Voyer et al., 2017). Recovery of glass (achieved during Leg 49) will enable electron and ion-probe analyses to measure volatile elements and therefore estimate eruption pressures and test the plume pulsing hypothesis.

Relationship to the IODP Science Plan

Challenge 8: What are the composition, structure, and dynamics of Earth's upper mantle?

The coincidence of Reykjanes Ridge with the Iceland plume provides an opportunity to observe the composition and behavior of Earth's interior. Basalts recovered by dredging at spreading centers provide us with a modern-day snapshot of the spatial patterns in mantle heterogeneity. However, recovering off-axis samples will provide an opportunity to constrain temporal variability. Major, rare earth, and trace element concentrations of basalts will be compared between sites and used as inputs to models of mantle melting.

Challenge 9: How are seafloor spreading and mantle melting linked to ocean crustal architecture?

Crustal architecture south of Iceland is dominated by two main features: the diachronous VSRs that straddle Reykjanes Ridge and the transition from smooth to segmented oceanic crust that took place at ~35 Ma. These features may have been formed because of the interaction between time-dependent mantle convection and plate spreading or a series of propagating rifts or patches of buoyant mantle upwelling. Drilling oceanic crust south of Iceland will allow us to unravel the origins of this architecture and will have implications for our understanding of the relationships between mantle melting, rifting, and plate spreading.

2. *Objective 2: oceanic circulation, gateways, and sedimentation*

Scientific justification

We plan to quantify how oceanic circulation in the North Atlantic Ocean has varied since Oligocene times. Deepwater flow in the North Atlantic is dominated by two oceanic gateways, the Iceland-Faroe Ridge and the Denmark Strait, that control the southward flow of water from the Norwegian Sea and exert a major influence on global ocean circulation. The rate of accumulation of contourite drift sediments in the North Atlantic Ocean is primarily controlled by deepwater flow along bathymetric rises; hence, the strength and pathways of deepwater currents are recorded by these drift sediments (e.g., Wright and Miller, 1996). These deposits provide an indirect proxy for temporal variations in deepwater flow. Additionally, short-term climatic effects relating to the location of oceanic fronts during both glacial–interglacial and (shorter) stadial–interstadial cycles may play a role in circulation patterns on shorter timescales (thousands of years). It has been suggested that uplift and subsidence of the Iceland-Faroe Ridge and Denmark Strait is influenced by mantle upwelling beneath Iceland and that there may therefore be an indirect connection between ocean circulation and mantle plume behavior (e.g., Parnell-Turner et al., 2015; Poore et al., 2011). We plan to test the correlation between mantle plume activity and ocean circulation by using sediment accumulation rates as a first-order proxy for deepwater current strength. The oldest drilled sediments in the Iceland Basin are ~3 Ma (Jansen and Raymo, 1996), and Expedition 395 will extend that record back to ~32 Ma, allowing us to investigate the relationships between mantle convection, oceanic gateway configuration, and climate.

High sedimentation rates of contourite drift deposits in the North Atlantic Ocean (12–16 cm/ky) have led to paleomagnetic and isotopic records that are among the most detailed available (Channell et al., 2002). Existing boreholes provide high-resolution climate records back to 1.7 Ma (Site 983), and this program will extend the high-resolution climate record further into late Pliocene times. The complete penetration of Gardar drift at proposed Site REYK-2A means that sedimentation rates may be constrained back to early Oligocene times. Work on Leg 162 sites demonstrates the utility of sediments for millennial-scale reconstructions of surface and deepwater properties (Figure **F7**) (Barker et al., 2015, 2019; Raymo et al., 1998). Planktonic foraminifer counts give a first-order impression of temperature and can trace latitudinal migration of the polar front, which fluctuates in line with millennial-scale temperature recorded by Greenland ice cores over the past ~100 ky (Bond et al., 1993). Similar relationships can be derived for intervals beyond the reach of Greenland ice cores, documented by the similarity between atmospheric CH_4 and %*Neogloboquadrina pachyderma* (Site 983; Figure **F7**). Although *N. pachyderma* didn't evolve until ~1.7 Ma, the extinct *Neogloboquadrina atlantica* can be used to trace cold/polar water masses during late Miocene–Pliocene times. Ice-rafted debris (IRD) is a useful tracer for rafted ice, which can reflect cold/freshening surface conditions proposed to affect ocean circulation through changes in surface buoyancy (Menviel et al., 2014). Ice rafting has occurred in the North Atlantic since northern hemisphere glaciation onset at around 2.7 Ma (Bailey et al., 2013), and its occurrence at Site 983 allows analysis on millennial timescales over the past 1.2 My (Figure **F7**). Sediments on the Björn and Gardar drifts experienced changes in accumulation rate due to variations in deepwater overflow of proto-North Atlantic Deep Water. Variations in the vigor of these overflows are detected using the sortable silt proxy (McCave et al., 2017); this approach has been used at Sites 983 and 984 to track overflow changes on submillennial timescales (Kleiven et al., 2011; Thornalley et al., 2013) (Figure **F7**). These proxies, in combination with foraminiferal oxygen isotopes (for temperature/salinity) and carbon (deep ocean mixing) give the potential to reconstruct submillennial variations in ocean properties throughout the Neogene.

Relationship to the IODP Science Plan

Challenge 1. How does Earth's climate system respond to elevated levels of atmospheric CO_2?

Subsidence and uplift of the Denmark Strait and Iceland-Faroe Ridge control the deepwater exchange between the Arctic Ocean, Nordic Seas, and Atlantic Ocean. Thus, the histories of these gateways and their associated deepwater flow are central to our understanding of Northern Hemisphere climate and its interaction with global thermohaline circulation. Sediments at Expedition 395 drilling sites accumulated at high rates (>10 cm/ky) and will therefore provide a millennial-scale paleoclimate record since early Neogene times. This extended record will span the critical middle Pliocene intervals when global mean surface temperatures were 2°–3°C warmer than today. We will be able to test the sensitivity of ocean circulation to changes in gateway conditions, which will provide constraints for the sensitivity of climate models to changes in atmospheric CO_2. Finally, the record of crustal alteration will allow us to examine the role of seafloor weathering in drawdown in CO_2 over the past 32 My.

3. *Objective 3: time-dependent hydrothermal alteration of oceanic crust*

Scientific justification

Expedition 395 will investigate the nature, extent, timing and duration of hydrothermal alteration in the Reykjanes Ridge flank. Hydrothermal circulation along MORs and across their flanks is responsible for one-third of the heat loss through the ocean crust. It influences tectonic, magmatic, and microbial processes on a global scale and is a fundamental component of global biogeochemical cycles. There is also growing evidence that the long-term carbon cycle is influenced by the reaction of seawater with the oceanic crust in low-temperature, off-axis hydrothermal systems, perhaps representing an important mechanism for carbon drawdown (e.g., Gillis and Coogan, 2011). The relative contribution of this process remains controversial because we don't know how much low-temperature alteration takes place off axis. Although the nature of the individual hydrothermal fluid rock reactions is generally understood, the magnitude and distribution of chemical exchange remain poorly quantified, as does the partitioning between high- and low-temperature exchange with crustal age. Consequently, the role of the production, hydrothermal alteration, and subsequent subduction of ocean crust in key global geochemical cycles remains uncertain. Drilled sections of hydrothermally altered crust from the Reykjanes Ridge flank will provide time-integrated records of geochemical exchange between crust and seawater along an age transect from 2.8 to 32.4 Ma. These sections will enable us to quantify the timing and extent of hydrothermal fluid–rock exchange across the Reykjanes Ridge flank and to assess the hydrothermal contributions of a rapidly sedimented slow-spreading ridge flank to global geochemical budgets.

Relationship to the IODP Science Plan

Challenge 10: What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?

This challenge requires a series of ocean-basin–wide transects that extend from 0 to 100 Ma crust across ridge flanks that have experienced different sedimentation or hydrogeologic histories. The proposed drill sites comprise a crustal flow line transect across the eastern flank of Reykjanes Ridge. The recovered cores will sample the uppermost ~130 m of lavas produced 2.8, 5.2, 12.4, 14.2, and 32.4 My ago at the slow-spreading Reykjanes Ridge, which will provide a unique opportunity to quantify the timing and extent of hydrothermal fluid–rock exchange in a slow-spreading ridge flank that experienced rapid sedimentation and variations in tectonic architecture.

Operations plan and drilling strategy

The Expedition 395 drilling and coring strategy is designed to maximize recovery of core material at five primary locations to meet the scientific objectives outlined above. Operations will occur along an east-west–oriented plate-spreading flowline on the eastern flank of Reykjanes Ridge, centered at ~60°N. Each site is expected to consist of a 155–970 m thick sequence of fine-grained sediments lying above basaltic crust. Sediments will be cored using a combination of the advanced piston corer (APC), extended core barrel (XCB), and rotary core barrel (RCB) systems to achieve our paleoceanographic objectives and are expected to be similar in composition to those recovered at Sites 983 and 984. Dominant lithologies encountered at these sites were silty clay, clay, clayey nannofossil mixed sediment, and nannofossil ooze (Jansen and Raymo, 1996). Based upon results from Leg 49 (e.g., Site 409), oceanic basement is expected to consist of vesicular olivine basalt with flow units that are ~4 m thick on average. All holes are expected to be abandoned after Expedition 395 and will not be used for future basement experiments.

Proposed drill sites

Expedition 395 consists of five primary sites and seven alternates (Tables **T1**, **T2**). Alternate sites for each primary site were chosen to provide a range of options dependent on the desired scientific outcomes and/or operational requirements that necessitate operations at an alternate site. Estimates of total sediment thickness at each site are based upon a combination of sonic velocities measured at Sites 983 and 984 and from seismic stacking velocities.

1. Proposed Site REYK-2A: the basement target is segmented oceanic crust, and the sedimentary target is Gardar drift. This location was chosen to intersect Gardar drift and the region of oceanic crust that is devoid of VSRs and VSTs. Contourite drift sediments here are expected to be ~970 m thick, and oceanic basement is expected to be 32.4 Ma in age. The basement appears to be gently dipping toward the east and is an uneven, bright reflection. The alternate site is REYK-1A.
2. Proposed Site REYK-3B: the basement target is VSR 3. This site is located at the crest of VSR 3 on 13.9 Ma crust with ~465 m thick sediment above the basement. The alternate site is REYK-4B.
3. Proposed Site REYK-6A: the basement target is VST 2b, and the sedimentary target is Björn drift. Located at the crest of Björn drift and over VST 2b, our major basement and sedimentary objectives will be addressed here. This site is placed at a localized basement high that has shallow dip and is laterally continuous. Basement is expected to be 12.7 Ma in age and overlain by ~705 m thick contourite sediments. The alternate site is REYK-5A.
4. Proposed Site REYK-11A: the basement target is VSR 2a. Basement is expected to be 5.7 Ma in age and located at the crest of VSR 2a. Sediment here is expected to be ~340 m thick, and the sediment/basement interface is a bright reflection that is low in dip. The alternate sites are REYK-7A and REYK-8A.
5. Proposed Site REYK-13A: the basement target is VST 1. Basement is expected to be 2.8 Ma in age and located at the basement low of VST 1. Sediment here is expected to be ~210 m thick, and the sediment/basement interface is a bright, laterally continuous, approximately horizontal reflection. The alternate sites are REYK-9A and REYK-10A.

Sediment coring strategy

Two proposed sites, REYK-2A and REYK-6A, have primary paleoceanographic objectives that target the sedimentary sequences of Gardar and Björn drifts, respectively. At each of these two sites, we will drill three sediment holes by triple coring with the APC and half-length APC (HLAPC) (Table **T1**). Cores from these three holes will be combined using stratigraphic correlation to allow compilation of complete paleoceanographic records across core breaks and zones of poor recovery. This approach will also provide sufficient material for whole-round microbiological and pore water sampling. Triple coring of the sediment section will comprise three APC/HLAPC holes (A, B, and C) to refusal, which is estimated to occur at 300 meters below seafloor (mbsf) depending on drilling conditions. The third hole (C) will be extended to ~700 m using the XCB system. After we complete downhole wireline logging in Hole C, Hole D will be drilled using the drill-in casing (DIC) system to 650 m to support the sediment zone and prevent premature loss of the hole or loss of a drill string. Hole D will then be reentered, and core will be recovered using the RCB system until reaching the final basement target.

The remaining three proposed sites, REYK-13A, REYK-11A, and REYK-3B, do not have high-priority paleoceanographic objectives. Therefore, to optimize operating time, single holes are planned at each of these sites and the sedimentary section will be cored using the RCB system until reaching basement (Table **T1**).

APC, HLAPC, and RCB cores will be collected in nonmagnetic core barrels. The XCB core barrels are composed of steel.

For more information on the coring tools, see **http://iodp.tamu.edu/tools**.

Basement coring strategy

Our basement objectives require recovery of samples from ~15 lava flow units to obtain a space- and time-averaged geochemical record of basalt composition. Leg 49 targeted VSRs near Iceland and encountered flow units that were 3–8 m thick (Luyendyk et al., 1979). Our operations plan includes as much as 130 m of basement penetration at each site; using a conservative estimate of 8 m average flow unit thickness, this penetration depth should allow us to intersect ~16 flow units. If flow units are <8 m thick on average, we will use this redundancy to make up for unforeseen delays in the schedule elsewhere. Basement recovery rates with a single bit during Leg 49 were 25% at Site 407 (which penetrated 177 m into basement) and 24% at Site 409 (which penetrated 239 m into basement). Our objectives can be achieved if we recover material from a sufficient number of distinct flow units, even if the overall recovery rate is lower than that of Leg 49. Because our objective is to obtain a sufficient number of flow units (rather than a specific basement penetration depth), we will stop basement coring once 15 flow units have been encountered. Flow units will be identified on board based upon changes in rate of penetration, grain size, presence of interlayered sediments, and petrographic characteristics including phenocryst assemblages and groundmass texture. This approach will ensure that a sufficient number of flows have been sampled without spending more time than necessary at a given site.

Variations in rate of penetration provided a near real-time estimate of flow unit boundaries during Leg 49. However, we acknowledge that this method assumes a constant weight on the drill bit, which may not be achievable in variable sea conditions. This approach also requires a sufficient thickness of sediments or rubble between flows. Nonetheless, once the cores are split (about 3–5 h after the core arrives on deck), it should be relatively fast for the shipboard petrologists to count the flow units and make a timely decision about whether to continue drilling ahead or not.

We will deploy a single RCB bit in each hole, which is expected to be sufficient given the expected penetration rate of 3 m/h and typical life of bit. Because the holes will not be required for future use, the RCB drill bit will be dropped in the hole prior to wireline logging operations.

Logging/downhole measurements strategy

Wireline logging is planned for all sites, and operations are designed to log the entire length of the cored section. Downhole log data provide the only in situ formation characterization and are the only data in sections of the holes where core recovery is incomplete, allowing interpretations even in core gaps. The drill pipe will be set 80–100 m into the hole to prevent it from collapsing, precluding logging of the uppermost sediments. Three different tool strings will be deployed: the triple combination (triple combo), the Formation MicroScanner (FMS)-sonic, and the Versatile Seismic Imager (VSI). We will use two variations of the triple combo tool string. The first configuration will consist of tools that log formation resistivity, density, porosity, natural (spectral) gamma radiation, magnetic susceptibility, and borehole diameter. The second configuration will utilize the Ultrasonic Borehole Imager (UBI) in place of the Magnetic Susceptibility Sonde (MSS). The UBI provides high-resolution images with 100% borehole wall coverage, allowing detection of small-scale fractures and complex formation contacts. The General Purpose Inclinometry Tool (GPIT) will be deployed with the UBI to allow orientation of the images. The FMS-sonic tool string will provide an oriented 360° resistivity image of the borehole wall and logs of formation acoustic velocity, natural gamma radiation, and borehole diameter. A check shot survey with the VSI tool string is also planned for all site locations to allow depth-to-traveltime conversion. A combination of sonic velocity and density data will be used to generate a synthetic seismic profile at each site, hence enabling lithostratigraphy to be tied to seismic stratigraphy, which will extend the knowledge gained from the cores over a much broader area. The VSI can only be run during daylight hours to enable the observation of marine mammals.

Downhole logging tools will be deployed in Hole A at proposed Sites REYK-3B, REYK-11A, and REYK-13A. They will consist of the triple combo tool string with the UBI, FMS-sonic, and VSI. At proposed Sites REYK-2A and REYK-6A, Hole C will be logged to the total penetration depth (~700 m) using the triple combo with the MSS, FMS-sonic, and VSI. After completed coring operations in Hole D, logging will take place from the base of the casing string (~650 m) to the total penetration depth of each site. All three tool strings will be deployed, including the triple combo with the UBI. For more information on the downhole logging tools, see **http://iodp.tamu.edu/tools/logging**.

Temperature formation measurements will be conducted using the third-generation advanced piston corer temperature (APCT-3) tool. This tool is housed in an APC cutting shoe and is deployed with the APC core barrel. The APCT-3 tool is only used in soft sediments.

Core orientation will be measured on all APC cores using the Icefield MI-5 core orientation tool or a gyroscopic tool. The Icefield MI-5 collects azimuth, inclination, toolface gravity, toolface magnetism, total magnetic field strength, magnetic dip angle, and probe temperature.

Risks and contingency

Our priority is to recover basalt samples from ~15 flow units in the basaltic basement at each site following the recovery of complete sedimentary sections and sampling of the sediment/basement interface. These objectives will require flexibility in our operational plans to counter any unexpected eventualities.

Sea surface conditions, even in the boreal summer, can be unsettled in the North Atlantic Ocean. Therefore, the greatest risk to the expedition is the loss of time due to adverse weather conditions. Other risks to the completion of the program include operational problems like difficulties installing casing or stuck pipe, lower than predicted penetration rates, or unstable borehole conditions. Hiatuses in the recovered sediments, which would result in incomplete recovery of paleoceanographic records, are considered a low risk because these were not encountered during Leg 162.

Operational decisions for time allocation will be based on an assessment of the recovered sedimentary and basaltic samples and wireline data along with the ability to meet the primary science objectives. Options to reduce operations time include reducing downhole logging activities, reducing basement penetration, and reducing from four to three holes at proposed Sites REYK-2A and REYK-6A.

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/top-resources/program-documents/policies-and-guidelines**. This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. 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.

Shipboard scientists are expected to submit sample requests (at **http://iodp.tamu.edu/curation/samples.html**) before the beginning of the expedition. Based on the submitted sample requests (shore based and shipboard), 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 may 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 majority of the sampling for postcruise research will take place at the Sampling Party, held 3–6 months after the expedition. The Sampling Party will be hosted at the Bremen Core Repository (BCR) in Bremen, Germany, and shipboard and shore-based scientists, students, and collaborators will be invited to help collect the thousands of anticipated samples. Sampling on the ship will consist of samples for shipboard measurements as well as personal research samples for ephemeral properties and hard rock. Although we will endeavor to collect as many of the hard rock samples on the ship as possible, some of the sampling may take place postcruise at the Sampling Party.

The minimum permanent archive will be the standard archive half of each core. 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.

Expedition scientists and scientific participants

The current list of participants for Expedition 395 can be found at **http://iodp.tamu.edu/scienceops/precruise/reykjanes/participants.html**.

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Table T1. Operations and time estimates for primary sites, Expedition 395

Site	Location (Latitude Longitude)	Seafloor Depth (mbsl)	Operations		Transit (days)	Drilling and Coring (days)	Wireline Logging (days)
Reykjavik			Begin Expedition	5.0	port call days		
			Transit ~283 nmi to Site REYK-2A @ 10.5 kt		1.1		
REYK-2A	59° 51.0360' N	2206	Hole A - APC/HLAPC coring to 300 mbsf		0.0	2.0	0.0
EPSP approved	23° 15.9840' W		Hole B - APC/HLAPC coring to 300 mbsf		0.0	1.5	0.0
to 1170 mbsf			Hole C - APC/HLAPC/XCB coring to 700 mbsf; downhole wireline logging with the Triple Combo, FMS Sonic, and VSP		0.0	4.0	1.6
			Hole D - Drill in 650 m of 10 3/4" casing		0.0	3.1	0.0
			Hole D - Reenter Hole D and drill without recovery to 675 mbsf; RCB coring to 1100 mbsf; downhole wireline logging with the Triple Combo(w/UBI), FMS Sonic, and VSP		0.0	5.4	1.4
			Sub-Total Days On-Site:	19.1			
			Transit ~98 nmi to REYK-3B @ 10.5 kt		0.4		
REYK-3B	60° 6.3006' N	2001	Hole A - RCB coring to 595 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP		0.0	5.4	1.4
EPSP approved	26° 30.1044' W						
to 665 mbsf			Sub-Total Days On-Site:	6.8			
			Transit ~6 nmi to REYK-6A @ 10.5 kt		0.0		
REYK-6A	60° 7.5060' N	1871	Hole A - APC/HLAPC coring to 300 mbsf		0.0	1.8	0.0
EPSP approved	26° 42.0960' W		Hole B - APC/HLAPC coring to 300 mbsf		0.0	1.5	0.0
to 905 mbsf			Hole C - APC/HLAPC/XCB coring to 700 mbsf; downhole wireline logging with the Triple Combo, FMS Sonic, and VSP		0.0	4.0	1.5
			Hole D - Drill in 650 m of 10 3/4" casing		0.0	3.3	0.0
			Hole D - Reenter Hole D and drill without recovery to 675 mbsf; RCB coring to 835 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP		0.0	3.3	1.2
			Sub-Total Days On-Site:	16.6			
			Transit ~39 nmi to REYK-11A @ 10.5 kt		0.2		
REYK-11A	60° 12.0000' N	1415	Hole A - RCB coring to 470 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP		0.0	4.1	1.3
EPSP approved	28° 0.0000' W						
to 540 mbsf			Sub-Total Days On-Site:	5.4			
			Transit ~15 nmi to REYK-13A @ 10.5 kt		0.1		
REYK-13A	60° 13.6860' N	1520	Hole A - RCB coring to 340 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP		0.0	3.5	1.1
EPSP approved	28° 30.0240' W						
to 410 mbsf			Sub-Total Days On-Site:	4.7			
			Transit ~307 nmi to Reykjavik @ 10.5 kt		1.2		
Reykjavik			End Expedition		3.0	43.0	9.6

Port Call Days:	5.0	Total Operating Days:	55.6
Days On-Site:	52.6	Total Expedition:	60.6

Table T2. Operations for alternate sites, Expedition 395.

Site	Location (Latitude Longitude)	Seafloor Depth (mbsl)	Operations	Drilling and Coring (days)	Wireline Logging (days)
REYK-1A	59° 50.9760' N	2209	Hole A - APC/HLAPC coring to 300 mbsf	2.0	0.0
EPSP approved	23° 14.8380' W		Hole B - APC/HLAPC coring to 300 mbsf	1.5	0.0
to 1155 mbsf			Hole C - APC/HLAPC/XCB coring to 955 mbsf; downhole wireline logging with the Triple Combo, FMS Sonic, and VSP	5.7	1.9
			Hole D - Drill in 650 m of 10 3/4" casing	3.1	0.0
			Hole D - Reenter Hole D and drill without recovery to 935 mbsf; RCB coring to 1085 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	5.3	1.4
			Sub-Total Days On-Site: 20.9		
REYK-4B	60° 6.0564' N	2109	Hole A - RCB coring to 545 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	5.4	1.4
EPSP approved	26° 27.6666' W				
to 615 mbsf			Sub-Total Days On-Site: 6.8		
REYK-5A	60° 7.5840' N	1894	Hole A - APC/HLAPC coring to 300 mbsf	1.9	0.0
EPSP approved	26° 45.0960' W		Hole B - APC/HLAPC coring to 300 mbsf	1.5	0.0
to 875 mbsf			Hole C - APC/HLAPC/XCB coring to 675 mbsf; downhole wireline logging with the Triple Combo, FMS Sonic, and VSP	3.7	1.5
			Hole D - Drill in 650 m of 10 3/4" casing	3.1	0.0
			Hole D - Reenter Hole D; RCB coring to 805 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	3.3	1.1
			Sub-Total Days On-Site: 16.1		
REYK-7A	60° 9.0420' N	1735	Hole A - RCB coring to 460 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	4.6	1.3
EPSP approved	27° 10.1880' W				
to 530 mbsf			Sub-Total Days On-Site: 5.9		
REYK-8A	60° 8.9460' N	1695	Hole A - RCB coring to 450 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	4.4	1.3
EPSP approved	27° 8.2200' W				
to 520 mbsf			Sub-Total Days On-Site: 5.7		
REYK-9A	60° 10.2120' N	1701	Hole A - RCB coring to 440 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	4.4	1.3
EPSP approved	27° 31.7964' W				
to 510 mbsf			Sub-Total Days On-Site: 5.7		
REYK-10A	60° 10.0020' N	1689	Hole A - RCB coring to 285 mbsf; downhole wireline logging with the Triple Combo+UBI, FMS Sonic, and VSP	3.6	1.1
EPSP approved	27° 28.3560' W				
to 355 mbsf			Sub-Total Days On-Site: 4.7		

Figure F1. Plume-ridge interaction in the North Atlantic Ocean. A. Dynamic topography, showing plume swell centered on Iceland (Hoggard et al., 2016). B. Horizontally polarized *S*-wave velocity from full-waveform tomographic model at 120 km depth (Rickers et al., 2013). Yellow circles = proposed drilling sites, dashed line = Mid-Atlantic Ridge.

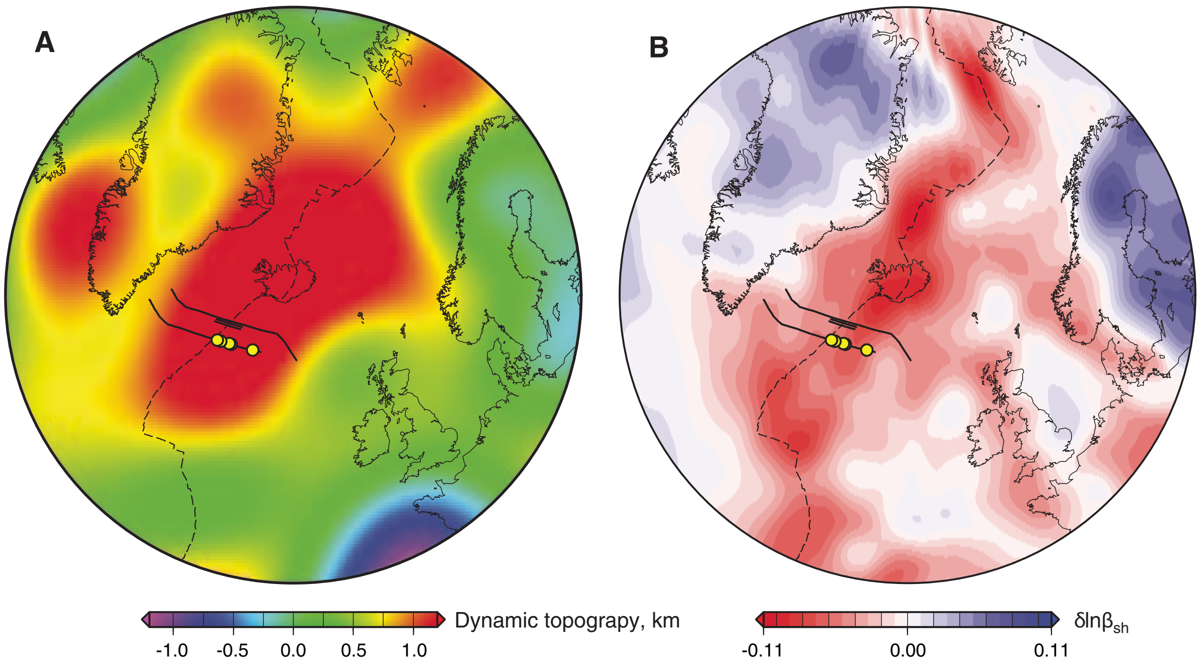


Figure F2. A. Proposed drilling sites and deepwater pathways, Expedition 395. Box = location of Figure F4. Yellow circles = proposed drilling sites, black circles = ODP/DSDP boreholes, solid black lines = seismic profiles, red dashed line = Mid-Atlantic Ridge, gray lines = magnetic polarity chrons, dotted black lines = deepwater currents. WBUC = Western Boundary Undercurrent, DSOW = Denmark Strait Overflow Water, ISOW = Iceland-Scotland Overflow Water, DS = Denmark Strait, IFR = Iceland-Faroe Ridge, RR = Reykjanes Ridge, BFZ = Bight Fracture Zone. B. Free-air gravity anomaly, filtered to remove wavelengths > 250 km. Open circles/triangles = dredged basalt samples (Murton et al., 2002; Jones et al., 2014), red star = Iceland plume center (Shorttle and Maclennan, 2011), arrows = V-shaped ridges, dotted polygons = transition from smooth to segmented ocean floor. Red and blue circles A (Smallwood and White, 1998) and B (Whitmarsh, 1971) and blue line C (Parkin and White, 2008) show locations of crustal thickness estimates from seismic refraction experiments.

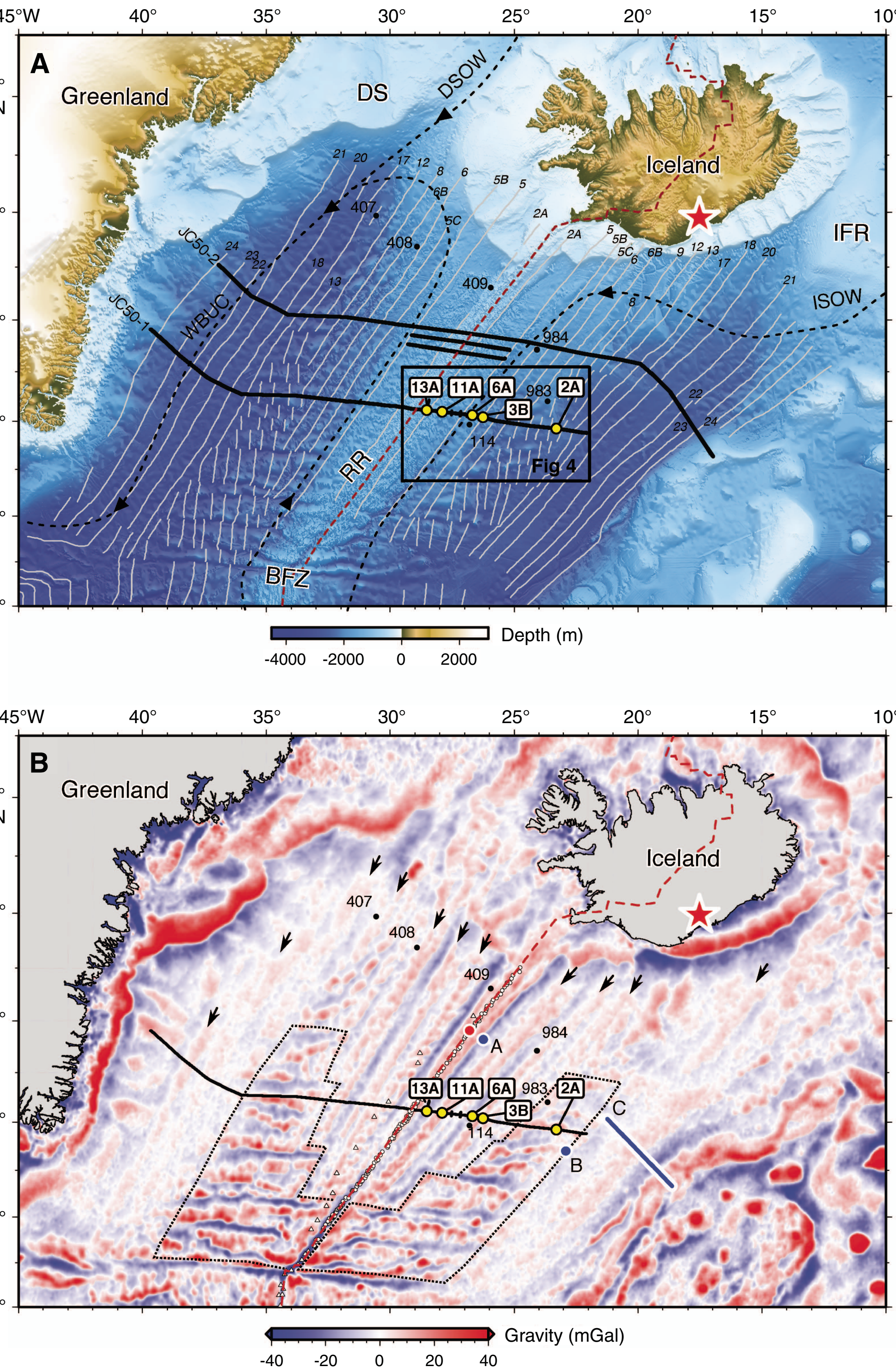


Figure F3. Competing hypotheses for V-shaped ridge (VSR) formation (Parnell-Turner et al., 2017). VST = V-shaped trough. A. Thermal pulsing hypothesis (Vogt, 1971). Dark gray blocks = lithospheric plates, pink block with red patches = asthenospheric channel containing thermal pulses, light gray block = upper mantle. Solid arrows = propagation direction of thermal pulses, dashed arrows = plate spreading direction. Yellow shading = melting region. Red/blue ribs = VSRs/VSTs. Black line = mid-ocean ridge. B. Propagating rift hypothesis (Hey et al., 2010). Solid arrows = propagating rift direction. VSRs are regarded as failed rifts with thicker crust and VSTs are regarded as pseudofaults that propagate along axis generating thinner crust. C. Buoyant mantle upwelling hypothesis (Martinez and Hey, 2017). Gray blobs = buoyant upwelling cells that generate damp melting and thicker crust in absence of thermal anomaly, vertical arrows = vertical upwelling within a given cell, dashed lines = dry/wet solidi.

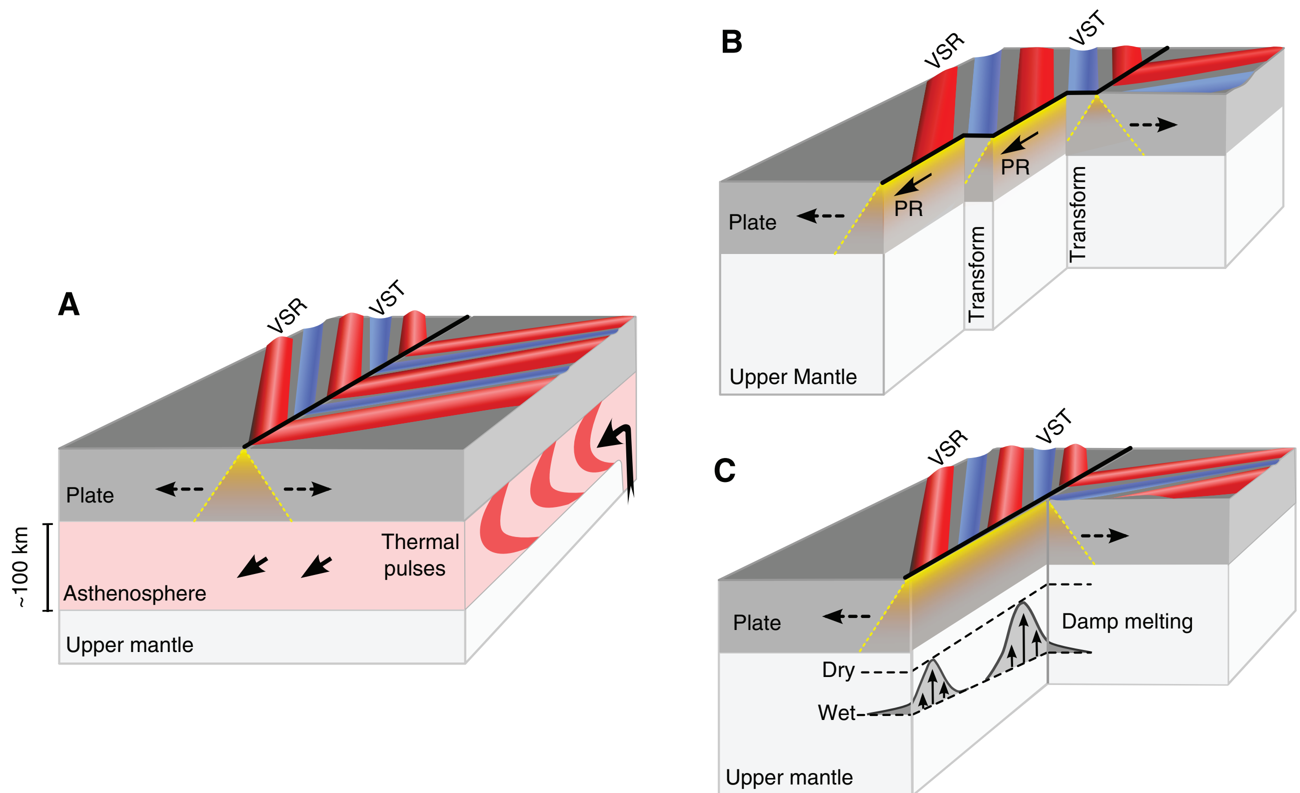


Figure F4. Satellite free-air gravity anomaly map showing drilling sites and age chrons, Expedition 395. Solid black lines = seismic reflection profiles, dashed line = Reykjanes Ridge (RR). Labeled gray lines = magnetic polarity chrons (Jones et al., 2002). Black dots = existing ODP/DSDP boreholes. VSR = V-shaped ridge, VST = V-shaped trough. Open circles/triangles = dredged basalt samples (Murton et al., 2002; Jones et al., 2014).

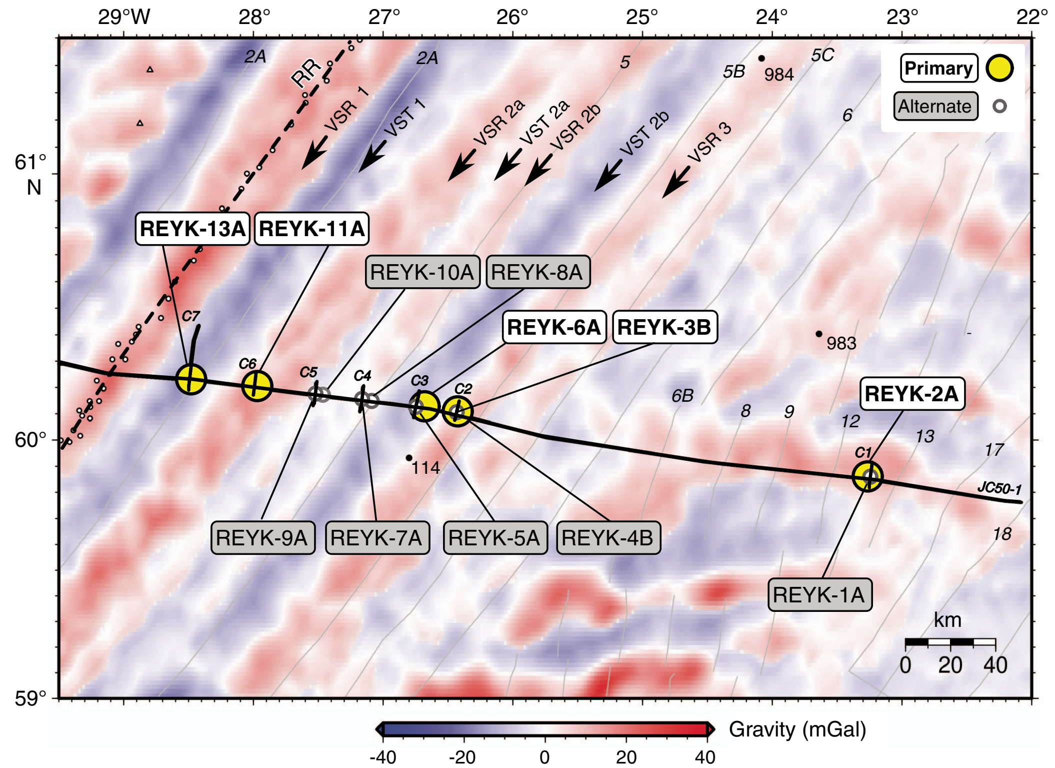


Figure F5. Portion of Seismic Reflection Profile JC50-1 (see Figure F2 for location). A. Uninterpreted time-migrated image. Dotted lines = sedimentary drifts. B. Interpretation. Yellow shading and gray lines = sedimentary strata; solid line = sediment/basement interface. Red dots = V-shaped ridges (VSRs), blue dots = V-shaped troughs (VSTs). Yellow circles = primary drilling sites. m = multiple reflections. Lines 983 and 984 = projected locations of Leg 162 drilling sites.

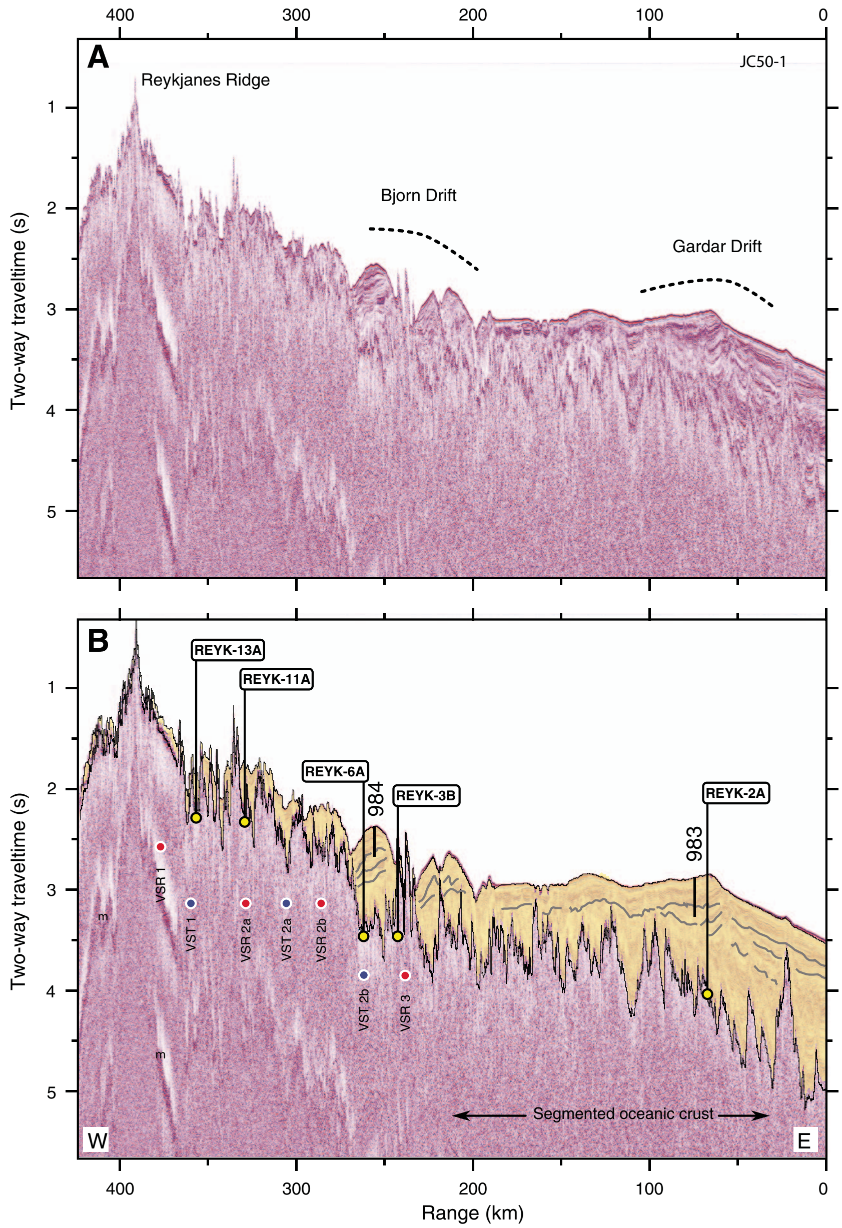


Figure F6. Geochemical data from dredged basalts along Reykjanes Ridge from 55°N to 63°N (Jones et al., 2014; Murton et al., 2002). VSR = V-shaped ridge, VST = V-shaped trough. Pink bands delineate regions where VSRs intersect ridge, width of VSR 1. A. Gravity. Black line = bathymetry, red/blue shaded line = short wavelength gravity anomaly. B. Nb/Y. Gray curve = best-fitting polynomial. Red and blue circles = projected locations of crustal thickness (tc) measurements. C. Mg#. D. $^{87}Sr/^{86}Sr$.

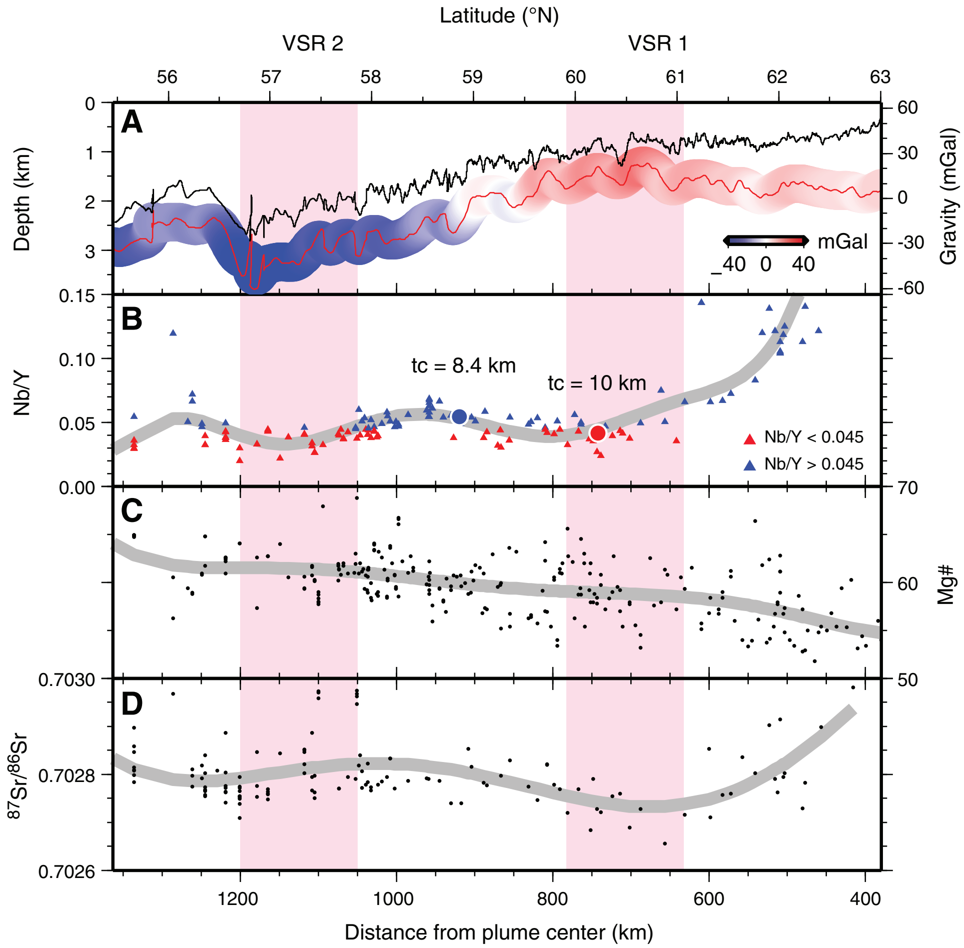
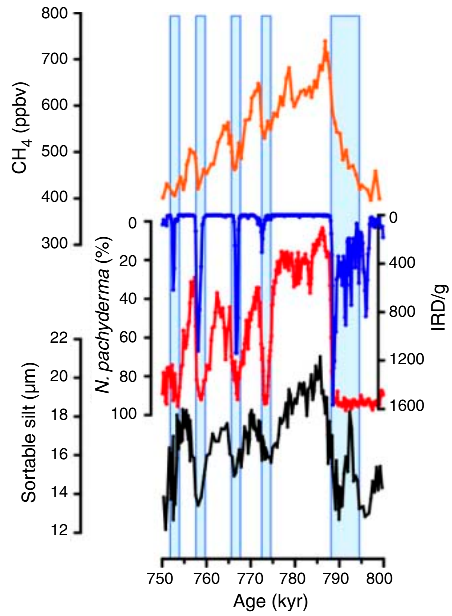


Figure F7. Submillennial-scale records from Site 983 (S. Barker, pers. comm., 2017; Barker et al., 2019). Orange line = atmospheric CH_4 from Antarctica (Loulergue et al., 2008), blue line = ice-rafted debris (IRD) per gram, red line = relative proportion of planktonic foraminifer *Neogloboquadrina pachyderma* versus all other species, black line = sortable silt (Kleiven et al., 2011). Variations in relative proportion of planktonic foraminifer *N. pachyderma* reflect latitudinal variations in the polar front, and IRD tracks the occurrence of ice rafting across the northeast Atlantic Ocean. Sortable silt record reveals weakening bottom currents at this site associated with millennial-scale cooling and ice rafting events. Records of %*N. pachyderma* and IRD/g have average temporal resolution of 177 y.



Site summaries

Site REYK-01A

Priority:	Alternate for REYK-02A
Position:	23.24726°W, 59.84961°N
Water depth (m):	2209
Target drilling depth (mbsf):	1085
Approved maximum penetration (mbsf):	1155
Survey coverage (track map; seismic profile):	CMP 10538 on JC50–1; CMP 1019 on JC50–C1 (Figure **AF1**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior; Oceanic Circulation, Gateways and Sedimentation; Time-Dependent Hydrothermal Alteration of Oceanic Crust This site will target the Gardar drift and segmented oceanic crust not located on a VSR or VST. The basement age is anticipated to be 32.4 Ma.
Drilling program:	Holes A/B: APC/HLAPC core to refusal; Hole C: APC/XCB Core to 955 m; Hole D: drill in casing to 650 m, drill without recovery to 935 m, RCB core to 1085 m
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI in Holes C and D. APCT-3 temperature measurements in Hole A. Core orientation as needed.
Nature of rock anticipated:	Recent to Oligocene clay or ooze. Olivine basalt flows.

Site REYK-02A

Priority:	Primary
Position:	23.26643°W, 59.85061°N
Water depth (m):	2206
Target drilling depth (mbsf):	1100
Approved maximum penetration (mbsf):	1170
Survey coverage (track map; seismic profile):	CMP 10710 on JC50–1; CMP 1019 on JC50–C1 (Figure **AF2**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior; Oceanic Circulation, Gateways and Sedimentation; Time-Dependent Hydrothermal Alteration of Oceanic Crust This site will target the Gardar drift and segmented oceanic crust not located on a VSR or VST. The basement age is anticipated to be 32.4 Ma.
Drilling program:	Holes A/B: APC/HLAPC core to refusal; Hole C: APC/XCB Core to 700 m; Hole D: drill in casing to 650 m, drill without recovery to 675 m, RCB core to 1100 m
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI in Holes C and D. APCT-3 temperature measurements in Hole A. Core orientation as needed.
Nature of rock anticipated:	Recent to Oligocene clay or ooze. Olivine basalt flows.

Site REYK-03B

Priority:	Primary
Position:	26.50174°W, 60.10501°N
Water depth (m):	2001
Target drilling depth (mbsf):	595
Approved maximum penetration (mbsf):	665
Survey coverage (track map; seismic profile):	CMP 39920 on JC50–1; CMP 685 on JC50–C2 (Figure **AF3**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust Obtain basement rocks on the crest of VSR 3. Basement age is 13.9 Ma.
Drilling program:	RCB core a single hole to 595 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-04B

Priority:	Alternate for REYK-03B
Position:	26.46111°W, 60.10094°N
Water depth (m):	2109
Target drilling depth (mbsf):	545
Approved maximum penetration (mbsf):	615
Survey coverage (track map; seismic profile):	CMP 39550 on JC50–1; CMP 685 on JC50–C2 (Figure **AF4**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust Obtain basement rocks on the crest of VSR 3. Basement age is 14.1 Ma.
Drilling program:	RCB core a single hole to 545 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-05A

Priority:	Alternate for REYK-06A
Position:	26.75156°W, 60.12641°N
Water depth (m):	1894
Target drilling depth (mbsf):	805
Approved maximum penetration (mbsf):	875
Survey coverage (track map; seismic profile):	CMP 42185 on JC50–1; CMP 1005 on JC50–C3 (Figure **AF5**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior; Oceanic Circulation, Gateways and Sedimentation; Time-Dependent Hydrothermal Alteration of Oceanic Crust This site will target the Björn drift and basement rocks in VST 2b. The basement age is 12.4 Ma.
Drilling program:	Holes A/B: APC/HLAPC core to refusal; Hole C: APC/XCB Core to 675 m; Hole D: drill in casing to 650 m, RCB core to 805 m
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI in Holes C and D. APCT-3 temperature measurements in Hole A. Core orientation as needed.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-06A

Priority:	Primary
Position:	26.70160°W, 60.12510°N
Water depth (m):	1871
Target drilling depth (mbsf):	835
Approved maximum penetration (mbsf):	905
Survey coverage (track map; seismic profile):	CMP 41740 on JC50–1; CMP 1005 on JC50–C3 (Figure **AF6**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior; Oceanic Circulation, Gateways and Sedimentation; Time-Dependent Hydrothermal Alteration of Oceanic Crust This site will target the Björn drift and basement rocks in VST 2b. The basement age is 12.7 Ma.
Drilling program:	Holes A/B: APC/HLAPC core to refusal; Hole C: APC/XCB Core to 700 m; Hole D: drill in casing to 650 m, drill without recovery to 675 m, RCB core to 835 m
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI in Holes C and D. APCT-3 temperature measurements in Hole A. Core orientation as needed.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-07A

Priority:	Alternate for REYK-11A
Position:	27.16977°W, 60.15074°N
Water depth (m):	1735
Target drilling depth (mbsf):	460
Approved maximum penetration (mbsf):	530
Survey coverage (track map; seismic profile):	CMP 45944 on JC50–1; CMP 899 on JC50–C4 (Figure **AF7**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site is located on VSR 2b with a basement age of 9.8 Ma.
Drilling program:	RCB core a single hole to 460 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-08A

Priority:	Alternate for REYK-11A
Position:	27.13699°W, 60.14913°N
Water depth (m):	1695
Target drilling depth (mbsf):	450
Approved maximum penetration (mbsf):	520
Survey coverage (track map; seismic profile):	CMP 45650 on JC50–1; CMP 899 on JC50–C4 (Figure **AF8**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site is located on VSR 2b with a basement age of 10.0 Ma.
Drilling program:	RCB core a single hole to 450 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-09A

Priority:	Alternate for REYK-13A
Position:	27.52994°W, 60.17019°N
Water depth (m):	1701
Target drilling depth (mbsf):	440
Approved maximum penetration (mbsf):	510
Survey coverage (track map; seismic profile):	CMP 49165 on JC50–1; CMP 843 on JC50–C5 (Figure **AF9**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site targets basement in VST 2a. The basement age is 7.7 Ma.
Drilling program:	RCB core a single hole to 440 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

Site REYK-10A

Priority:	Alternate for REYK-13A
Position:	27.47257°W, 60.16668°N
Water depth (m):	1689
Target drilling depth (mbsf):	285
Approved maximum penetration (mbsf):	355
Survey coverage (track map; seismic profile):	CMP 48650 on JC50–1; CMP 843 on JC50–C5 (Figure **AF10**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site targets basement in VST 2a. The basement age is 8.1 Ma.
Drilling program:	RCB core a single hole to 285 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Miocene clay or ooze. Olivine basalt flows.

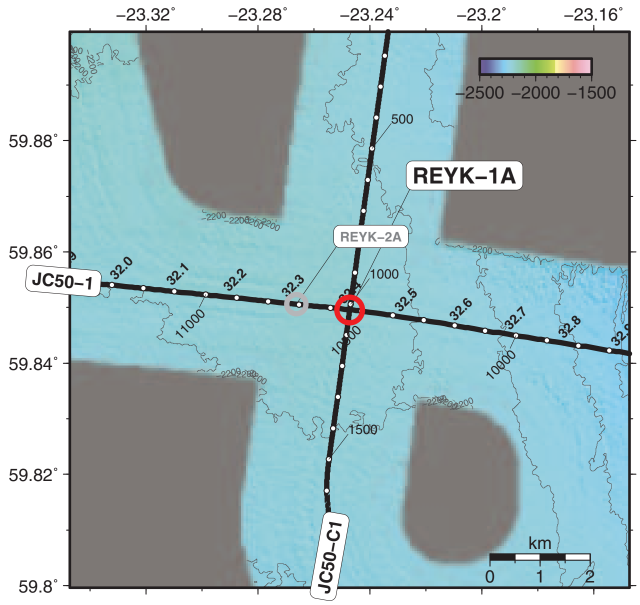
Site REYK-11A

Priority:	Primary
Position:	28.00000°W, 60.19994°N
Water depth (m):	1415
Target drilling depth (mbsf):	470
Approved maximum penetration (mbsf):	540
Survey coverage (track map; seismic profile):	CMP 53393 on JC50–1; CMP 888 on JC50–C6 (Figure **AF11**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site is located on VSR 2a with a basement age of 5.2 Ma.
Drilling program:	RCB core a single hole to 470 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Pliocene clay or ooze. Olivine basalt flows.

Site REYK-13A

Priority:	Primary
Position:	28.50040°W, 60.22818°N
Water depth (m):	1520
Target drilling depth (mbsf):	340
Approved maximum penetration (mbsf):	410
Survey coverage (track map; seismic profile):	CMP 57881 on JC50–1; CMP 3720 on JC50–C7 (Figure **AF12**)
Objective(s):	Science Objectives: Crustal Accretion and Mantle Plume Behavior, Time-Dependent Hydrothermal Alteration of Oceanic Crust This site targets basement in VST 1. The basement age is 2.8 Ma.
Drilling program:	RCB core a single hole to 340 m.
Logging/Downhole measurements program:	Downhole wireline logging using the Triple Combo+UBI, FMS-Sonic, and VSI.
Nature of rock anticipated:	Recent to Pliocene clay or ooze. Olivine basalt flows.

Figure AF1. Site REYK-1A.



Site Summary: Expedition 395 Site REYK–1A

Category: **Alternate**

Location: –23.24726 °W, 59.84961 °N

CMP 10538 on JC50–1; CMP 1019 on JC50–C1

Water depth: 2209 m / 2.980 s TWTT

Sediment thickness: 955 mbsf / 3.978 s TWTT

Basement target thickness: 130 m

Total target depth: 1085 mbsf / 4.126 s TWTT

Basement age: 32.44 Ma

Interpretation:

Gray = seabed ; red = G2 (1.0 Ma); green = G3 (1.25 Ma);
blue = G4; orange = G5; black = basement

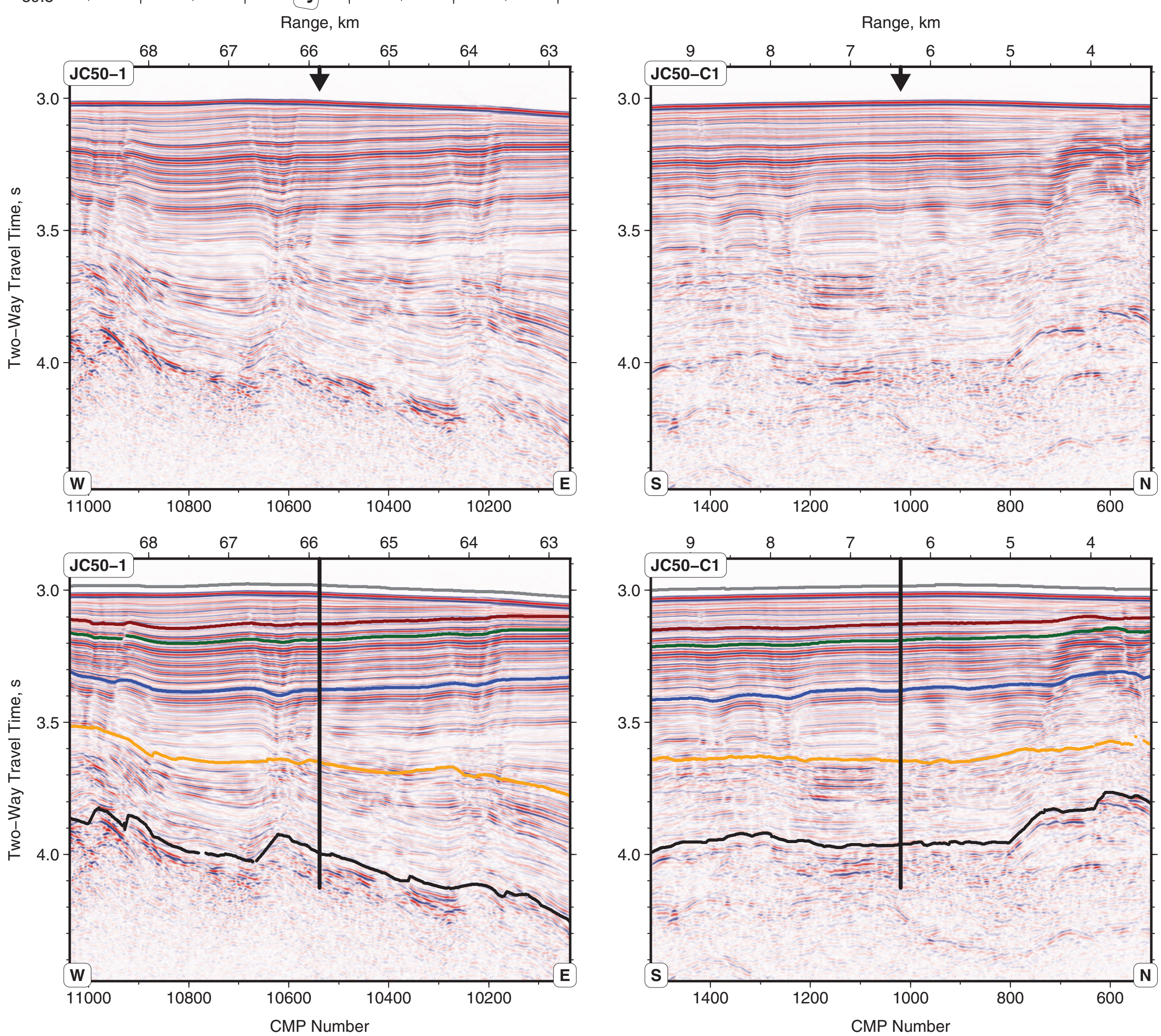


Figure AF2. Site REYK-2A.

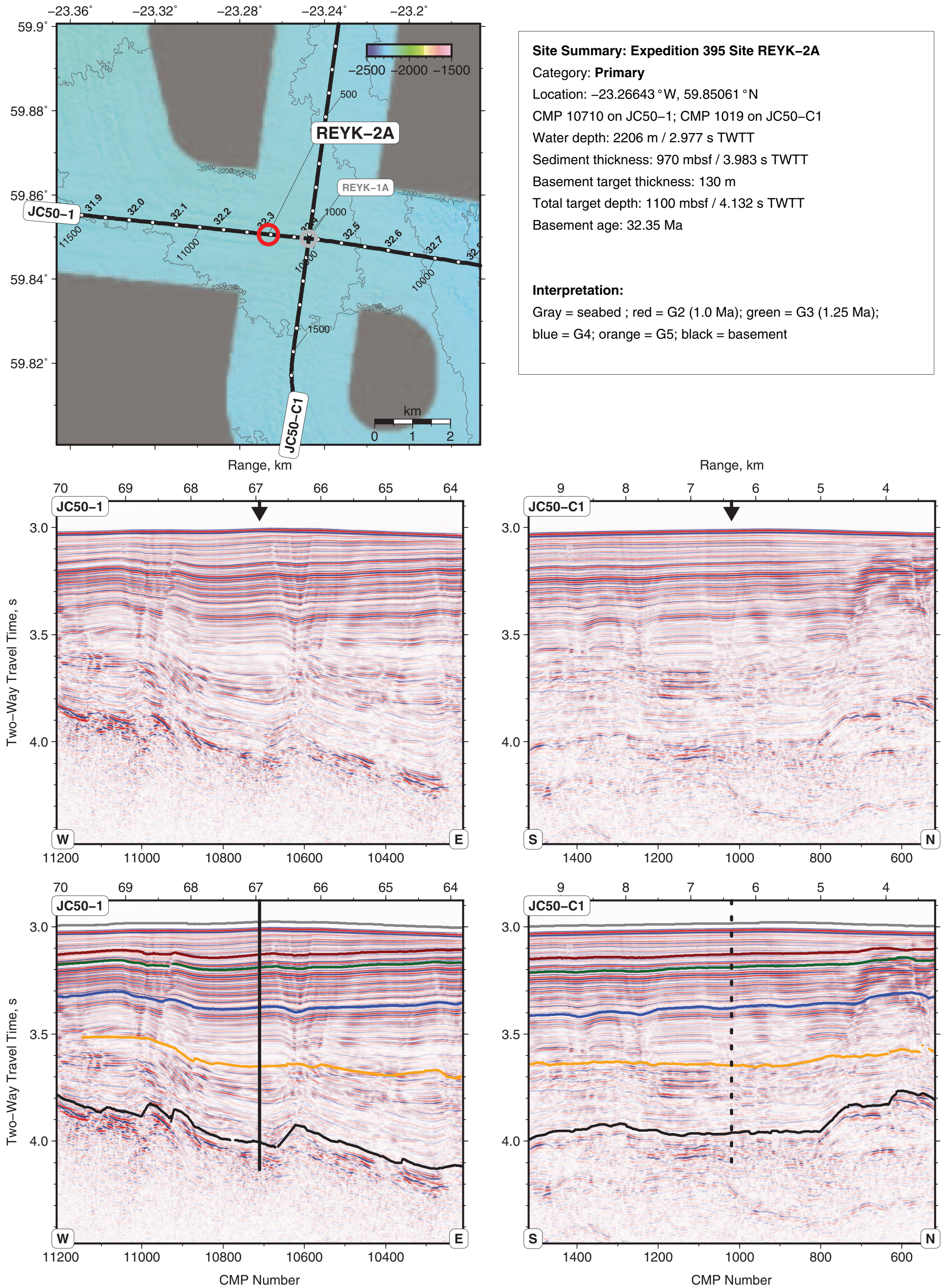


Figure AF3. Site REYK-3B.

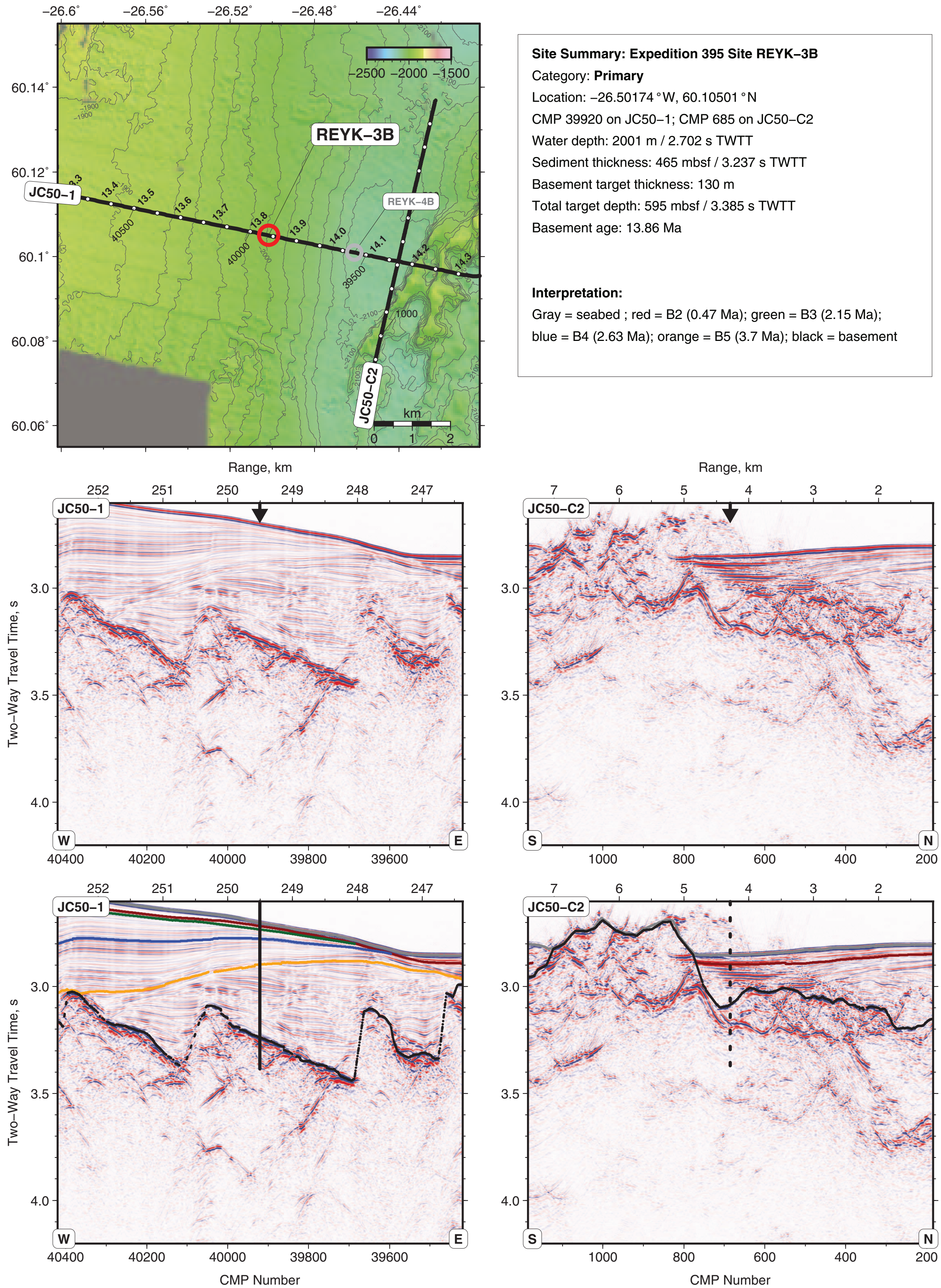


Figure AF4. Site REYK-4B.

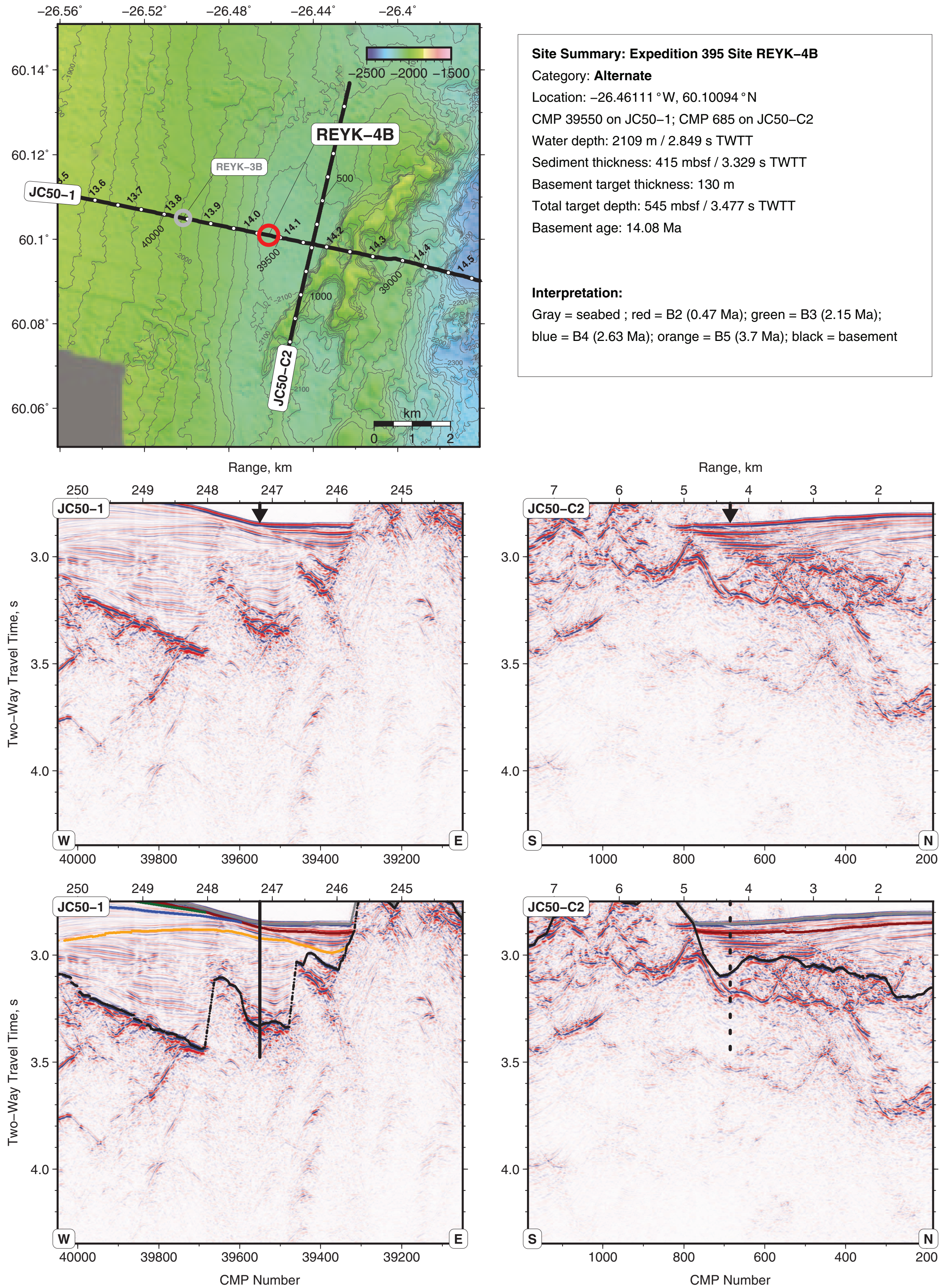
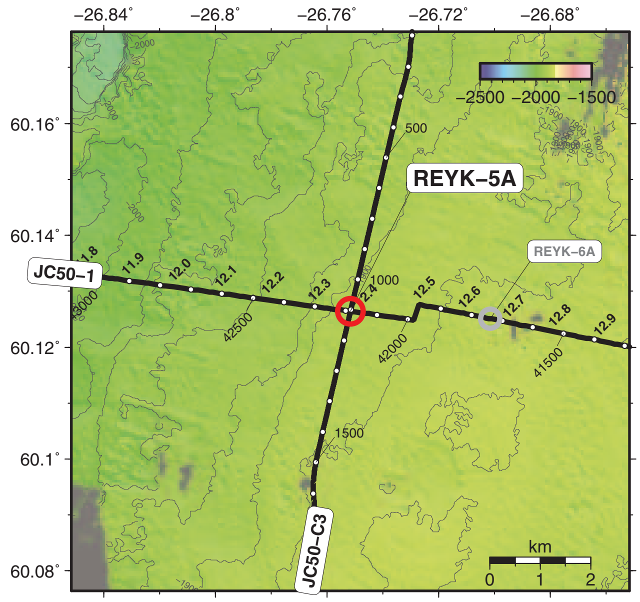


Figure AF5. Site REYK-5A.



Site Summary: Expedition 395 Site REYK–5A
Category: **Alternate**
Location: –26.75156 °W, 60.12641 °N
CMP 42185 on JC50–1; CMP 1005 on JC50–C3
Water depth: 1894 m / 2.553 s TWTT
Sediment thickness: 675 mbsf / 3.288 s TWTT
Basement target thickness: 130 m
Total target depth: 805 mbsf / 3.436 s TWTT
Basement age: 12.40 Ma

Interpretation:
Gray = seabed ; red = B2 (0.47 Ma); green = B3 (2.15 Ma); blue = B4 (2.63 Ma); orange = B5 (3.7 Ma); black = basement

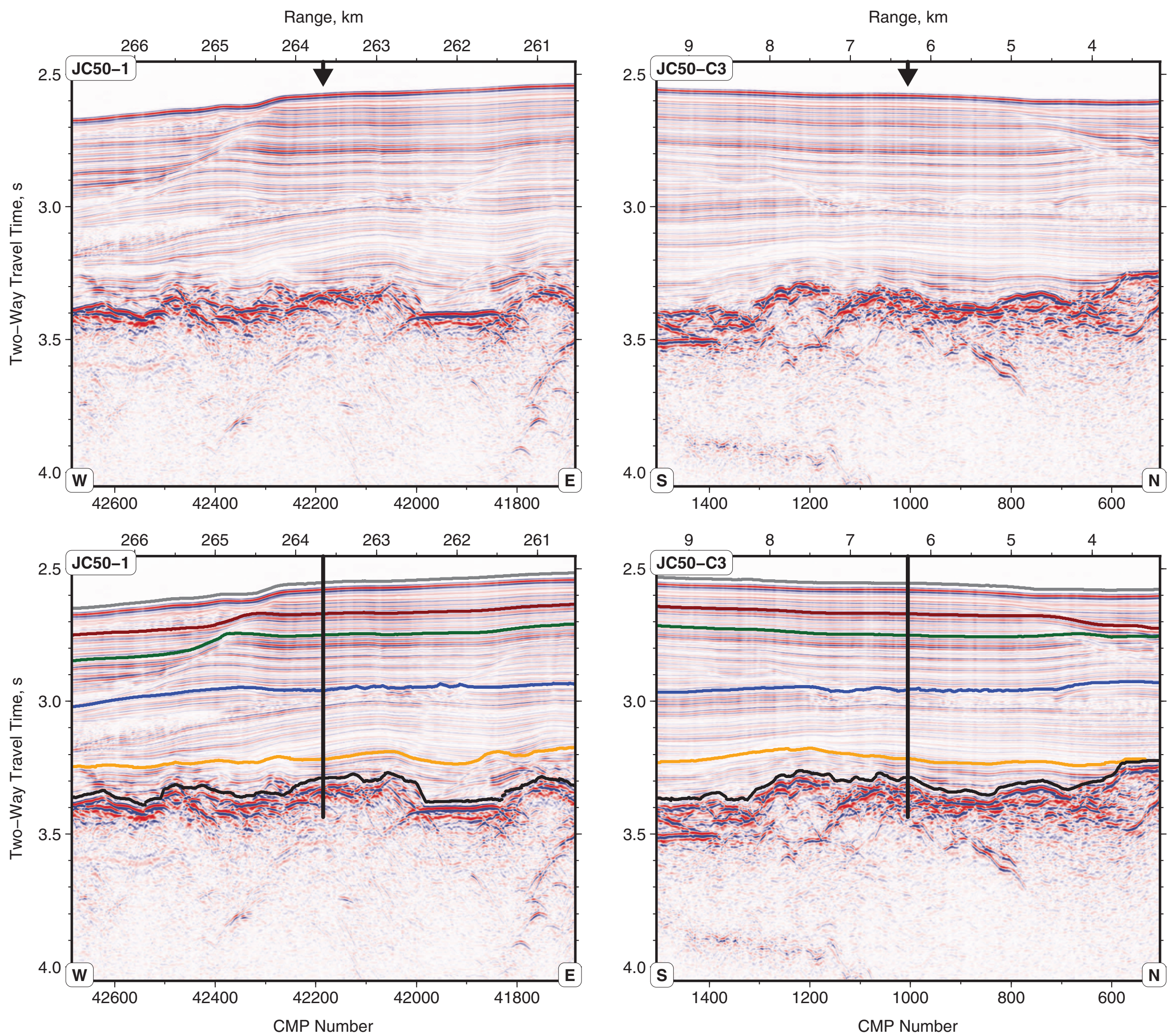


Figure AF6. Site REYK-6A.

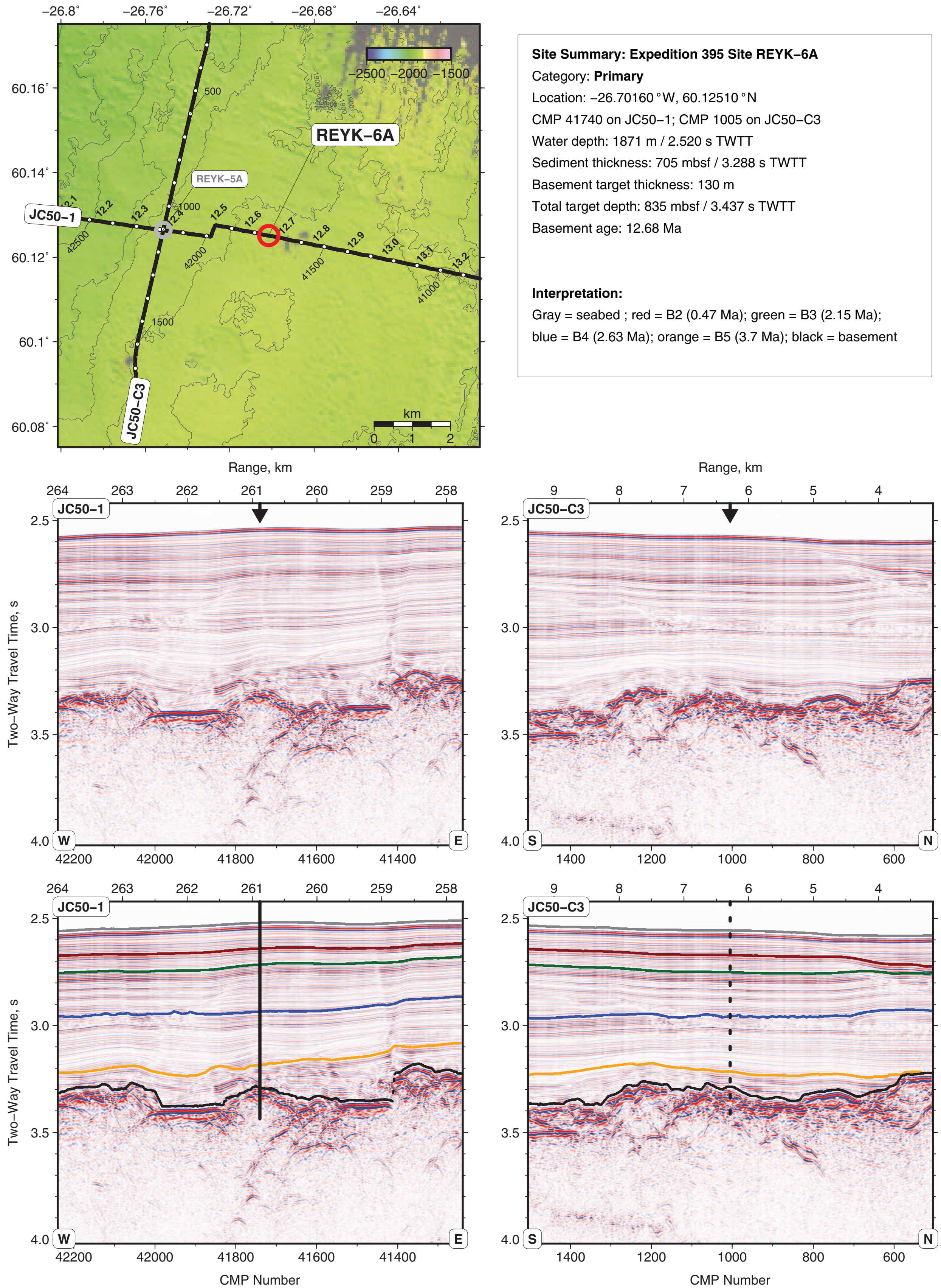


Figure AF7. Site REYK-7A.

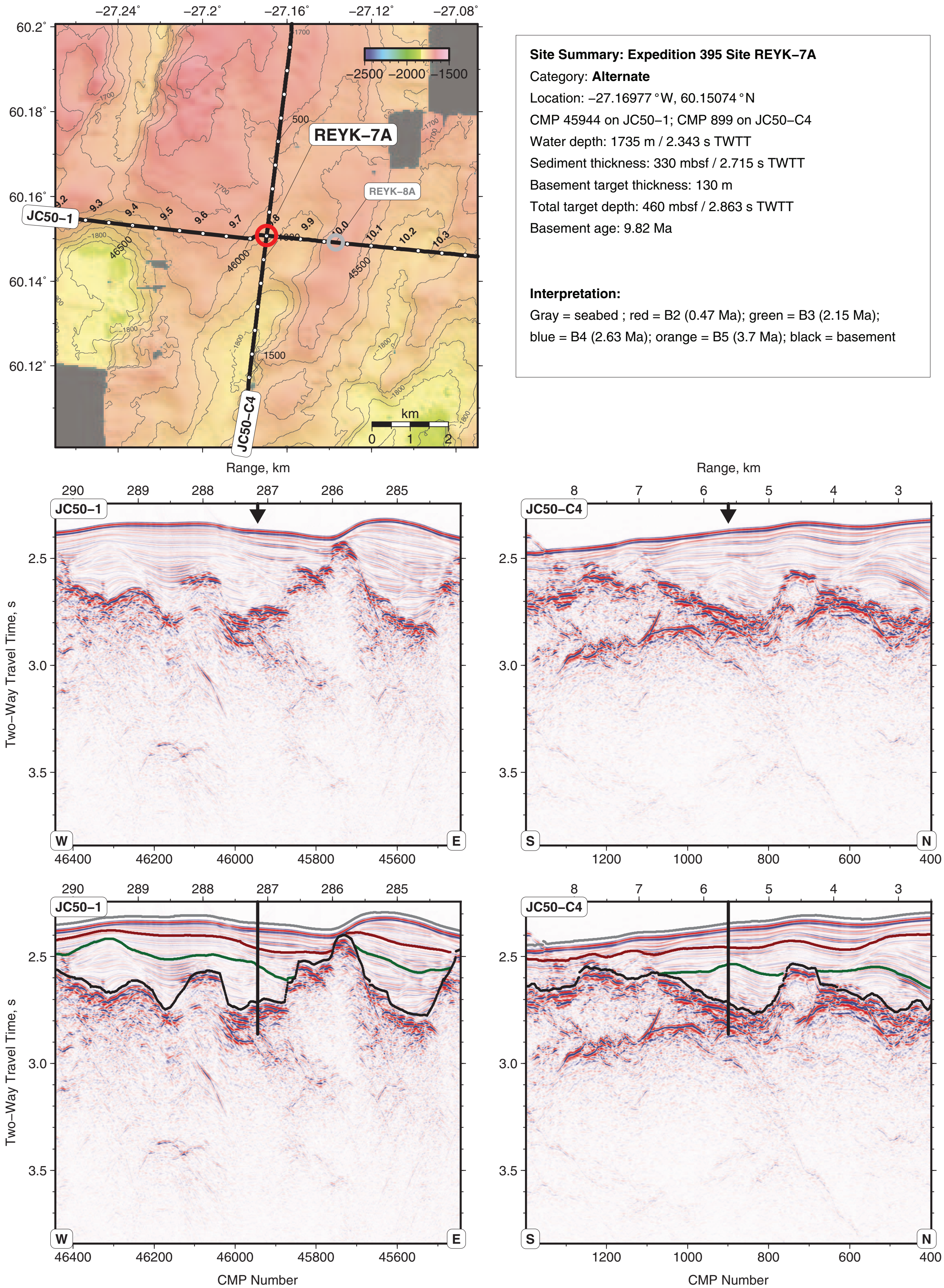


Figure AF8. Site REYK-8A.

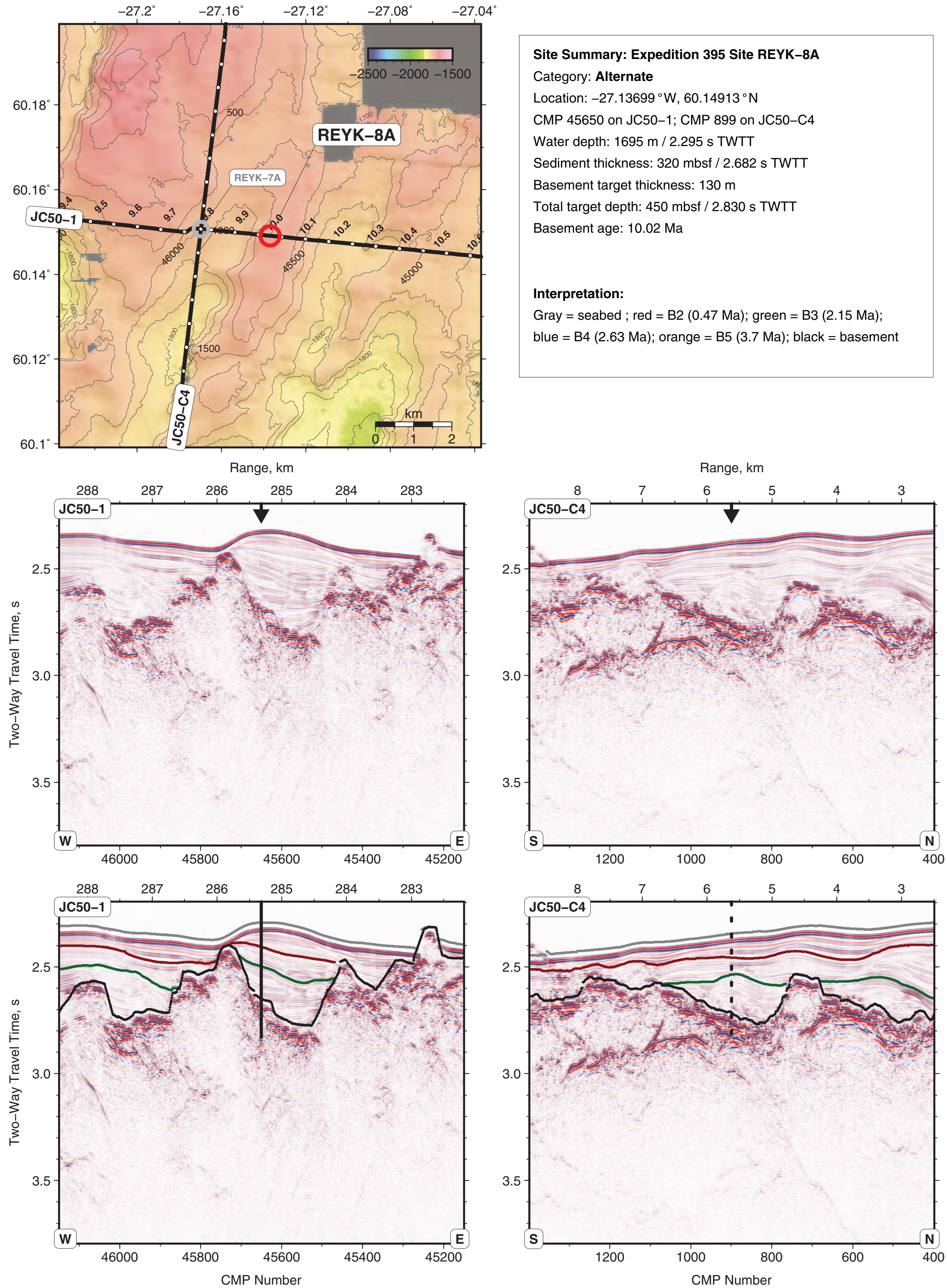


Figure AF9. Site REYK-9A.

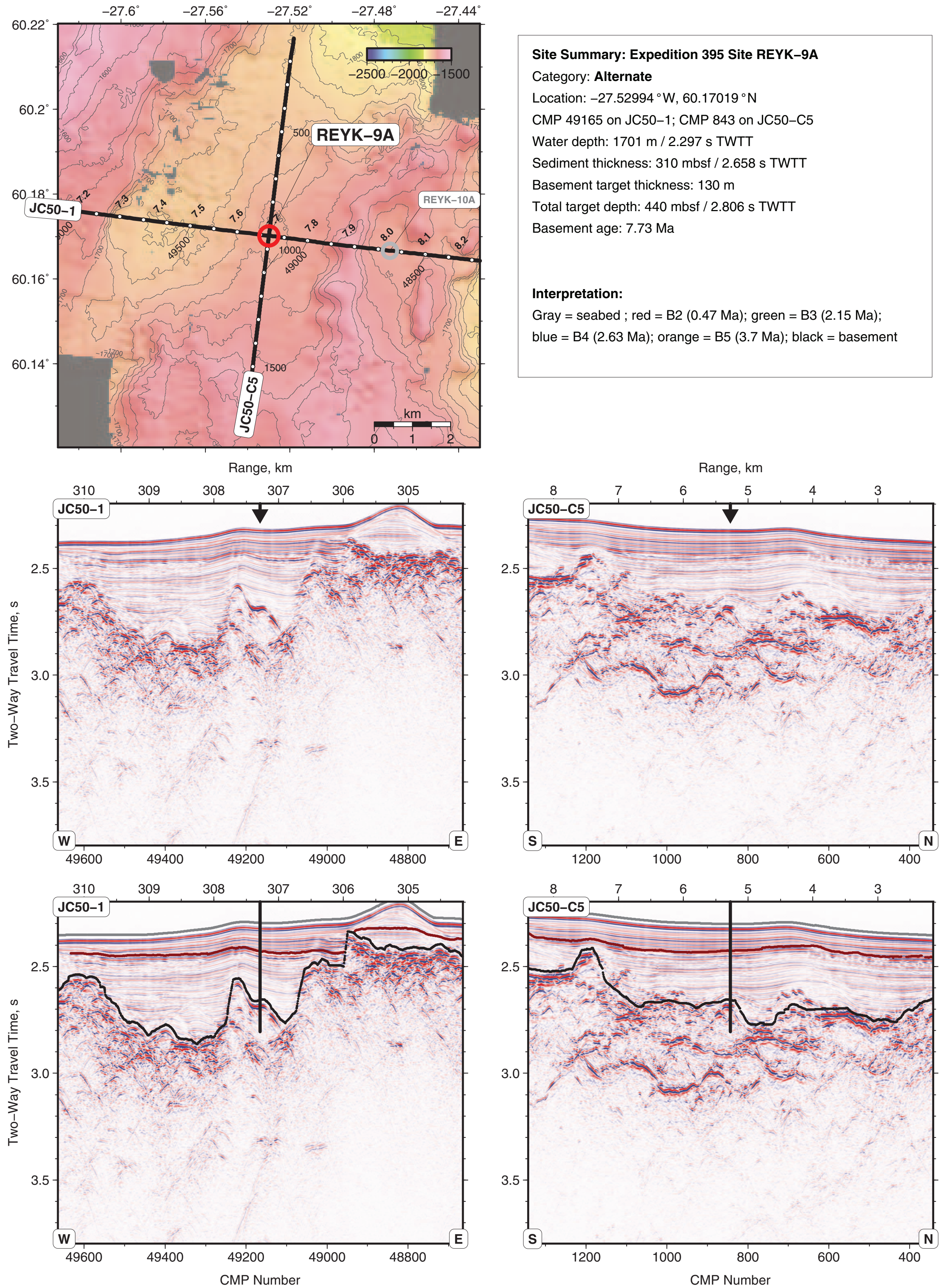


Figure AF10. Site REYK-10A.

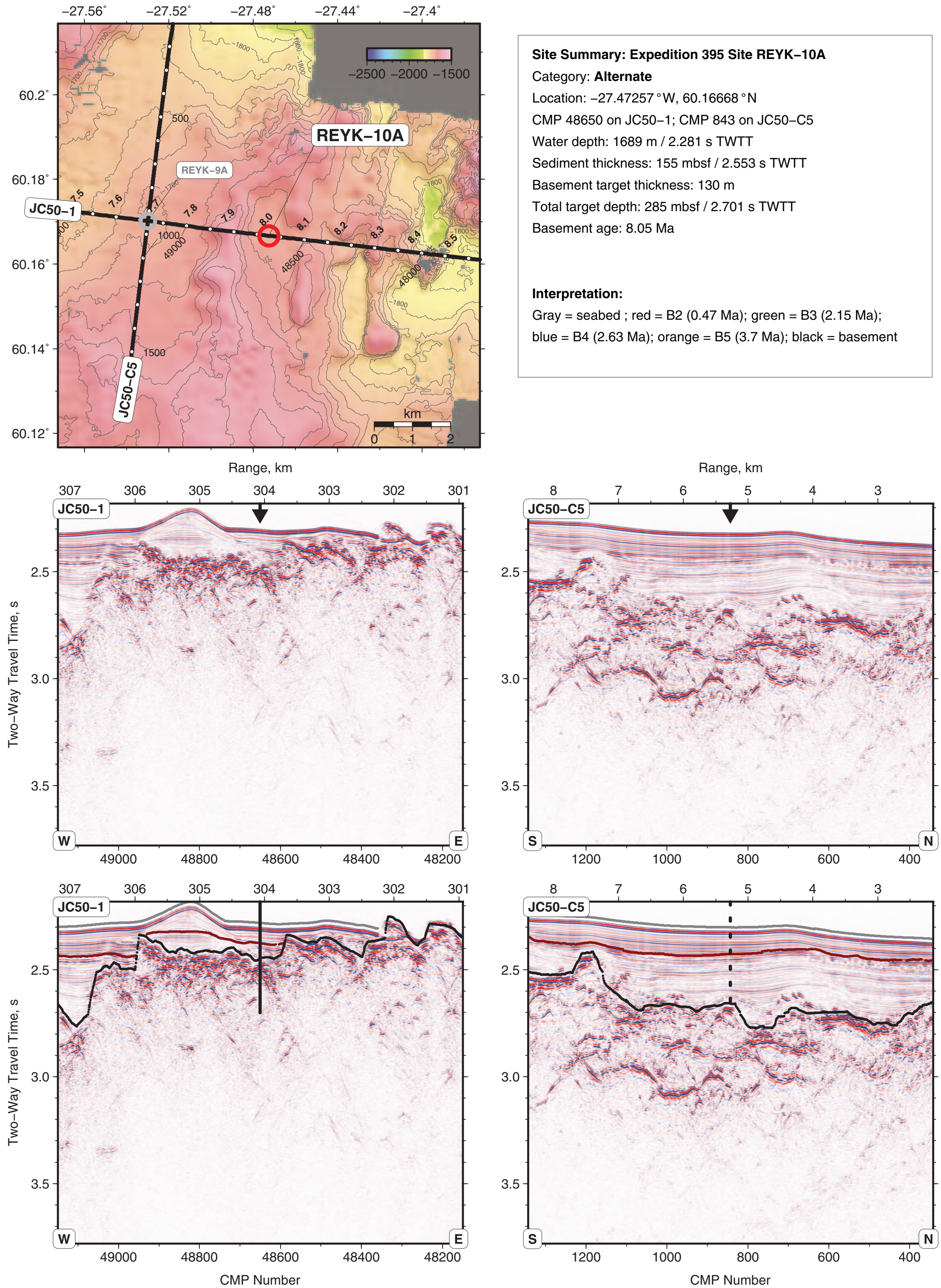


Figure AF11. Site REYK-11A.

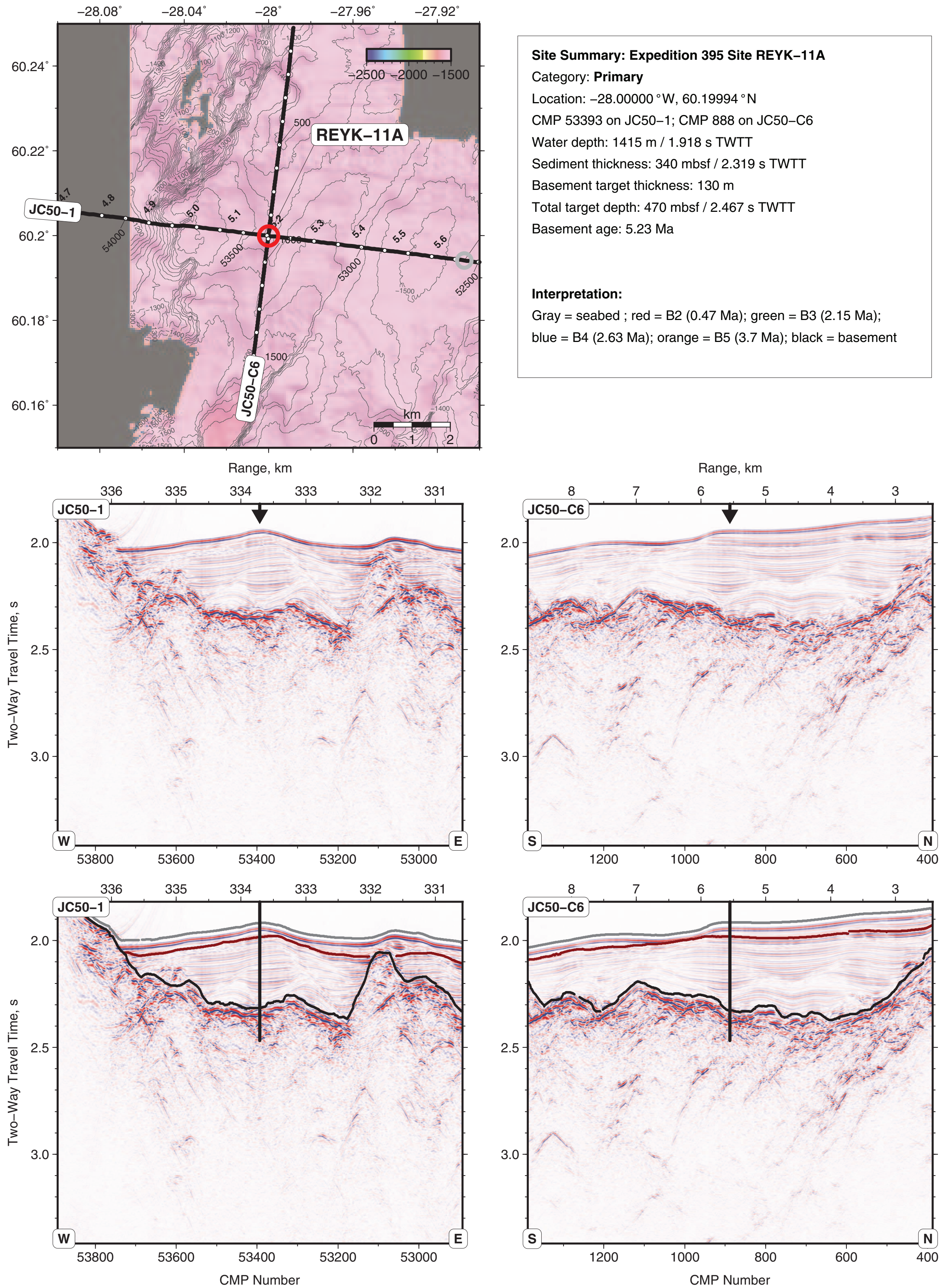
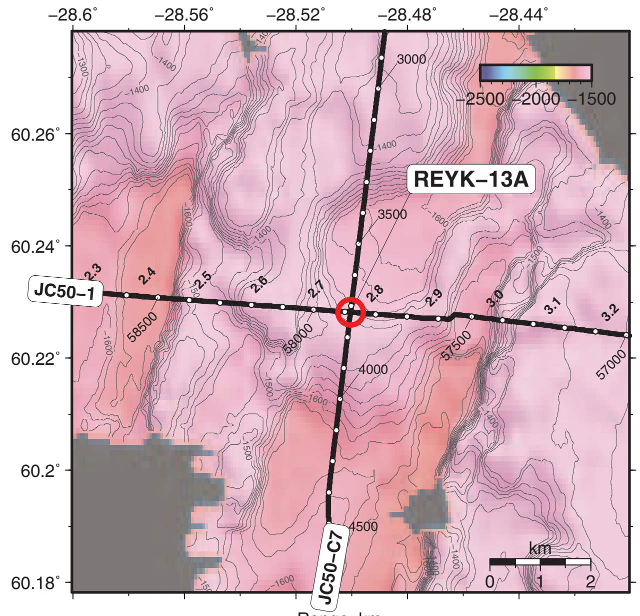


Figure AF12. Site REYK-13A.



Site Summary: Expedition 395 Site REYK–13A
Category: **Primary**
Location: –28.50040 °W, 60.22818 °N
CMP 57881 on JC50–1; CMP 3720 on JC50–C7
Water depth: 1520 m / 2.053 s TWTT
Sediment thickness: 210 mbsf / 2.318 s TWTT
Basement target thickness: 130 m
Total target depth: 340 mbsf / 2.466 s TWTT
Basement age: 2.80 Ma

Interpretation:
Gray = seabed ; red = B2 (0.47 Ma); green = B3 (2.15 Ma); blue = B4 (2.63 Ma); orange = B5 (3.7 Ma); black = basement