International Ocean Discovery Program
Expedition 361 Scientific Prospectus

South African Climates (Agulhas LGM Density Profile)

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Abstract

The Agulhas Current is the strongest western boundary current in the Southern Hemisphere, transporting some 70 Sv of warm and saline surface waters from the tropical Indian Ocean along the East African margin to the tip of Africa. Exchanges of heat and moisture with the atmosphere influence southern African climates, including individual weather systems such as extratropical cyclone formation in the region and rainfall patterns. Recent ocean models and paleoceanographic data further point at a potential role of the Agulhas Current in controlling the strength and mode of the Atlantic Meridional Overturning Circulation (AMOC) during the Late Pleistocene. Spillage of saline Agulhas water into the South Atlantic stimulates buoyancy anomalies that act as a control mechanism on the basin-wide AMOC, with implications for convective activity in the North Atlantic and Northern Hemisphere climate.

International Ocean Discovery Program (IODP) Expedition 361 aims to extend this work to periods of major ocean and climate restructuring during the Pliocene/Pleistocene to assess the role that the Agulhas Current and ensuing (interocean) marine heat and salt transports have played in shaping the regional- and global-scale ocean and climate development. This expedition will core six sites on the southeast African margin and Indian–Atlantic ocean gateway. The primary sites are located between 416 and 3040 m water depths.

The specific scientific objectives are

- To assess the sensitivity of the Agulhas Current to changing climates of the Pliocene/Pleistocene, in association with transient to long-term changes of high-latitude climates, tropical heat budgets, and the monsoon system;
- To reconstruct the dynamics of the Indian–Atlantic gateway circulation during such climate changes, in association with changing wind fields and migrating ocean fronts;
- To examine the connection between Agulhas leakage and ensuing buoyancy transfer and shifts of the AMOC during major ocean and climate reorganizations during at least the last 5 My; and
- To address the impact of Agulhas variability on southern Africa terrestrial climates and, notably, rainfall patterns and river runoff.

Additionally, Expedition 361 will complete an intensive interstitial fluids program at four of the sites aimed at constraining the temperature, salinity, and density structure of the Last Glacial Maximum (LGM) deep ocean, from the bottom of the ocean to the base of the main thermocline, to address the processes that could fill the LGM ocean and control its circulation.

Expedition 361 will seek to recover ~5200 m of sediment in total. The coring strategy will include the triple advanced piston corer system along with the extended core barrel coring system where required to reach target depths. Given the significant transit time required during the expedition (15.5 days), the coring schedule is tight and will require detailed operational planning and flexibility from the scientific party. The final operations plan, including the number of sites to be cored and/or logged, is contingent upon the R/V *JOIDES Resolution* operations schedule, operational risks, and the outcome of requests for territorial permission to occupy particular sites.

All relevant IODP sampling and data policies will be adhered to during the expedition. Beyond the interstitial fluids program, shipboard sampling will be restricted to acquiring ephemeral data and to limited low-resolution sampling of parameters that may be critically affected by short-term core storage. Most sampling will be deferred to a postcruise sampling party that will take place at the Gulf Coast Repository in College Station, Texas (USA). A substantial onshore X-ray fluorescence scanning plan is anticipated and will be further developed in consultation with scientific participants.

Schedule for Expedition 361

Expedition 361 is based on International Ocean Discovery Program (IODP) drilling proposal 702-Full2 and APL-845 (available at **http://www.iodp.org/active-proposals**). Following ranking by the IODP Scientific Advisory Structure, the expedition was scheduled for the research vessel *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 Port Louis, Mauritius, on 30 January 2016 and to end in Cape Town, South Africa, on 31 March 2016. A total of 56 days will be available for the 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://www.iodp.tamu.edu/publicinfo/drillship.html**.

Background

Importance of the Agulhas Current in the ocean climate system

The Agulhas Current is an integral part of the South Indian Ocean subtropical gyre circulation and constitutes the strongest western boundary current in the Southern Hemisphere oceans (Lutjeharms, 2006), transporting approximately 70 Sv (1 Sv = 10^6 m^3/s) of warm, saline tropical surface waters to the tip of Africa (Figure **F1**). This volume transport is about twice that of the Gulf Stream transport into the North Atlantic (Cunningham et al., 2007) and, like its northern counterpart, the Agulhas Current fosters exchanges of heat and moisture with the atmosphere that influence regional climates and weather systems (Reason and Mulenga, 1999). A portion of the Agulhas waters invades the South Atlantic through Agulhas rings (Arhan et al., 2001) that transport between 5 and 20 Sv of warm, saline water from the Indian Ocean to the South Atlantic—the so called interocean "warm water route" of the global oceanic thermohaline circulation (THC). Ocean models and paleoceanographic data strongly suggest that the spillage of saline Agulhas water into the South Atlantic stimulates regional buoyancy anomalies that ultimately impact convective activity in the northern North Atlantic, plausibly acting as a control mechanism on the basin-wide Atlantic Meridional Overturning Circulation (AMOC) (Weijer, 2001; Weijer et al., 2002; Knorr and Lohmann, 2003; van Sebille et al., 2009; Biastoch et al., 2008, 2009b).

Numerical simulations specifically point at the Agulhas water "leakage" as a modulator of the AMOC and a rheostat for the ventilation of the deep ocean. Hence, the significance of the Agulhas Current is threefold:

1. The Agulhas Current constitutes a prominent component of the global THC; it carries surface waters into the Atlantic that compensate for the export of deep water from the Atlantic Basin to the world ocean.
2. The Agulhas leakage transfers salt to the South Atlantic that impacts the buoyancy structure there and plausibly contributes to

mode changes and variability of the AMOC; it defines the transient behavior of the AMOC and ultimately may trigger climate variability in the North Atlantic region.
3. Agulhas warm water transport along the southeast African continental margin stimulates air-sea exchanges and drives interannual variability connected with the Indian Ocean Dipole (IOD) mode with implications for southern Africa regional climate and weather systems.

Interest in the long-term evolution of ocean circulation off southern Africa on Pliocene–Pleistocene timescales has concentrated in the past on the Atlantic side of the continent. Deep Sea Drilling Program (DSDP) Legs 40 and 75 in 1974 and 1980 and Ocean Drilling Program (ODP) Legs 108 and 114 in 1986 and 1987 targeted the southwest African continental slope and rise north and south of the Walvis Ridge in order to explore marine conditions during the opening of the South Atlantic, including the origin and paleoceanographic history of the eastern Walvis Ridge and carbonate dissolution cycles. More recently, ODP Leg 175 in 1997 targeted the southeastern Atlantic margin between 5° and 32°S to assess the history of the Benguela Current and upwelling off Angola and Namibia. ODP Leg 208 in 2003 drilled a transect of six sites on Walvis Ridge to gain insight into paleoceanographic events such as the Paleocene/Eocene Thermal Maximum event and the early Oligocene Oi-1 cold event.

The eastern continental margin off southern Africa is poorly represented in the database of drill sites. Only a single site (DSDP Site 242) has been drilled within the direct reaches of the South Indian western boundary current. The site is positioned on Davie Ridge, at the northern entrance of the Mozambique Channel, and was occupied during DSDP Leg 25 in 1972 (Schlich et al., 1974) to provide data on the structure and geological history of the East African margin and western Madagascar.

Expedition 361 aims to fill the gap of drill sites by retrieving multiple copies of advanced piston corer (APC)/extended core barrel (XCB) cores at six sites in three sectors of the greater Agulhas Current system (Figure **F2**):

1. Northern sector in the Mozambique Channel that provides the source waters for the Agulhas Current,
2. Central sector in the confluence region where the southwestern extension of the East Madagascar Current converges with the Mozambique Channel throughflow to form the Agulhas Current, and
3. Southern sector in the Indian–Atlantic Ocean gateway at the tip of Africa with Agulhas retroflection, Agulhas return current, and Agulhas leakage.

Agulhas leakage and the AMOC

The dynamics of the Agulhas leakage and its possible impact on the AMOC and global climate have been explored in a number of ocean and climate models of different complexity. The models highlight wind stress, buoyancy forcing, and planetary-wave perturbations as the primary parameters that define the leakage and AMOC strengths (Beal et al., 2011). Saltwater entering the South Atlantic with Agulhas rings stimulates planetary (Kelvin and Rossby) waves that propagate across the Atlantic Basin and perturb the AMOC (Biastoch et al., 2009a). Short-term variability potentially associated with Agulhas leakage is observed in the subtropical North Atlantic (de Ruijter et al., 1999), whereas some of the interannual to decadal AMOC variability seen in the models plausibly stems from the frequency of Agulhas ring shedding that, in turn, is modulated by the IOD and El Niño Southern Oscillation (ENSO) modes (de Ruijter et al., 1999; Gordon and Haxby, 1990). The basin-scale radiation of planetary waves triggered by the Agulhas leakage hence constitutes a "fast-response" mechanism that operates on interannual to decadal timescales.

The advection of saltwater entering from the Agulhas region to the convection centers in the North Atlantic Ocean is another important variable defining the AMOC response to Agulhas leakage. Seeding numerical Lagrangian floats into the Agulhas retroflection area (van Sebille et al., 2010) in high-resolution ocean general circulation models reveals an advective transit time of 30–40 y from the Agulhas Current to the North Atlantic (van Sebille et al., 2001). These time estimates in principle agree with those obtained with lower-resolution models (Weijer, 2001). Continuing heat exchange with the overlying atmosphere augments the density anomaly associated with leaked Agulhas saltwater parcels as they drift northward (Weijer, 2001; Haarsma et al., 2001). Agulhas leakage therefore stimulates an AMOC response with a time delay dictated by the advective timescale for the excess salt to reach the North Atlantic, whereas the new AMOC equilibrium state is achieved several hundred years later when buoyancy fluxes and mixing are in balance (Weijer, 2001; Hughes et al., 2009). Establishing the impact of wind forcing on the Agulhas leakage and its subsequent effect on the AMOC is not straightforward. This is because the strength and position of the Southern Hemisphere mid-latitude westerlies affect the Agulhas leakage and AMOC simultaneously (Biastoch et al., 2009b; Toggweiler and Samuels, 1995; Sijp and England, 2009) by shifting the position of the Subtropical Front (STF) south of Africa. The STF defines the width of the Agulhas leakage corridor, hence the strength of the leakage. Additionally, the westerlies control the northward Ekman transport in the Southern Ocean, which forces deep water to ascend to the upper ocean, conceivably "pulling" the deep branch of the AMOC (Toggweiler and Samuels, 1995; Visbeck, 2007). Through their influence on deepwater upwelling and AMOC strength, the westerly winds and Agulhas buoyancy fluxes likely play important roles in the regulation of the ocean's ability to store carbon (Watson and Garabato, 2006; Backeberg et al., 2012), which posits a further plausible control of Agulhas leakage on climate.

Paleoceanography of the Agulhas Current system

The Agulhas Current region is an area in which retrieval of high-quality sediment cores is difficult. The southeast African margin has a very narrow shelf and a steep continental slope, leading to frequent sediment instability and slumping. Further, the vigorous Agulhas Current and its mesoscale variability with meanders and eddies that frequently reach the seafloor can cause sediment redistribution. Yet, a number of recently published studies and currently ongoing work demonstrate the excellent quality of paleoceanographic records achievable to reconstruct both surface and deepwater variability in the region. For instance, the continuous presence of subtropical planktonic foraminifers (e.g., *Globorotalia menardii*) has been used to infer persistent Indian–Atlantic surface water flow during the last 450 ky, whereas the transient occurrence of subpolar species (*Neogloboquadrina pachyderma* dex.) suggests intermittent incursions of cold sub-Antarctic waters in the Agulhas corridor during glacial periods (Rau et al., 2002, 2006). These changes plausibly involved meridional shifts of the STF and Subantarctic Fronts. At the tip of Africa, maximum abundance of the so-called "Agulhas leakage fauna" (ALF) appears to be related to minima in precession (maxima in northern summer insolation) (Peeters et al., 2004), indicating a possible teleconnection to the monsoon system. Provenance studies using $^{87}Sr/^{86}Sr$ and $^{230}Th_{xs}$ flux estimates (Franzese et al., 2006) suggest reduced advection of sediments derived from Agulhas water and possibly even reduced Agulhas leakage during peak glacial times. Sea-surface temperature (SST) records and ocean productivity indicators near the eastern entrance of the Indian–Atlantic ocean gateway support such a scenario in that they suggest during some full-glacial stages the STF moved northward by as much as 7° in latitude (Bard and Rickaby, 2009), thus potentially severely reducing Agulhas Current transports into the gateway and limiting leakage to the South Atlantic. However, this picture is contrasted by substantial increases of the ALF fauna (Peeters et al., 2004) in the Agulhas corridor at the termination of glacial periods alluding to an involvement of Agulhas leakage in interhemispheric ocean and climate change, notably the resumption of North Atlantic Deep Water formation (Peeters et al., 2004). Recent multiple-proxy data from planktonic foraminifers along sediment cores on the Agulhas Bank provide the first detailed pictures of surface ocean climatology in the area (Figure **F3**). Continued warming across full-glacial stages (marine isotope Stages [MIS] 2 and 6) displayed in planktonic Mg/Ca data plausibly indicates increased influence of warm Agulhas water in the region and/or reduced northward advection of cold subantarctic surface water (Martínez-Méndez et al., 2010). This pattern is consistent with the hypothesis that peak Agulhas leakage occurred during glacial terminations and plausibly aided the AMOC to shift to its full-strength interglacial mode (Knorr and Lohmann, 2003, 2007). SST and salinity records at an upstream location along the southeast African margin (26°S) (Caley et al., 2001) display a prominent 41 ky cyclicity that was used to suggest that long-term Agulhas Current variations were associated with high-latitude (as opposed to regional tropical) climate forcing. A high-resolution faunal record of tropical species *G. menardii* abundance at ODP Site 1087 in the southern Benguela region was used to infer that the Agulhas leakage strengthened during every glacial termination of the past 1.3 My (Caley et al., 2012). Multiple-species stable isotope and alkenone data from ODP Site 1085, slightly further north, suggest that Agulhas leakage variability during MIS 11 was directly related to AMOC activity and wind forcing. Site 1085 shows evidence for strengthened leakage at the end of the MIS 11 that may have contributed to renewed ice sheet build-up and the demise of MIS 11 (Dickson et al., 2010).

Recent reconstructions detailing the fine-scale surface ocean variability from the Atlantic sector of the Agulhas corridor using a tropical foraminiferal species (*Globigerinoides ruber*) that is closely associated with the tropical Agulhas water advection confirm a connection of leakage maxima with glacial–interglacial climate changes and extend it to millennial-scale salinity anomalies that systematically coincide with accelerated warming at the end of the North Atlantic cold phases (stadials) (Marino et al., 2013). This finding lends credence to earlier hypothetical considerations (Lutjeharms, 2006) and numerical models (Knorr and Lohmann, 2003; Weijer et al., 2002; Biastoch et al., 2008) pointing to Indian–Atlantic salt leakage as an essential modulator of abrupt climate change. X-ray fluorescence (XRF) records of elemental concentrations reveal abrupt pulses of river runoff at the southeast African margin that document the incursion of humid phases that can be plausibly connected with millennial-scale Northern Hemisphere cold events (Ziegler et al., 2013). Rainfall intensity today in southeast Africa is driven by SST variability in the southwest Indian Ocean and the Agulhas Current regime (Reason and Mulenga, 1999; Walker, 1990; Jury et al., 1993; Reason, 2002; Singleton and Reason, 2007) in connection with Indian SST dipole variations (Reason, 2002) and ENSO (Schouten et al., 2002a, 2002b) and basin-scale modes (Behera et al., 2001; Hermes and Reason, 2005) related to large-scale atmospheric forcing. The XRF profiles allude to far-field connections of these oscillators in the past with Northern Hemisphere abrupt climate swings.

Density profile of the LGM ocean

The circulation of the deep ocean at the LGM is a crucial piece of the puzzle to understand past variations in CO_2 and glacial–interglacial cycles more generally. In the modern ocean, we use the patterns of temperature and salinity to map the distribution of deepwater masses. In addition, these values inform the balance of air–sea exchange processes that are required to form deep water in the first place. They are an integrated record of climate at high latitudes. For the LGM, a full temperature-salinity (T-S) plot has remained elusive. However, sampling deep ocean sediments for their interstitial fluids and then measuring $\delta^{18}O$ and $[Cl^-]$ on the water can provide an advectively and diffusively altered record of these tracers for the LGM (Adkins et al., 2002; Adkins, 2013). With local $\delta^{18}O$ data from benthic foraminifers, the pore water information can be turned into a single point on the LGM T-S diagram. The current version of this plot, from sampling IODP material, contains only four points (Figure **F4**) that imply that most of the ocean lies close to the freezing point at the LGM. Most surprisingly, the salt gradient in the modern Atlantic of fresh southern-sourced waters and salty northern-sourced waters appears to have flipped at the LGM. This implies the saltiest waters of the LGM ocean were formed around Antarctica. In the years since this early work, the analytical measurement of $[Cl^-]$ has been improved, several new sampling strategies have targeted increasing throughput, and the data analysis tools used to model the data have been improved. The next most important step in constraining the temperature, salinity, and density structure of the LGM deep ocean is to obtain depth transects of these properties. Samples taken from the same region of the ocean and spanning from 450 to 3040 m water depth would greatly constrain the processes that could fill the LGM deep ocean and control its circulation. To this end, we will be adding a fourth, 150 m deep hole to four of the Expedition 361 sites.

Site survey data

The supporting site survey data for Expedition 361 are archived at the IODP Site Survey Data Bank (**http://ssdb.iodp.org/SSDBquery/queryResults.php?submitButton=Search+-%3E&subQuery=&propArray%5B%5D=P702**).

Scientific objectives

The specific scientific objectives of Expedition 361 are centered on the following themes:

- Variability of the greater Agulhas Current system under contrasting climatic regimes: Agulhas Current variability under early Pliocene warm conditions, during the mid-Pliocene expansion of Northern Hemisphere ice sheets, and through the mid-Pleistocene transition;
- The role of Agulhas leakage in transient and long-term shifts of the AMOC during these climatic transitions: proxy records of Agulhas leakage mode/strength during periods of major climatic reorganizations and of AMOC variations through the same intervals;
- The response of the Agulhas Current system to Antarctic climate variability and bipolar linkages: evidence for Agulhas leakage variation in highly resolved temporal records will be com-

pared to Antarctic and bipolar climate changes, as well as to evidence for shifts of Southern Ocean fronts bordering the Agulhas corridor at the southern tip of Africa;

- The remote tropical origins of Agulhas Current variability: evidence for Agulhas leakage variation in highly resolved temporal records will be compared to records of Indonesian Throughflow and monsoon modulation on the Agulhas Current source region, as well as to impacts on warm and saltwater transports along the southeast African margin and Indian–Atlantic saltwater leakage;
- Southern African climate sensitivity: comparison of varying Agulhas Current warm water transports with rainfall patterns in southern Africa in connection with the Pliocene/Pleistocene evolution of tropical climates, Intertropical Convergence Zone migration, and tectonic history of eastern Africa;
- Glacial–interglacial variations in the Southern Ocean's role in the carbon cycle: nutrient cycling, productivity, and pCO_2 and their role in global biogeochemical cycles, particularly in the Agulhas Plateau site; and
- The character of bottom waters in the glacial ocean: high-resolution interstitial water samples will be used to estimate the temperature and salinity properties of the deep ocean at the LGM and to deconvolve the temperature and ice volume control on $\delta^{18}O$ of benthic foraminifers.

To achieve these scientific objectives we plan to employ a suite of methodologies to enable reconstruction of surface ocean climatology and Agulhas Current water transports and of deepwater circulation/ventilation connected with the AMOC and deepwater export to the Indian and Southern Oceans. Analytical methodologies aim at the reconstruction of SST, sea-surface salinity (SSS), thermocline structure (THS), surface ecology (SE), ocean fronts (OF), paleoproductivity (PP), Agulhas leakage (AL), deepwater temperature (DWT), deepwater salinity (DWS), paleocurrent speed (PCS), chemical ventilation (CVR), water mass end-member mixing (WEM), and hydroclimate/rainfall runoff and weathering/erosion (HRW):

- Quantitative micropaleontology: planktonic foraminiferal and diatom census counts, nannofossil assemblages, palynology, and dinocysts and transfer functions and modern analog techniques (SST, SE, OF, PP, and AL)
- Stable isotope geochemistry: multiple-species planktonic foraminiferal and coccolithophore $\delta^{18}O$ and $\delta^{13}C$, compound-specific deuterium, and δD (SST, SSS, THS, and OF)
- Trace metal geochemistry: planktonic foraminiferal and coccolithophore Mg/Ca, Cd/Ca, and Sr/Ca (SST, THS, and PP) and benthic foraminiferal Mg/Ca and Cd/Ca (DWT, WEM, and CVR)
- Organic geochemistry: biomarkers UK37 and Tex86 (SST, PP, and SE)
- Provenance of terrigenous sediments: neodymium isotopes, ε_{Nd} strontium isotopes, K/Ar ages, elemental compositions in bulk detrital sediment fraction, and thermochronology of detrital sand grains (AL, HRW, and WEM)
- Radiogenic isotope geochemistry (ε_{Nd}) of authigenic fraction (including foraminiferal calcite) (WEM)
- Stable isotope geochemistry: benthic foraminiferal $\delta^{18}O$ and $\delta^{13}C$ (DWT, WEM, and CVR)
- Sedimentology: sortable silt, clay mineralogy (PCS and WEM)
- XRF records using downcore scanning technology (HRW)
- Interstitial fluid geochemistry: $\delta^{18}O$ and [Cl^-] (DWT and DWS)

The multiproxy approach seeks to enable robust reconstructions of surface ocean climatologic patterns, deep ocean water mass dispersal, and the connection between both (1) pycnocline depths that are likely to fluctuate in the course of varying warm/salty water transports in the Agulhas Current (e.g., warm pool development) and leakage into the South Atlantic, (2) surface ocean density gradients as an indicator for the migration of regional ocean fronts, (3) contribution of Agulhas Current water transports to the T-S variability in the Indian–Atlantic ocean gateway and Agulhas leakage, (4) identification of surface ocean conditions within the Agulhas Current system related to Antarctic climate variability, and (5) deep ocean circulation shifts in relation to Agulhas Current climatology and Agulhas leakage intensity.

Operations plan/Drilling strategy

Expedition 361 aims to achieve a coring program that prioritizes six primary sites and eight alternate sites in 198–3040 m of water depth (Tables **T1**, **T2**). Six of the sites (three primary and three alternate) are in Mozambique waters (MZC, ZAM, and LIM sites), five (two primary and three alternate) are in South African waters (CAPE and NV sites), and three (one primary and two alternate) are in international waters (APT sites). The final operations plan and number of sites to be cored is contingent upon the *JOIDES Resolution* operations schedule, operational risks (see **Risks and contingency**), and the outcome of requests for territorial permission to occupy these sites.

The coring strategy will consist of APC/ half-length advanced piston corer (HLAPC) coring to refusal using nonmagnetic core barrels in three holes at each site to ~200 meters below seafloor (mbsf) or refusal, then deepening the hole to target depth using the XCB coring system. An additional hole will be cored to a depth of 150 mbsf using the APC at Sites MZC-01C, LIM-01B, NV-02C, and APT-01B. These cores will be used for high-resolution pore water sampling and will be the second hole cored at each of the sites. At this time, all APC cores will be oriented using the Icefield MI-5 tool. Temperature measurements will be taken only in Hole A using the APCT-3 temperature tool. Downhole wireline logging is planned at Sites MZC-01C, NV-02C, APT-01B, and CAPE-01C. However, coring is the main priority of this expedition and the logging program may be cut back if operational time is does not allow for it.

For planning purposes, the APC/HLAPC refusal depth is estimated at 200 meters below seafloor (mbsf), although we anticipate that this may be exceeded at some of the more mud-rich sites with target depths greater than 200 mbsf. APC refusal is conventionally defined in two ways: (1) a complete stroke (as determined from the standpipe pressure after the shot) is not achieved because the formation is too hard and (2) excess force (>100,000 lb) is required to pull the core barrel out of the formation because the sediment is too cohesive or "sticky." In cases where a significant stroke can be achieved but excessive force cannot retrieve the barrel, the core barrel can be "drilled over" (i.e., after the inner core barrel is successfully shot into the formation, the bit is advanced to some depth to free the APC barrel). When APC/HLAPC refusal occurs in a hole before the target depth is reached, the XCB system will be used to advance the hole.

The target depth at five of the six primary proposed sites (MZC-01C [300 mbsf], ZAM-05A [207 mbsf], NV-02C [350 mbsf], APT-01B [300 mbsf], and CAPE-01C [350 mbsf]) is greater than the APC refusal depth. The deeper sections will be advanced by XCB coring in all of the holes, time permitting. Triple-APC holes will allow us to build a composite stratigraphic section at each site for the upper ~200 mbsf.

Two primary sites (ZAM-05A and LIM-01B) and three alternate sites (LIM-02B, ZAM-01B, and ZAM-04B) fall under the IODP shallow-water guidelines.

According to the current operations plan, Expedition 361 will core ~5700 m of sediment and potentially recover ~5200 m of core. The estimated amount of core recovered is based on 100% recovery with the APC system and 65% recovery with the XCB system.

Logging/downhole measurements strategy

Formation temperature measurements

We plan on using the advanced piston corer temperature tool (APCT-3) to measure formation temperature in the first hole of each site. The APCT-3 can only be used with the APC system.

Core orientation

We plan to orient all APC cores with the Icefield MI-5 tool and will make use of nonmagnetic coring hardware to the maximum extent possible.

Downhole wireline logging

Downhole wireline logging using the triple combo and the Formation MicroScanner (FMS)-sonic tool strings is planned at Sites MZC-01C, NV-02C, APT-01B, and CAPE-01C. Additionally, the Versatile Seismic Imager will be deployed to create a vertical seismic profile. The logging tools will be run in the final hole at each site (either C or D, depending on whether a pore water profile is planned). However, coring is the top priority at each site, and the scheduled logging program may be modified or abandoned if the coring objectives are not met in the allotted time.

The triple combo tool string consists of the Accelerator Porosity Sonde, the Hostile Environment Litho-Denisty Sonde, the Hostile Environment Natural Gamma Ray Sonde/Enhanced Digital Telemetry Cartridge, the High-Resolution Laterolog Array/Phasor Dual Induction-Spherically Focused Resistivity Tool, and the magnetic susceptibility sonde. The FMS-sonic tool consists of the Dipole Sonic Imager tool, the FMS, and the General Purpose Inclinometry Tool. The downhole logging data will be sent to the Lamont-Doherty Earth Observatory Borehole Group for processing during the expedition and returned to the shipboard Downhole Logging Scientists for interpretation.

Risks and contingency

The potential risks identified are

- Unstable hole conditions that can impact coring recovery and downhole logging operations;
- The presence of sand beds or turbidites that can be detrimental to core recovery;
- Weather: the expedition is scheduled to run into the peak cyclone season (January/March);
- Strong surface currents (up to 4 kt) are present that can make it difficult for the ship to remain stationed over the site; not remaining within a given radius of the site can put stress on the drill pipe;
- Shallow water: if the drill string becomes stuck in the hole, it is more difficult to extract it in shallow water (<500 m); remaining stationed over the site can be more difficult, which can put stress on the drill pipe; and
- Piracy activity: there is historical piracy activity in the region of Site MZC-01C.

All of these factors may impact drilling, coring, and downhole logging operations.

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines (**http://www.iodp.org/program-documents**). 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) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling. The SAC is composed of the Co-Chief Scientists, Expedition Project Manager, and IODP Curator on shore and curatorial representative in place of the Curator onboard the ship.

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. Success will require collaboration, integration of complementary data sets, and consistent methods of analysis. Substantial collaboration and cooperation within the scientific party is therefore highly encouraged (see below).

Every member of the science party is obligated to carry out scientific research for the expedition and publish the results. Shipboard and shore-based scientists are expected to submit sample requests (at **http://web.iodp.tamu.edu/sdrm**) at least 3 months before the beginning of the expedition. Based on sample requests submitted by this deadline, 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 SAC. Given the specific objectives of Expedition 361, great care will be taken to maximize shared sampling to promote integration of data sets and enhance scientific collaboration among members of the scientific party. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to sample requests and access to samples and data during the expedition and the 1 y postexpedition moratorium period require approval of the SAC.

Beyond the interstitial fluids program, shipboard sampling will be restricted to acquiring ephemeral data types and to limited low-resolution sampling (e.g., for stratigraphic purposes [biostratigraphy and magnetostratigraphy], physical properties, and geochemical and microbiological analyses). Shipboard biostratigraphic and paleomagnetostratigraphic sampling will also be restricted to rapidly produce age models that are critical to the overall objectives of the expedition and to the planning for higher resolution postcruise sampling.

Sampling for the majority of individual scientist's personal research will be postponed until a shore-based sampling party implemented between 3 and 5 months after the expedition at the Gulf Coast Repository at Texas A&M University in College Station, Texas (USA). Following the sampling party, the cores will be housed at the Kochi Core Center (KCC) at Kochi University in Kochi (Japan). The KCC repository houses cores from the Pacific Ocean (west of the western boundary of the Pacific plate), Indian Ocean (north of 60°), Kerguelen Plateau, and Bering Sea. Prior to the sampling party, selected cores will be scanned by XRF to help guide postcruise sampling requests.

There may be considerable demand for samples from a limited amount of cored material for some critical intervals at certain sites. Critical intervals may require special handling that includes a higher sampling density, reduced sample size, or continuous core sampling for a set of particular high-priority research objectives. The SAC may require revision of the approved sampling plan before critical intervals are sampled, and a special sampling plan shall be developed to maximize scientific return and participation and to preserve some material for future studies. The SAC can decide at any stage during the expedition or during the 1 y moratorium period which recovered intervals should be considered as critical.

All collected data and samples will be protected by a 1 y postcruise moratorium, during which time data and samples are available only to the Expedition 361 science party and approved shore-based participants. This moratorium will extend 1 y following the completion of the postcruise sampling party (not 1 y from the end of the time at sea). We anticipate that specific shipboard and shore-based scientific party members may require specific sampling methods. Participants are encouraged to specifically identify their needs in their requests.

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Table T1. Operations plan for primary proposed sites, Expedition 361. EPSP = Environmental Protection and Safety Panel. APC = advanced piston corer, XCB = extended core barrel. APCT-3 = advanced piston corer temperature tool, FMS-sonic = Formation MicroScanner sonic tool string, VSI = Versatile Seismic Imager.

Site	Location (Latitude Longitude)	Seafloor depth (mbrf)	Operations description	Transit (days)	Drilling coring (days)	LWD/MWD log (days)
Port Louis, Mauritius			Begin expedition 5.0	Port call days		
			Transit ~122 nmi to WP1 @ 10.5 kt	0.5		
			Transit ~602 nmi to WP2 @ 10.5 kt	2.4		
			Transit ~171 nmi to WP3 @ 10.5 kt	0.7		
			Transit ~586 nmi to MZC-01C @ 10.5 kt	2.3		
MZC-01C	15°49.25'S	2168	Hole A - APC/XCB to 300 mbsf with APCT-3 measurements	0.0	2.1	0.0
EPSP	41°46.12'E		Hole B - APC to 150 mbsf	0.0	1.0	0.0
to 449 mbsf			Hole C - APC/XCB to 300 mbsf	0.0	1.5	0.0
			Hole D - APC/XCB to 300 mbsf then log with triple combo, FMS-sonic, & VSI	0.0	1.7	1.1
			Subtotal days on-site: 7.4			
			Transit ~349 nmi to ZAM-05A @ 10.5 kt	1.4		
ZAM-05A	19°21.30'S	427	Hole A - APC to 207 mbsf with APCT-3 measurements	0.0	1.0	0.0
EPSP	36°54.90'E		Hole B - APC to 207 mbsf	0.0	0.6	0.0
to 207 mbsf			Hole C - APC to 207 mbsf	0.0	0.7	0.0
			Subtotal days on-site: 2.3			
			Transit ~271 nmi to WP4 @ 10.5 kt	1.1		
			Transit ~137 nmi to LIM-01B @ 10.5 kt	0.5		
LIM-01B	25°49.26'S	461	Hole A - APC to 180 mbsf with APCT-3 measurements	0.0	0.8	0.0
EPSP	34°46.14'E		Hole B - APC to 150 mbsf	0.0	0.6	0.0
to 250 mbsf			Hole C - APC to 180 mbsf	0.0	0.5	0.0
			Hole D - APC/XCB to 180 mbsf	0.0	0.6	0.0
			Subtotal days on-site: 2.4			
			Transit ~366 nmi to NV-02C @ 10.5 kt	1.4		
NV-02C	31°12.42'S	3051	Hole A - APC/XCB to 350 mbsf with APCT-3 measurements	0.0	2.5	0.0
EPSP	31°31.44'E		Hole B - APC 150 mbsf	0.0	1.2	0.0
to 550 mbsf			Hole C - APC/XCB to 350 mbsf	0.0	2.1	0.0
			Hole D - APC/XCB to 350 mbsf then log with triple combo, FMS-sonic, & VSI	0.0	2.4	1.2
			Subtotal days on-site: 9.4			
			Transit ~683 nmi to APT-01B @ 10.5 kt	2.7		
APT-01B	41°25.56'S	2702	Hole A - APC/XCB to 300 mbsf with APCT-3 measurements	0.0	2.1	0.0
EPSP	25°16.02'E		Hole B - APC to 150 mbsf	0.0	1.1	0.0
to 398 mbsf			Hole C - APC/XCB to 300 mbsf	0.0	1.7	0.0
			Hole D - APC/XCB to 300 mbsf then log with triple combo, FMS-sonic, & VSI	0.0	2.1	1.2
			Subtotal days on-site: 8.2			
			Transit ~532 nmi to CAPE-01C @ 10.5 kt	2.1		
CAPE-01C	35°3.53'S	2659	Hole A - APC/XCB to 350 mbsf with APCT-3 measurements	0.0	2.4	0.0
EPSP	17°24.06'E		Hole B - APC/XCB to 350 mbsf	0.0	2.0	0.0
to 550 mbsf			Hole C - APC/XCB to 350 mbsf then log with triple combo, FMS-sonic, & VSI	0.0	2.3	1.2
			Subtotal days on-site: 7.8			
			Transit ~86 nmi to WP5 @ 10.5 kt	0.3		
			Transit ~3 nmi to Cape Town @ 10.5 kt	0.0		
Cape Town, South Africa			End expedition	15.5	32.9	4.7

Port call:	5.0	Total operating days:	53.1
Subtotal on-site:	37.6	Total expedition:	58.1

Table T2. Operations plan for alternate proposed sites, Expedition 361. EPSP = Environmental Protection and Safety Panel. APC = advanced piston corer, XCB = extended core barrel. APCT-3 = advanced piston corer temperature tool, FMS-sonic = Formation MicroScanner sonic tool string.

Site	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Drilling Coring (days)	LWD/MWD Log (days)
CAPE-02A	35°3.97'S	2795	Hole A - APC/XCB to 180 mbsf with APCT-3 measurements	1.4	0.0
EPSP	17°12.53'E		Hole B - APC/XCB to 180 mbsf	1.0	0.0
to 380 mbsf			Hole C - APC/XCB to 180 mbsf	1.3	0.0
			Subtotal days on-site: 3.8		
CAPE-02B	35°4.79'S	2754	Hole A - APC/XCB to 260 mbsf with APCT-3 measurements	1.9	0.0
EPSP	17°13.18'E		Hole B - APC/XCB to 260 mbsf	1.5	0.0
to 460 mbsf			Hole C - APC/XCB to 260 mbsf then log with triple combo and FMS-sonic	1.8	0.9
			Subtotal days on-site: 6.1		
CAPE-03B	35°3.78'S	2692	Hole A - APC/XCB to 350 mbsf with APCT-3 measurements	1.9	0.0
EPSP	17°18.28'E		Hole B - APC/XCB to 350 mbsf	1.6	0.0
to 470 mbsf			Hole C - APC/XCB to 350 mbsf then log with triple combo and FMS-sonic	1.9	0.9
			Subtotal days on-site: 6.2		
APT-04A	41°23.16'S	2825	Hole A - APC/XCB to 350 mbsf with APCT-3 measurements	2.5	0.0
EPSP	25°31.74'E		Hole B - APC/XCB to 350 mbsf	2.1	0.0
to 350 mbsf			Hole C - APC/XCB to 350 mbsf then log with triple combo and FMS-sonic	2.4	1.0
			Subtotal days on-site: 7.9		
APT-05A	41°26.88'S	2636	Hole A - APC/XCB to 430 mbsf with APCT-3 measurements	2.8	0.0
EPSP	25°8.46'E		Hole B - APC/XCB to 430 mbsf	2.4	0.0
to 430 mbsf			Hole C - APC/XCB to 430 mbsf then log with triple combo and FMS-sonic	2.7	1.0
			Subtotal days on-site: 9.0		
LIM-02B	25°36.72'S	266	Hole A - APC to 300 mbsf with APCT-3 measurements	1.0	0.0
EPSP	34°43.32'E		Hole B - APC to 300 mbsf	0.8	0.0
to 350 mbsf			Hole C - APC to 300 mbsf then log with triple combo and FMS-sonic	0.9	0.8
			Subtotal days on-site: 3.6		
ZAM-01B	19°22.32'S	306	Hole A - APC to 200 mbsf with APCT-3 measurements	0.8	0.0
EPSP	36°53.10'E		Hole B - APC to 200 mbsf	0.6	0.0
to 250 mbsf			Hole C - APC to 200 mbsf	0.7	0.0
			Subtotal days on-site: 2.0		
ZAM-04B	19°8.96'S	209	Hole A - APC/XCB to 237 mbsf with APCT-3 measurements	0.9	0.0
EPSP	37°0.71'E		Hole B - APC/XCB to 237 mbsf	0.7	0.0
to 237 mbsf			Hole C - APC/XCB to 237 mbsf then log with triple combo and FMS-sonic	0.9	0.8
			Subtotal days on-site: 3.3		

Figure F1. Agulhas Current and Indian–Atlantic water transports. Figure schematically displays main surface ocean features in the region. Note the spillage of Agulhas rings (blue circular arrows) into the South Atlantic. A far-field connection into the tropical Pacific and Indonesian Throughflow is indicated. From Gordon (2003). "The influence of the Agulhas system of currents and eddies around southern Africa extends far beyond that region. Hence the especial need for a better understanding of the complex phenomena" (Gordon, 2003).

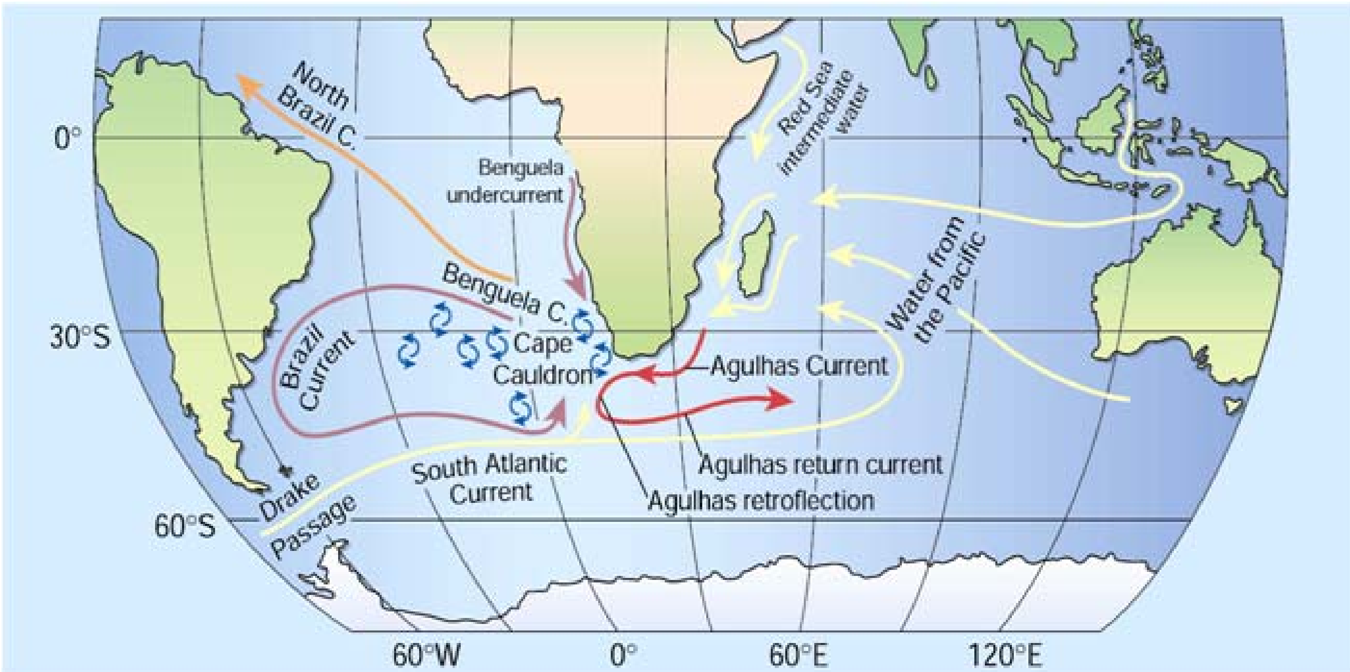


Figure F2. Expedition 361 primary and alternate drilling site locations. Alternate site names are in parentheses.

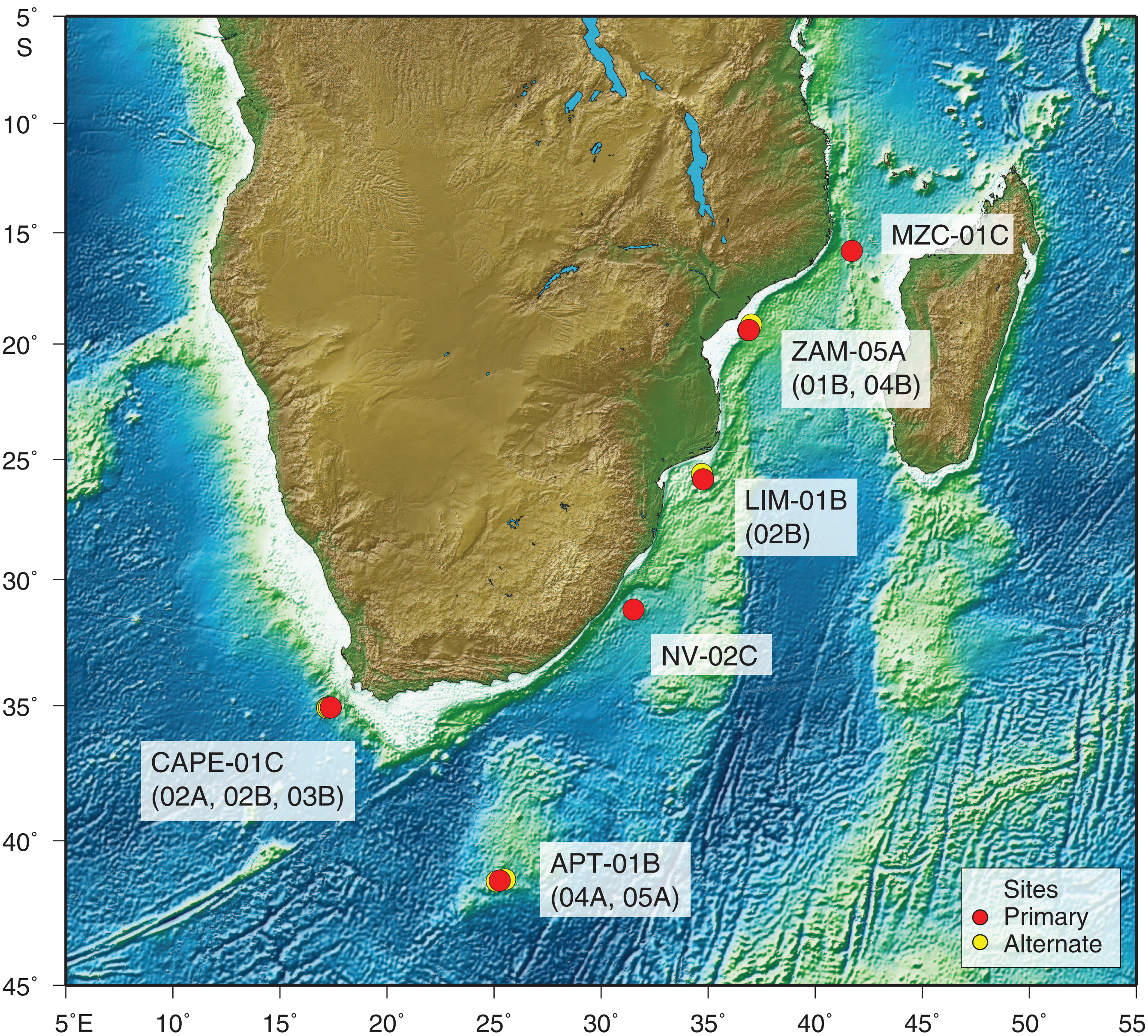


Figure F3. Palaeoceanographic profiles along sediment Core MD96-2080 (location of proposed Site CAPE-01C). A. Planktonic $\delta^{18}O$ showing glacial–interglacial climates. B. Distribution of Agulhas leakage fauna (ALF) in neighboring Core MD96-2081. C. Temperature variation along Core MD96-2080 from planktonic Mg/Ca, insert displays ALF section from the same core. D. Salinity estimated from paleothermometry combining data from A and C. Data from Peeters et al. (2004) and Martinez-Mendez et al. (2010). SSS = sea-surface salinity, SST = sea-surface temperature.

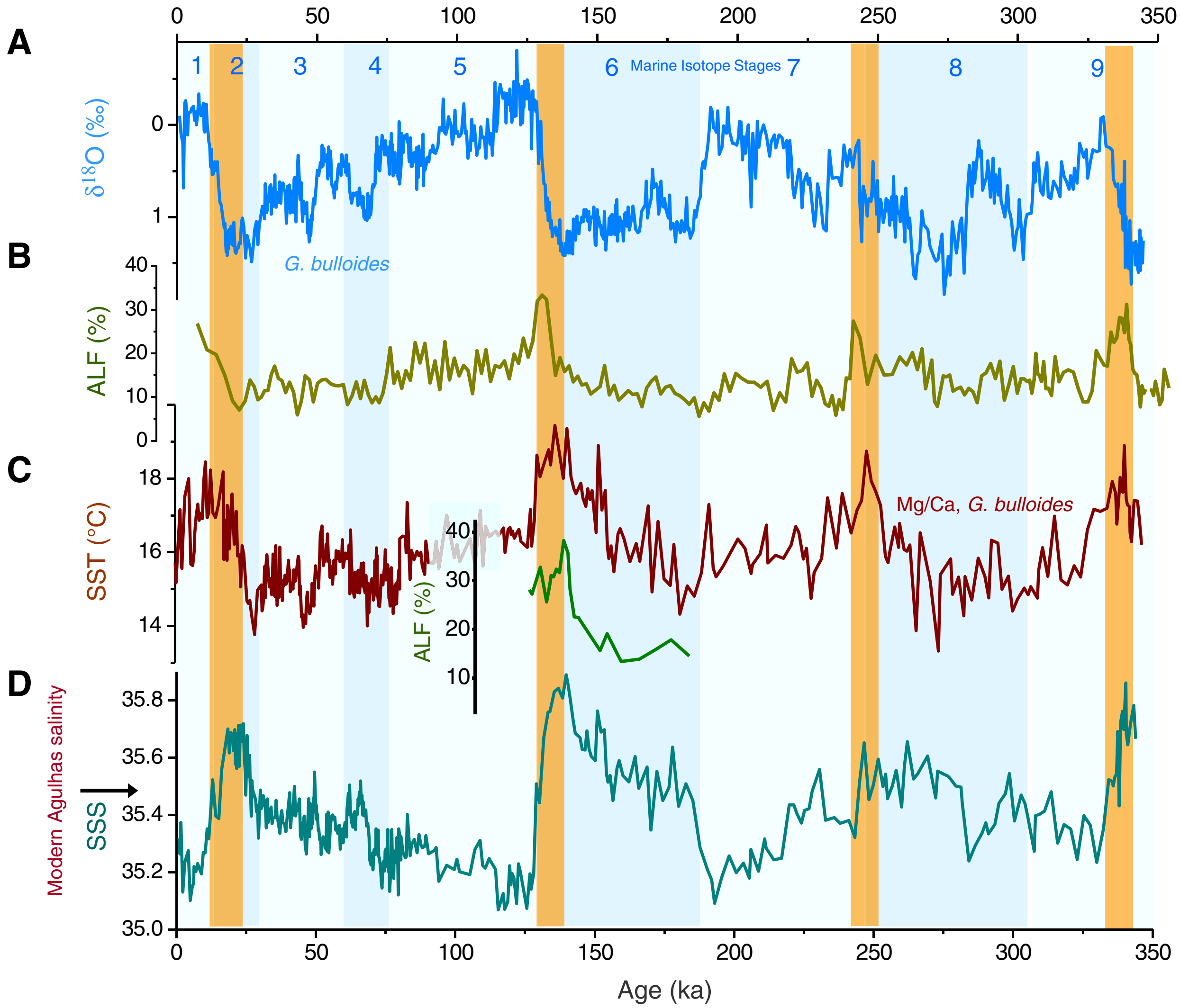
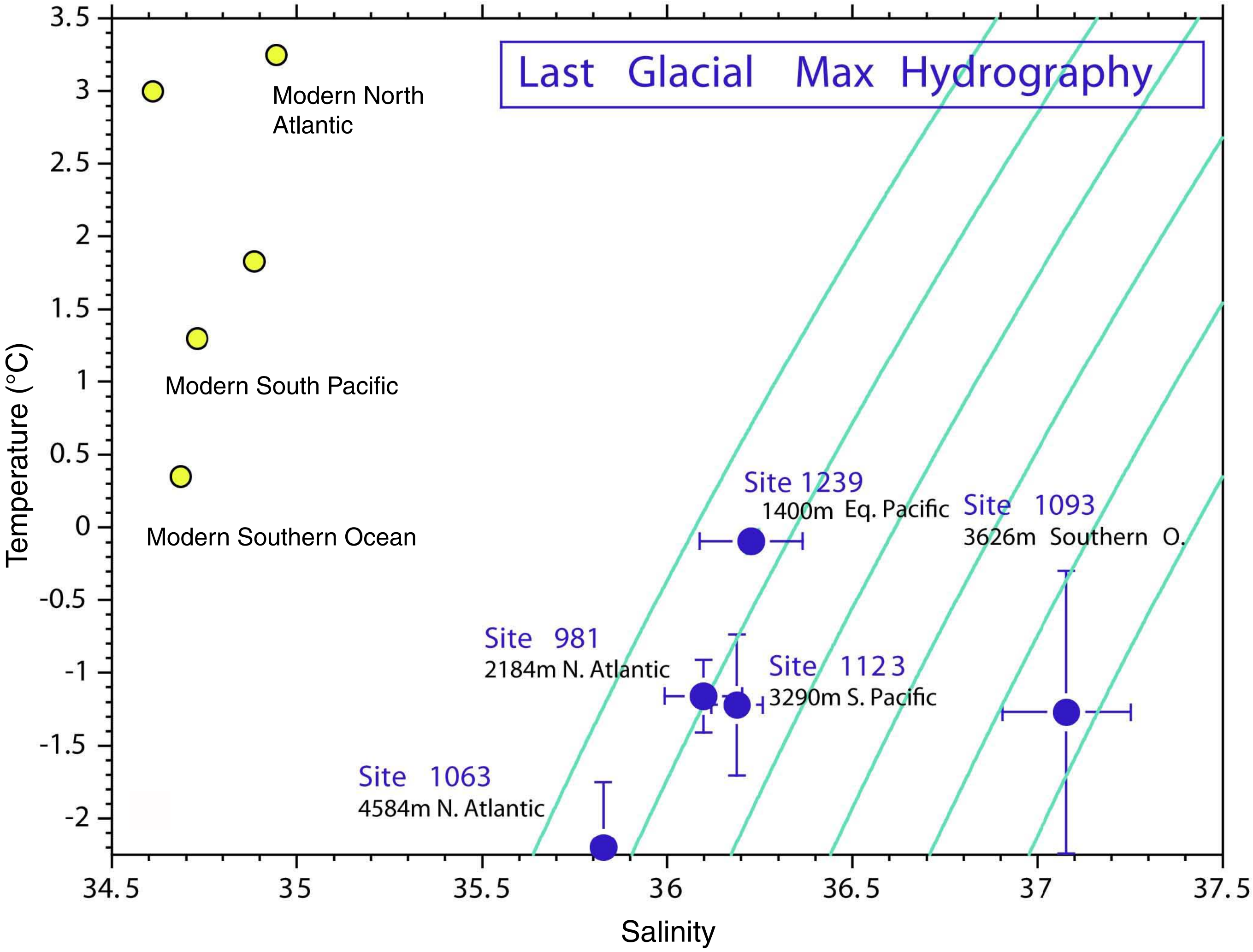


Figure F4. T-S plot for the LGM. Based on the type of pore water data we propose to collect here, this plot shows several differences with the modern. Yellow dots are the location of modern bottom waters where the cores for the blue LGM points were collected. The ODP site numbers and green isopycnals provide context.



Site summaries

Site MZC-01C

Priority:	Primary
Position:	15°49.25′S, 41°46.12′E
Water depth (m):	2157
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	449
Previous drilling in area:	DSDP Site 242 (2275 m water depth), eastern flank of Davie Ridge in the northern Mozambique Channel; the single hole penetrated 676 m of Quaternary to upper Eocene sediments
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF1**) Line GeoB08-205 (SP500) (Figures **AF2**, **AF3**)
Objective(s):	• Reconstruct Mozambique Current warm water transports during periods of orbitally modulated and suborbitally accelerated climate changes • Assess the influence of far-field upstream forcing (i.e., monsoonal, Indonesian Throughflow, and Red Sea outflow) on southeast African warm water transports
Drilling program:	Triple APC as far as possible and XCB where required to achieve 300 m for Holes A, C, and D APC to 150 m for Hole B Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole D with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Foraminifer-rich clay, nannofossil ooze

Site ZAM-05A

Priority:	Primary
Position:	19°21.30′S, 36°54.90′E
Water depth (m):	416
Target drilling depth (mbsf):	207
Approved maximum penetration (mbsf):	207
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the northern Mozambique Channel; the single hole penetrated 676 m of Quaternary to upper Eocene sediments MD79257 (20°24′S, 36°20′E, 1260 m); record of surface ocean hydrography of the last climatic cycle (Bard et al., 1997)
Survey coverage (track map; seismic profile):	Bathymetry and site track map (Figures **AF4**, **AF5**) Line GeoB08-192 (SP6949-ZAM-05A) (Figures **AF6**, **AF7**)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along the southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 207 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	No logging planned
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site LIM-01B

Priority:	Primary
Position:	25°49.26′S, 34°46.14′E
Water depth (m):	450
Target drilling depth (mbsf):	180
Approved maximum penetration (mbsf):	250
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the MD79257 (20°24′S, 36°20′E, 1260 m); record of surface ocean hydrography of the last climatic cycle (Bard et al., 1997)
Survey coverage (track map; seismic profile):	Bathymetry and site track map (Figures **AF8**; **AF9**) Line GeoB08-230 (SP5408-LIM-01B) (Figures **AF10**, **AF11**)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 180 m for Holes A, B, and D APC to 150 m for Hole C Temperature measurements: APCT-3 for Hole A Orientation on Holes A, B, and C using the Icefield MI-5 tool
Logging/Downhole measurements program:	No logging planned
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site NV-02C

Priority:	Primary
Position:	31°12.42′S, 31°31.44′E
Water depth (m):	3040
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	550
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the RRS *Charles Darwin*, Cruise 154, 2004, CD154-10-06P: 9.7 m long piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF12**) Line GeoB08-233 (SP406-NV-02C) (Figure **AF13**) Line GeoB08-235 (Figure **AF14**)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 350 m for Holes A, C, and D APC to 150 m for Hole B Temperature measurements: APCT-3 for Hole A Orientation for all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole D with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site APT-01B

Priority:	Primary
Position:	41°25.56′S, 25°16.02′E
Water depth (m):	2691
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	398
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF15**) Line AWI-98014 (SP2054-APT-01B) (Figure **AF16**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of North Atlantic Deep Water (NADW) to the Circumpolar Deep Water (CDW) • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of European Project for Ice Coring in Antarctica (EPICA) ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 300 m for Holes A, C, and D APC to 150 m for Hole B Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole D with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Silty foraminifer-bearing mud with varying carbonate contents and incursions of ice rafted debris

Site CAPE-01C

Priority:	Primary
Position:	35°03.53′S, 17°24.06′E
Water depth (m):	2648
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	550
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF17**) Line GeoB08-240 (SP714) (Figures **AF18**, **AF19**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 350 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on Holes A, B, and C using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Foraminifer-bearing mud with varying carbonate contents

Site ZAM-04B

Priority:	Alternate
Position:	19°08.96′S, 37°00.71′E
Water depth (m):	198
Target drilling depth (mbsf):	237
Approved maximum penetration (mbsf):	237
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the northern Mozambique Channel; the single hole penetrated 676 m of Quaternary to upper Eocene sediments MD79257 (20°24′S, 36°20′E, 1260 m); record of surface ocean hydrography of the last climatic cycle (Bard et al., 1997)
Survey coverage (track map; seismic profile):	Bathymetry and site track map (Figures **AF4**, **AF5**) Line GeoB08-195 (SP800) (Figures **AF20**, **AF21**)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 237 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site ZAM-01B

Priority:	Alternate
Position:	19°22.32′S, 36°53.10′E
Water depth (m):	295
Target drilling depth (mbsf):	200
Approved maximum penetration (mbsf):	250
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the northern Mozambique Channel; the single hole penetrated 676 m of Quaternary to upper Eocene sediments MD79257 (20°24′S, 36°20′E, 1260 m); record of surface ocean hydrography of the last climatic cycle (Bard et al., 1997)
Survey coverage (track map; seismic profile):	Bathymetry and site track map (Figures **AF4**, **AF5**) Line GeoB08-200 (SP2655-ZAM-01B) (Figures **AF22**, **AF23**)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 220 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	No logging planned
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site LIM-02B

Priority:	Primary
Position:	25°36.72′S, 34°43.32′E
Water depth (m):	255
Target drilling depth (mbsf):	300
Approved maximum penetration (mbsf):	350
Previous drilling in area:	Site 242 (2275 m water depth), eastern flank of Davie Ridge in the MD79257 (20°24′S, 36°20′E, 1260 m); record of surface ocean hydrography of the last climatic cycle (Bard et al., 1997)
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figures **AF8**, **AF9**) Line GeoB05-014 (SP9134-LIM-02B) (Figures **AF10**, **AF11**, **AF24**) Line GeoB08-230 (SP667)
Objective(s):	• Generate high-resolution Pliocene–Pleistocene–Holocene profile of southern African continental climate changes on orbital and suborbital timescales • Establish linking between southern African terrestrial climates and southeast Indian heat budgets, notably warm water transports along southeast African margin and associated ocean-atmosphere heat and moisture transfer • Reconstruct upstream control on Agulhas leakage through headwater variability (Mozambique Current) during periods of orbitally modulated and suborbitally accelerated climate changes
Drilling program:	Triple APC as far as possible and XCB where required to achieve 300 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	No logging planned
Nature of rock anticipated:	Foraminifer-bearing sandy/silty/clayey hemipelagic mud

Site APT-05A

Priority:	Alternate
Position:	41°26.88′S, 25°08.46′E
Water depth (m):	2625
Target drilling depth (mbsf):	430
Approved maximum penetration (mbsf):	430
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF15**) Line AWI-98014 (SP1750-APT-05A) (Figure **AF16**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 430 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-sonic, and VSI
Nature of rock anticipated:	Silty foraminifer-bearing mud with varying carbonate contents and incursions of ice rafted debris

Site APT-04A

Priority:	Alternate
Position:	41°23.16′S, 25°31.74′E
Water depth (m):	2814
Target drilling depth (mbsf):	350
Approved maximum penetration (mbsf):	350
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF15**) Line AWI-98014 (SP2650-APT-04A) (Figure **AF16**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep-ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 350 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-Sonic, and VSI
Nature of rock anticipated:	Silty foraminifer-bearing mud with varying carbonate contents and incursions of ice rafted debris

Site CAPE-03B

Priority:	Alternate
Position:	35°03.78′S, 17°18.28′E
Water depth (m):	2681
Target drilling depth (mbsf):	270
Approved maximum penetration (mbsf):	470
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF17**) Line GeoB08-236 (SP13748) (Figures **AF25**, **AF26**) Line GeoB08-244 (SP387) (Figures **AF27**, **AF28**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep-ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 270 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-Sonic, and VSI
Nature of rock anticipated:	Foraminifer-bearing mud with varying carbonate contents

Site CAPE-02A

Priority:	Alternate
Position:	35°03.97′S, 17°12.53′E
Water depth (m):	2784
Target drilling depth (mbsf):	180
Approved maximum penetration (mbsf):	380
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF17**) Line GeoB08-242 (SP626-CAPE-02A) (Figures **AF29**, **AF30**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC to 180 m for Holes A, B, and C Triple APC as far as possible and XCB where required to achieve 300 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on Holes A, B, and C: Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-sonic and VSI
Nature of rock anticipated:	Foraminifer-bearing mud with varying carbonate contents

Site CAPE-02B

Priority:	Alternate
Position:	35°04.79′S, 17°13.18′E
Water depth (m):	2743
Target drilling depth (mbsf):	260
Approved maximum penetration (mbsf):	460
Previous drilling in area:	R/V *Marion Dufresne* Cruise SWAF MD128, 2002, Core MD02-2589, total length 34.5 m; long CALYPSO giant piston core
Survey coverage (track map; seismic profile):	Bathymetric sketch and site track map (Figure **AF17**) Line GeoB08-242 (SP746-CAPE-02B) (Figures **AF29**, **AF30**)
Objective(s):	• Recover complete sequence of Pliocene–Pleistocene–Holocene sediments from high-accumulation rate contourite (expected sedimentation rates of 8–10 cm/ky) • Linkage between surface/deep-ocean changes in the sub-Antarctic zone and climate in Antarctica • Export of NADW to the CDW • Variability of regional ocean fronts and width of Agulhas corridor • Extend the paleoclimatic record from high southern latitudes beyond the reach of EPICA ice core (i.e., into early Pleistocene and Pliocene) • Investigate contribution of Southern Ocean water masses to global ocean THC during key time of Pliocene–Pleistocene global climatic evolution
Drilling program:	Triple APC as far as possible and XCB where required to achieve 260 m for Holes A, B, and C Temperature measurements: APCT-3 for Hole A Orientation on all APC holes using the Icefield MI-5 tool
Logging/Downhole measurements program:	Hole C with triple combo, FMS-Sonic, and VSI
Nature of rock anticipated:	Foraminifer-bearing mud with varying carbonate contents

Figure AF1. Seismic line track map with the locations of Site MZC-01C and DSDP Site 242. Contour lines = bathymetry.

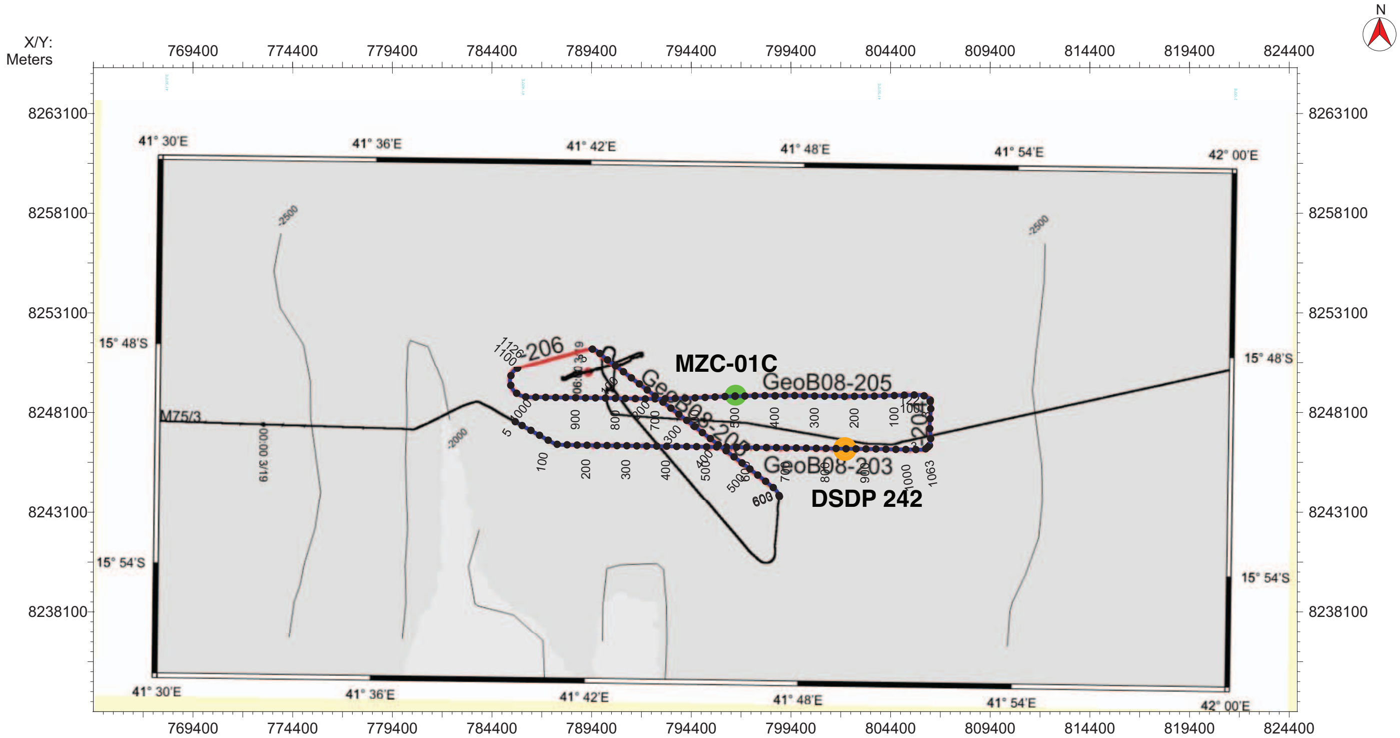


Figure AF2. Seismic Line GeoB08-205 with location of Site MZC-01C.

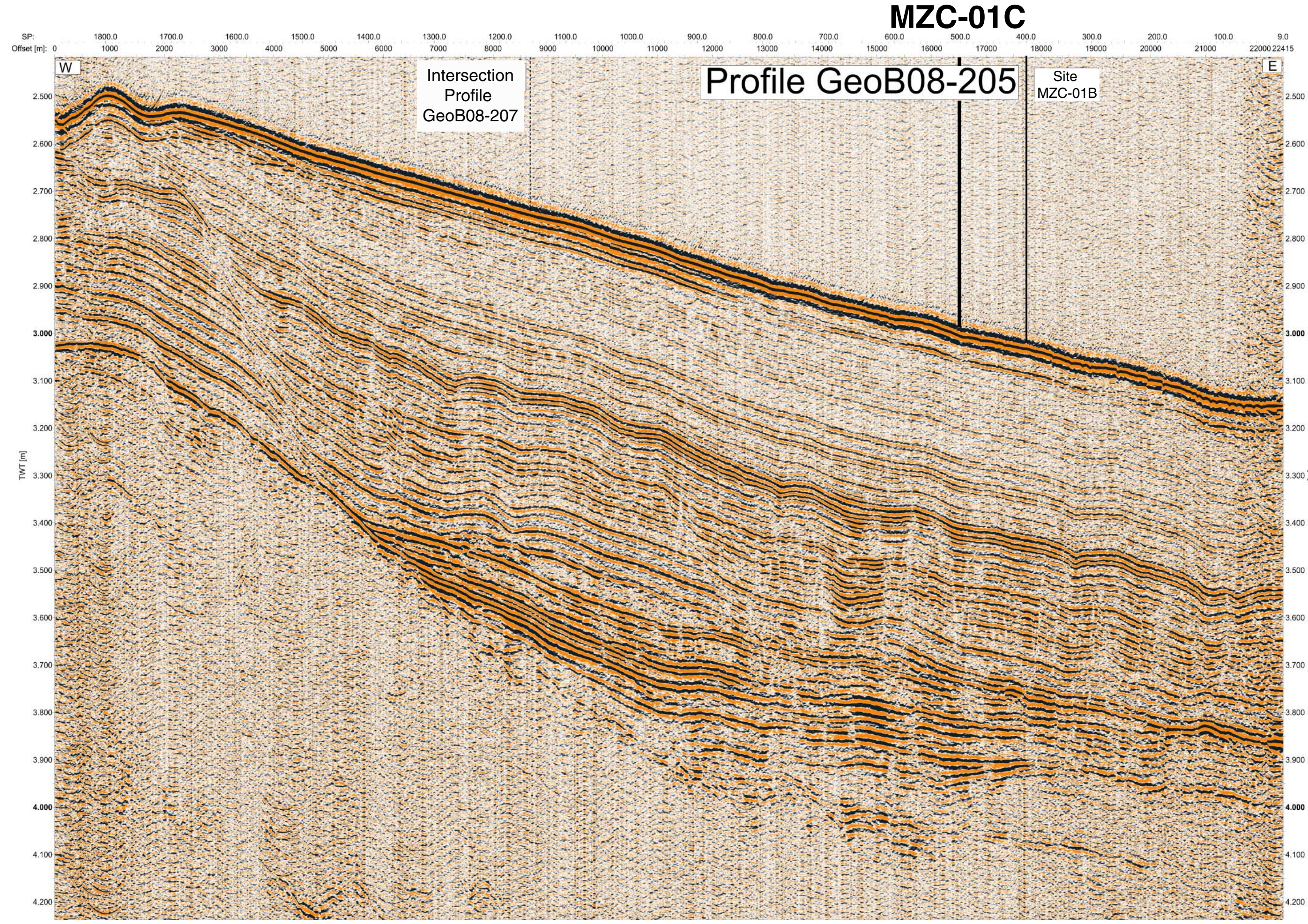


Figure AF3. Interpreted seismic Line GeoB08-205 with location of Site MZC-01C and depth of penetration.

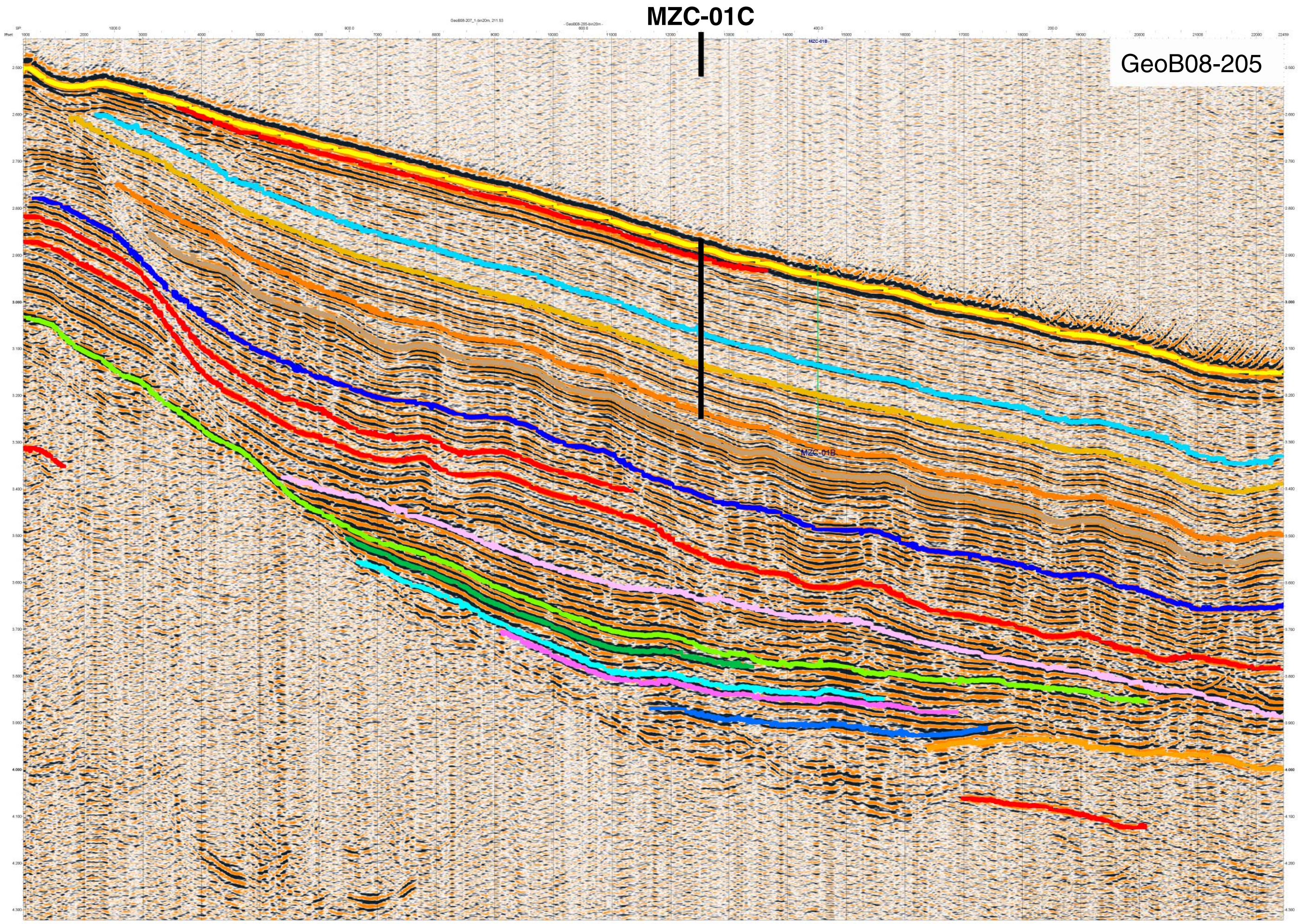


Figure AF4. Seismic line track map for the ZAM sites showing the positions of Sites ZAM-01B, ZAM-04B, and ZAM-05A.

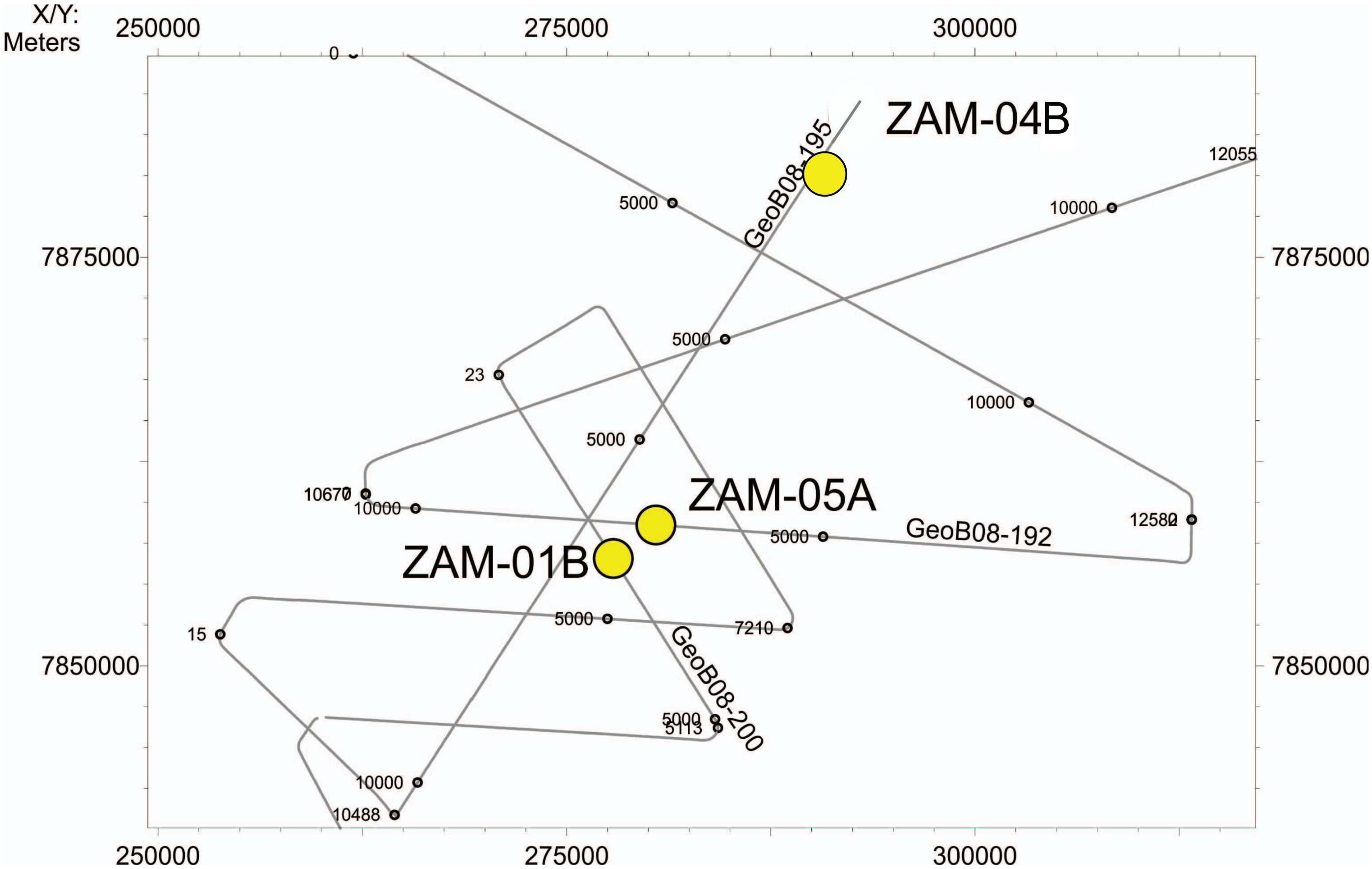


Figure AF5. Seismic line tracks with the bathymetry along the tracks showing Sites ZAM-01B, ZAM-04B, and ZAM-05A.

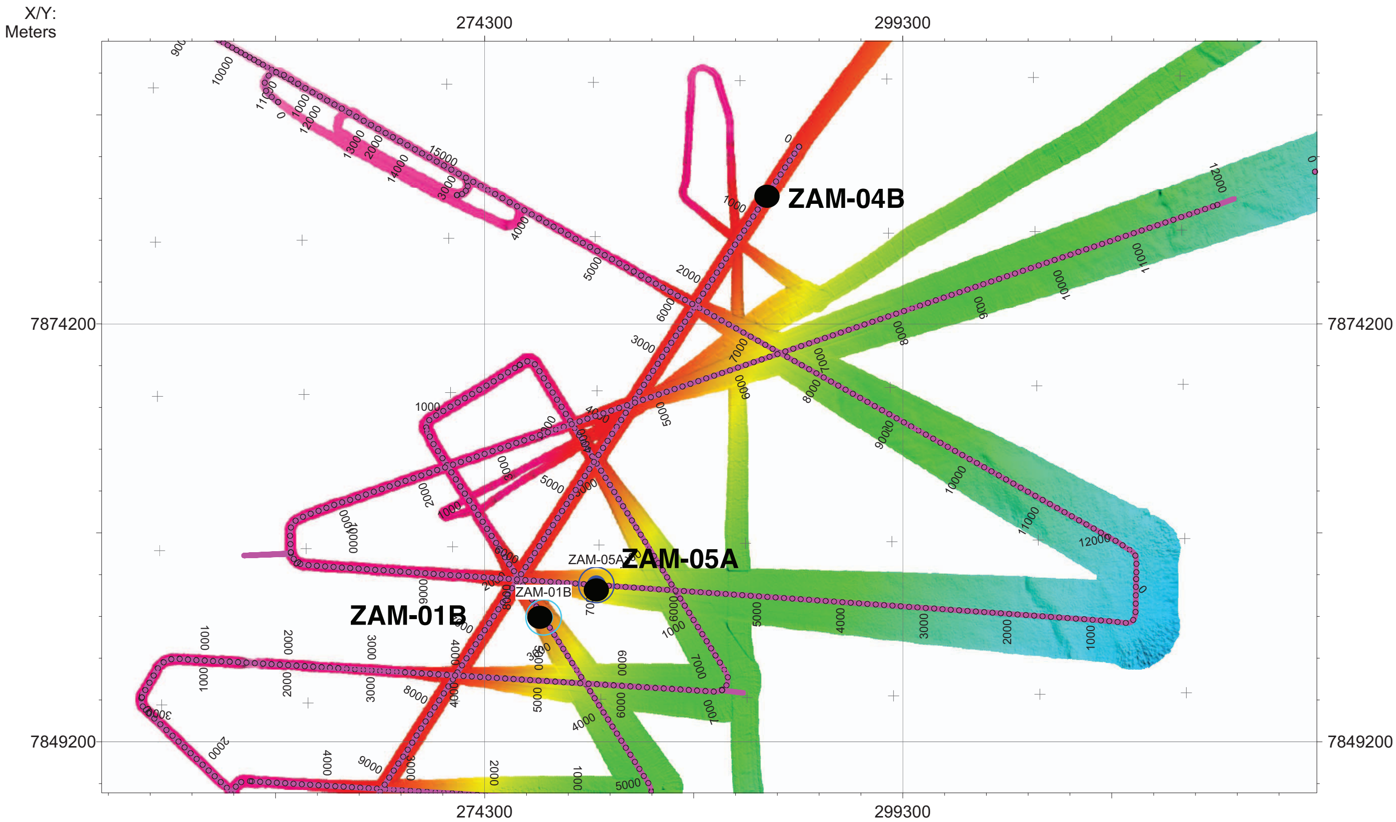


Figure AF6. Seismic Line GeoB08-192 with position of Site ZAM-05A.

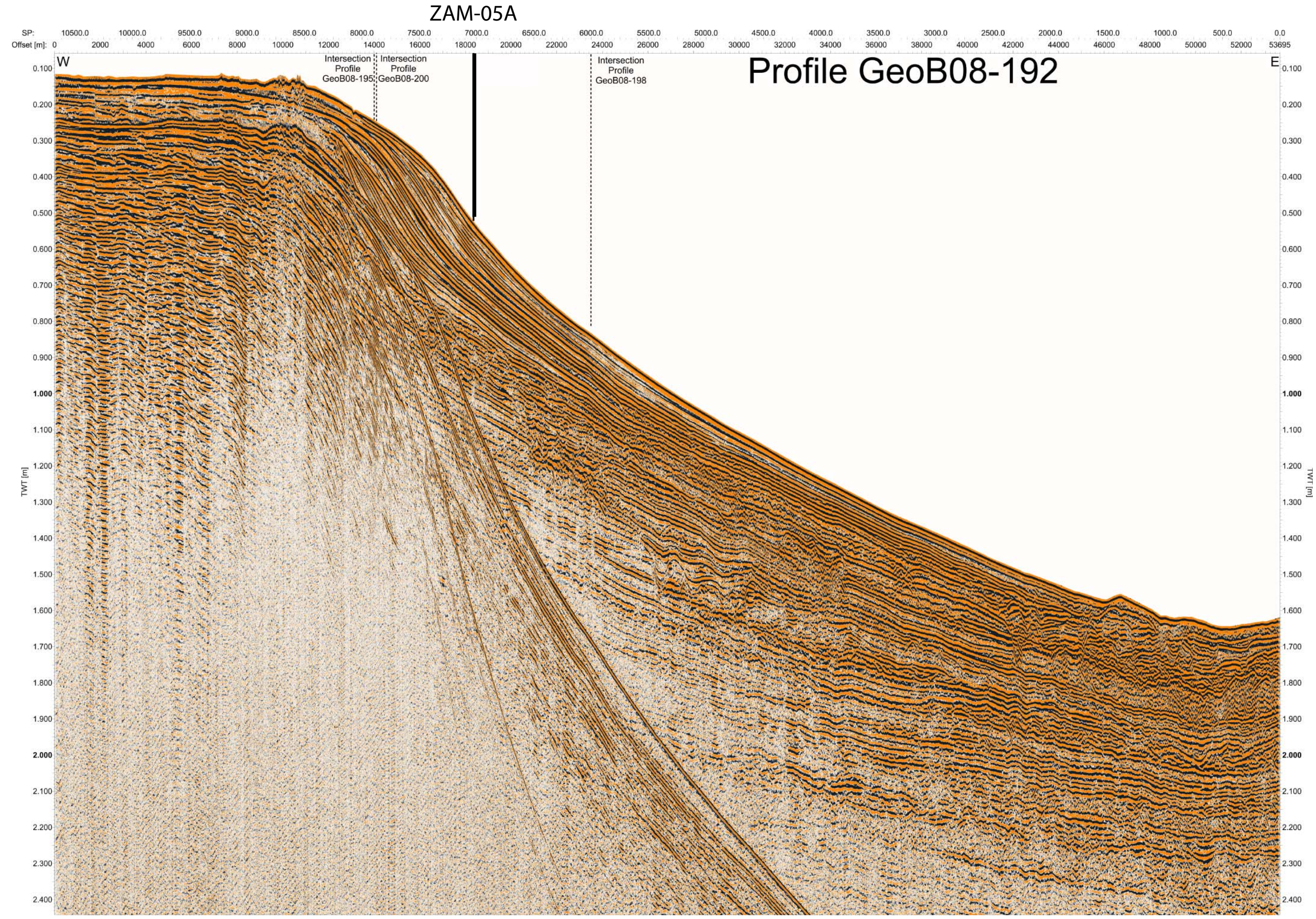


Figure AF7. Seismic Line GeoB08-192 with position of Site ZAM-05A and depth of penetration.

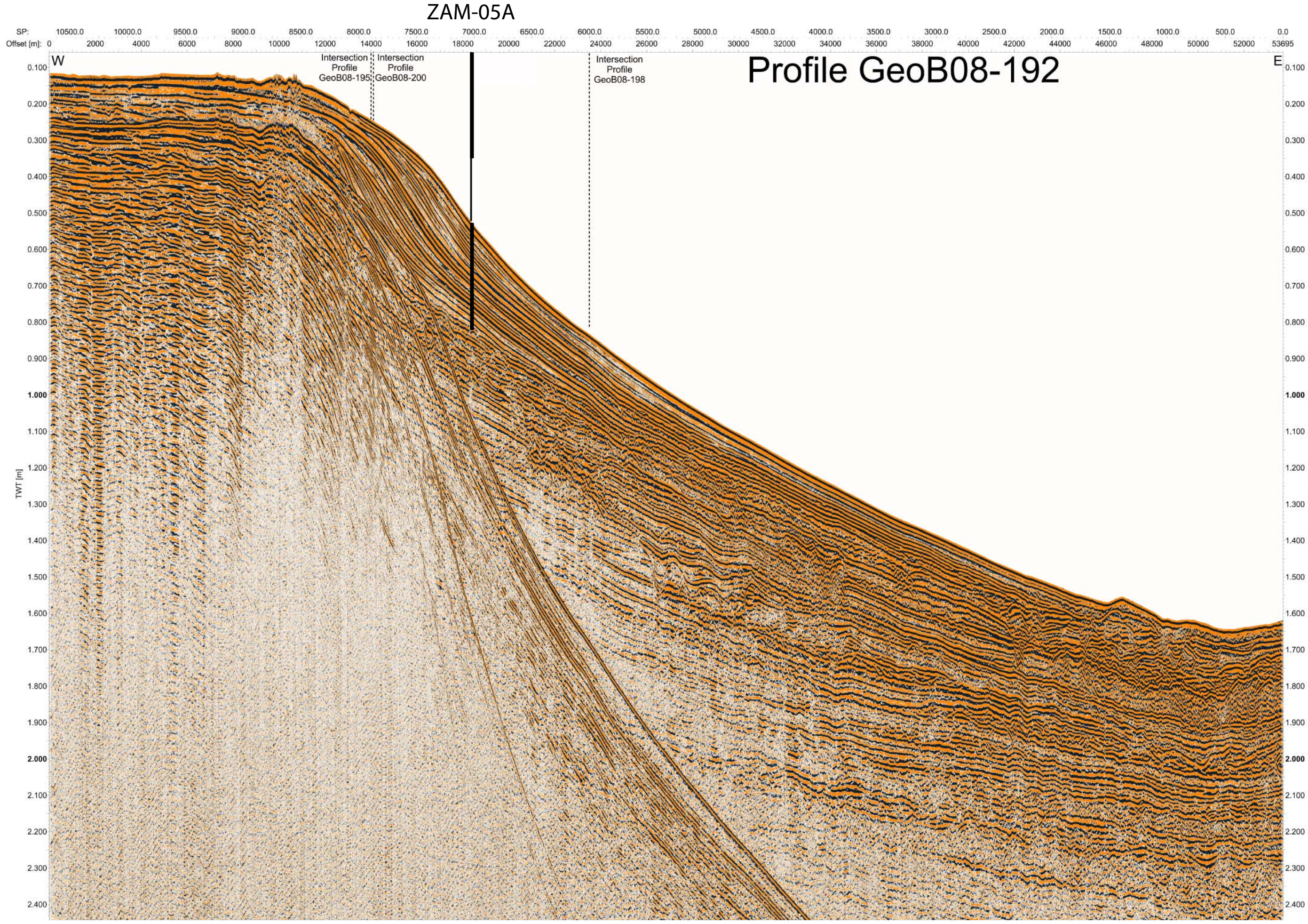


Figure AF8. Seismic line track map of the LIM sites showing Sites LIM-01B and LIM-02B.

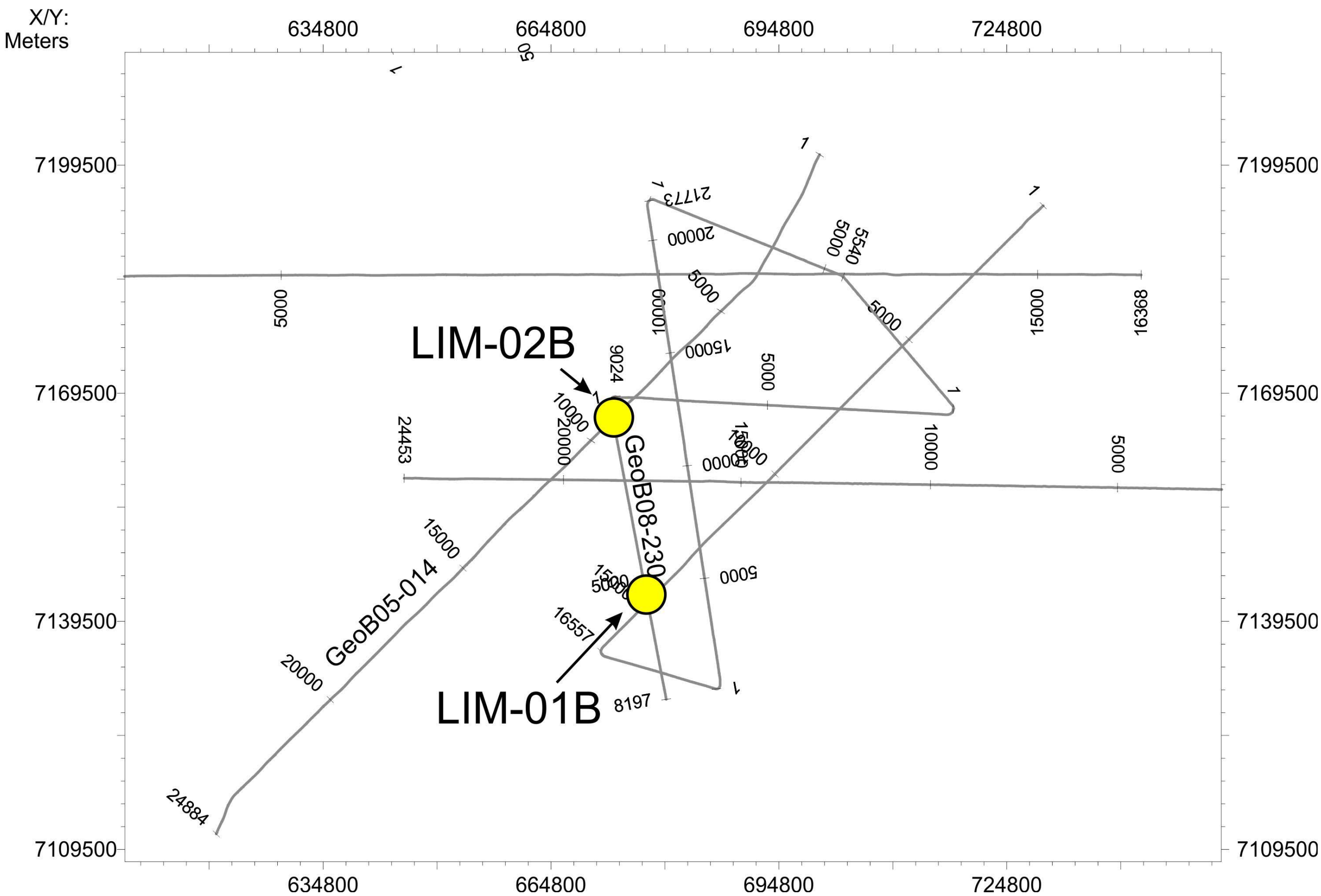


Figure AF9. Bathymetry along the seismic track lines for the LIM sites showing Sites LIM-01B and LIM-02B.

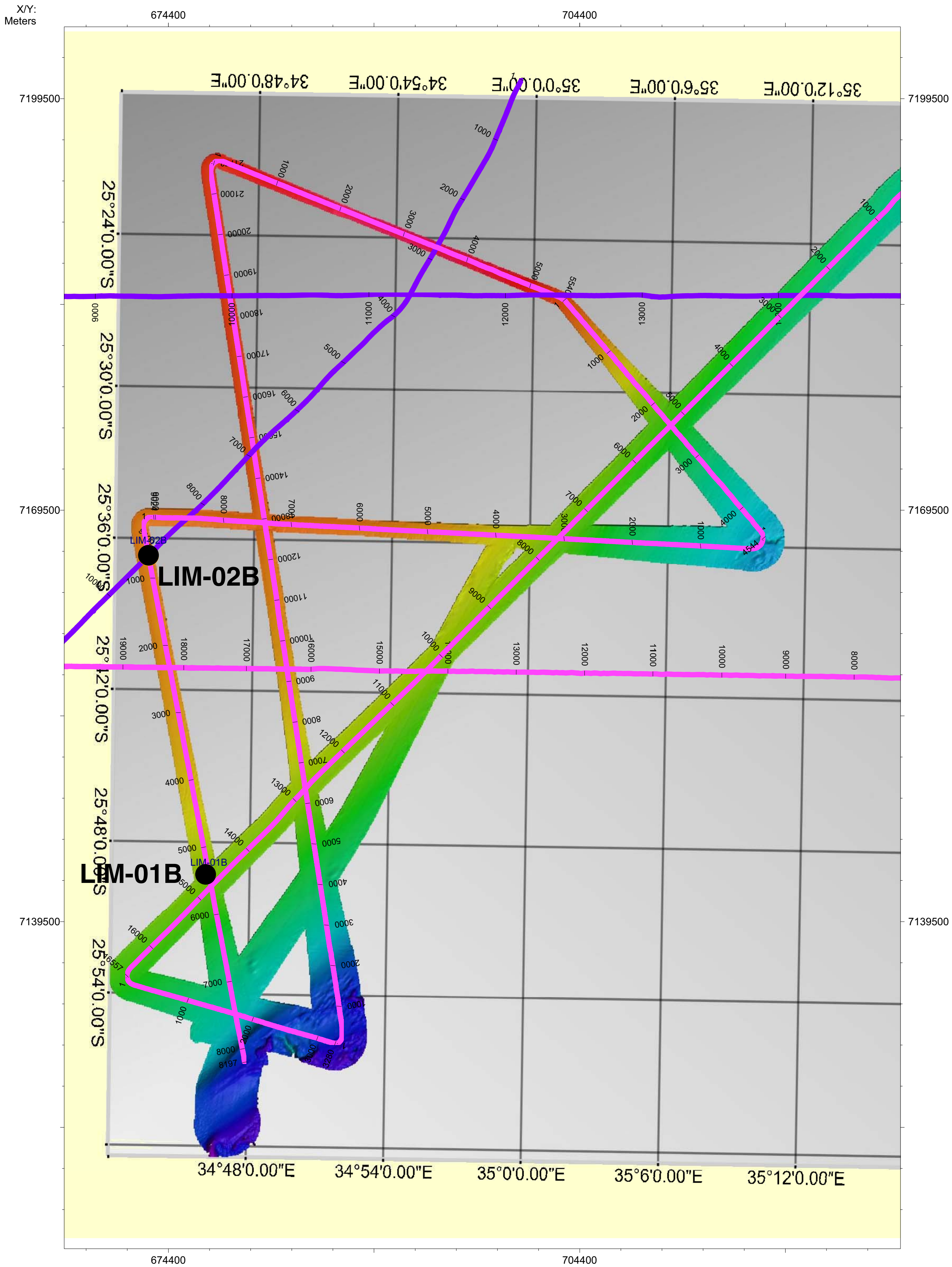


Figure AF10. Seismic Line GeoB08-230 with locations of Sites LIM-01B and LIM-02B.

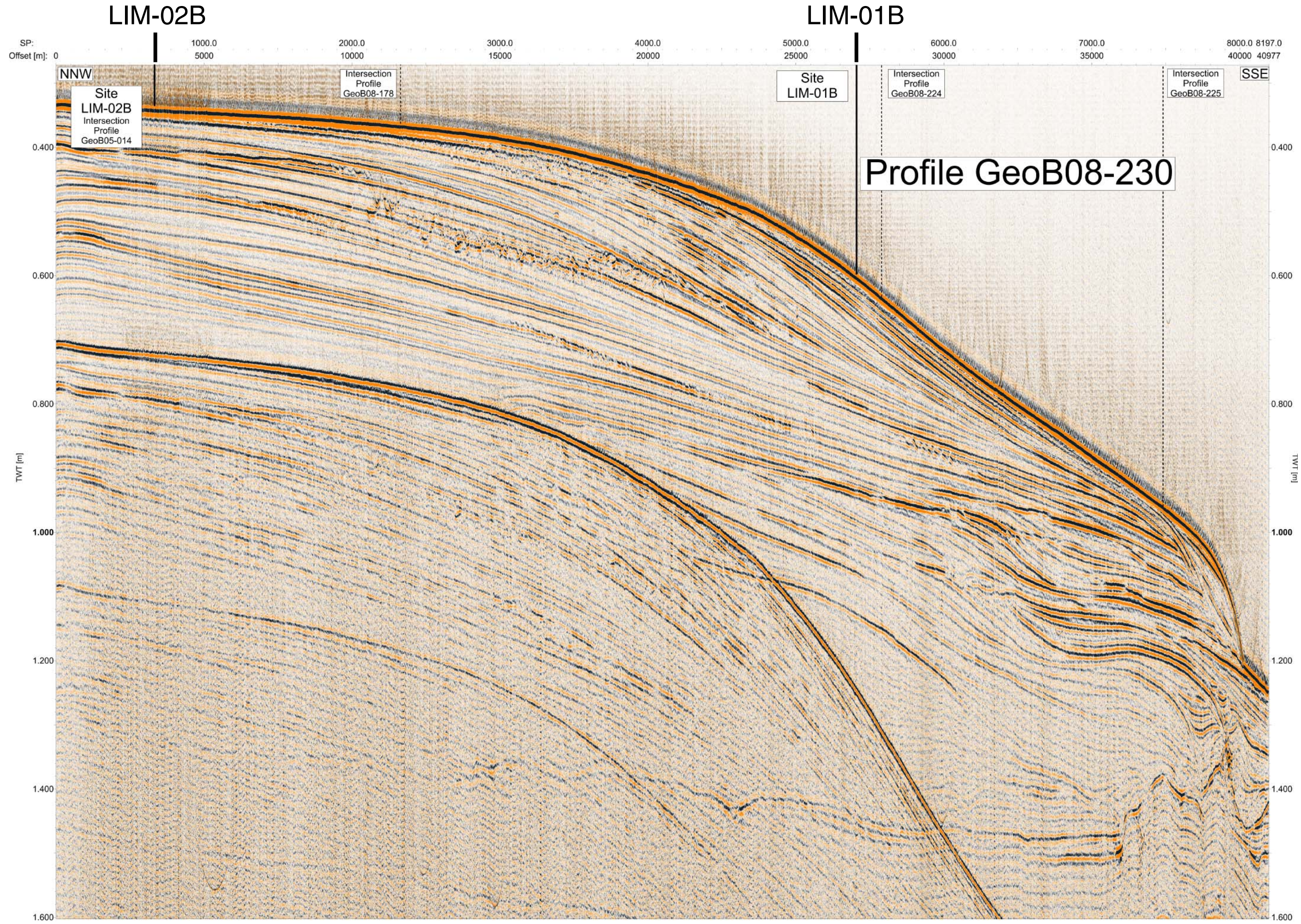


Figure AF11. Seismic Line GeoB08-230 with locations of Sites LIM-01B and LIM-02B and depth of penetration.

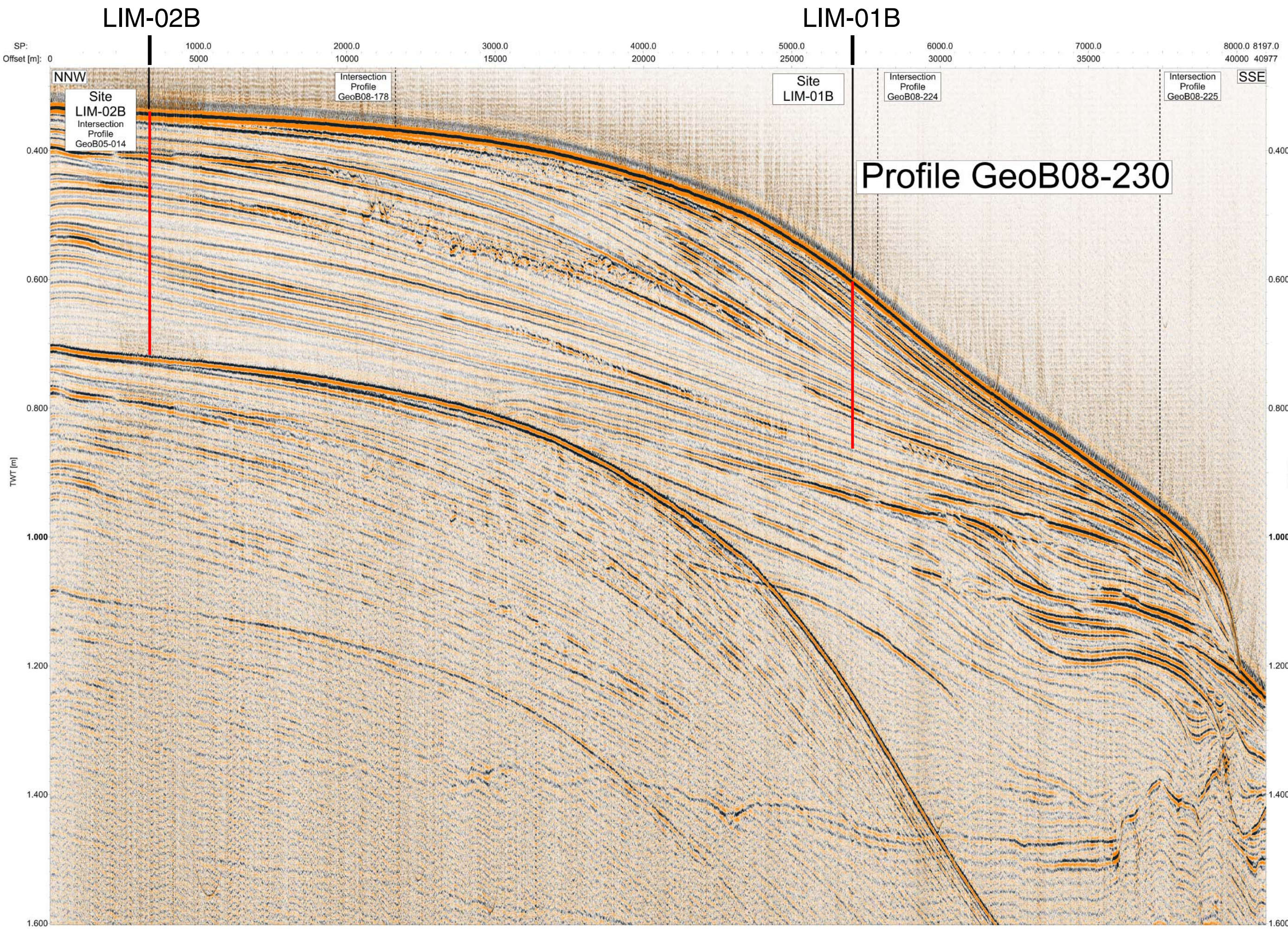
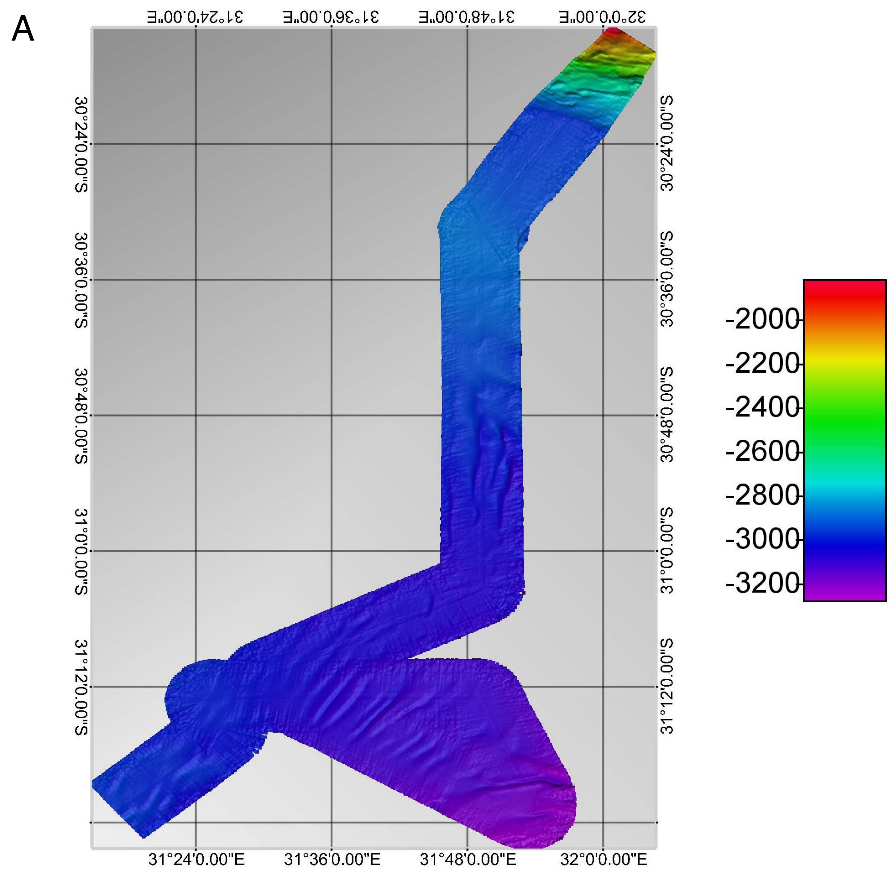


Figure AF12. (A) Seismic line track map and (B) bathymetry along the tracks for Site NV-02C.



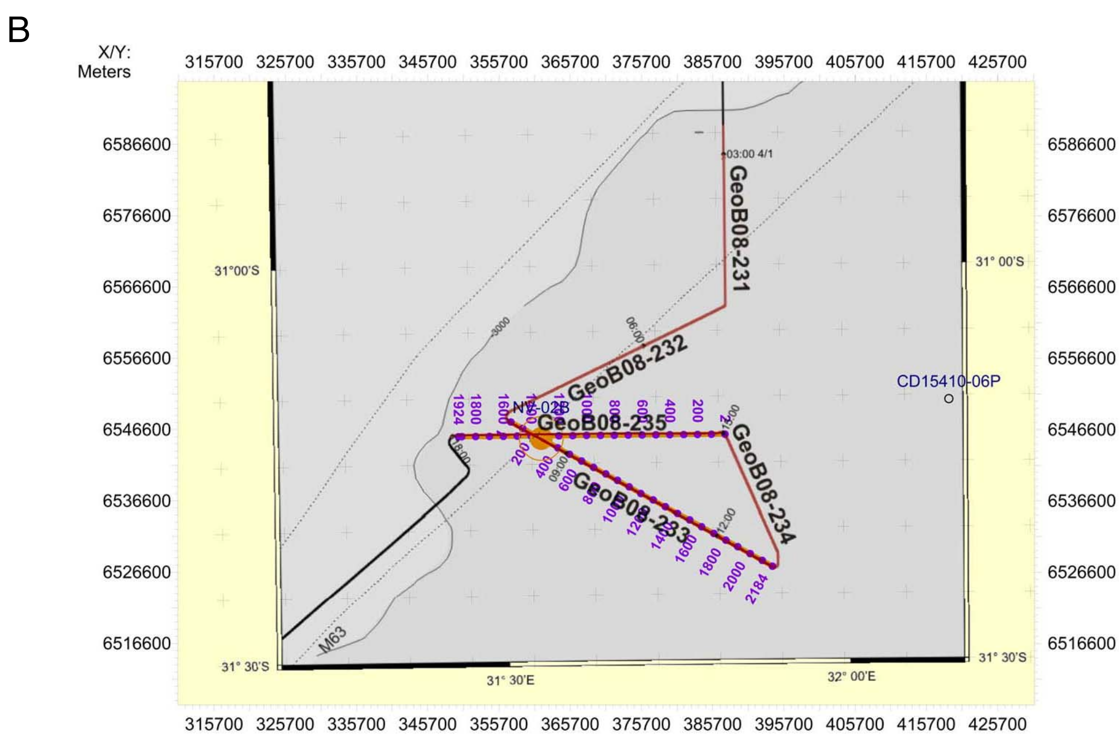


Figure AF13. Interpreted seismic Line GeoB08-233 with location and depth of penetration of Site NV-02C.

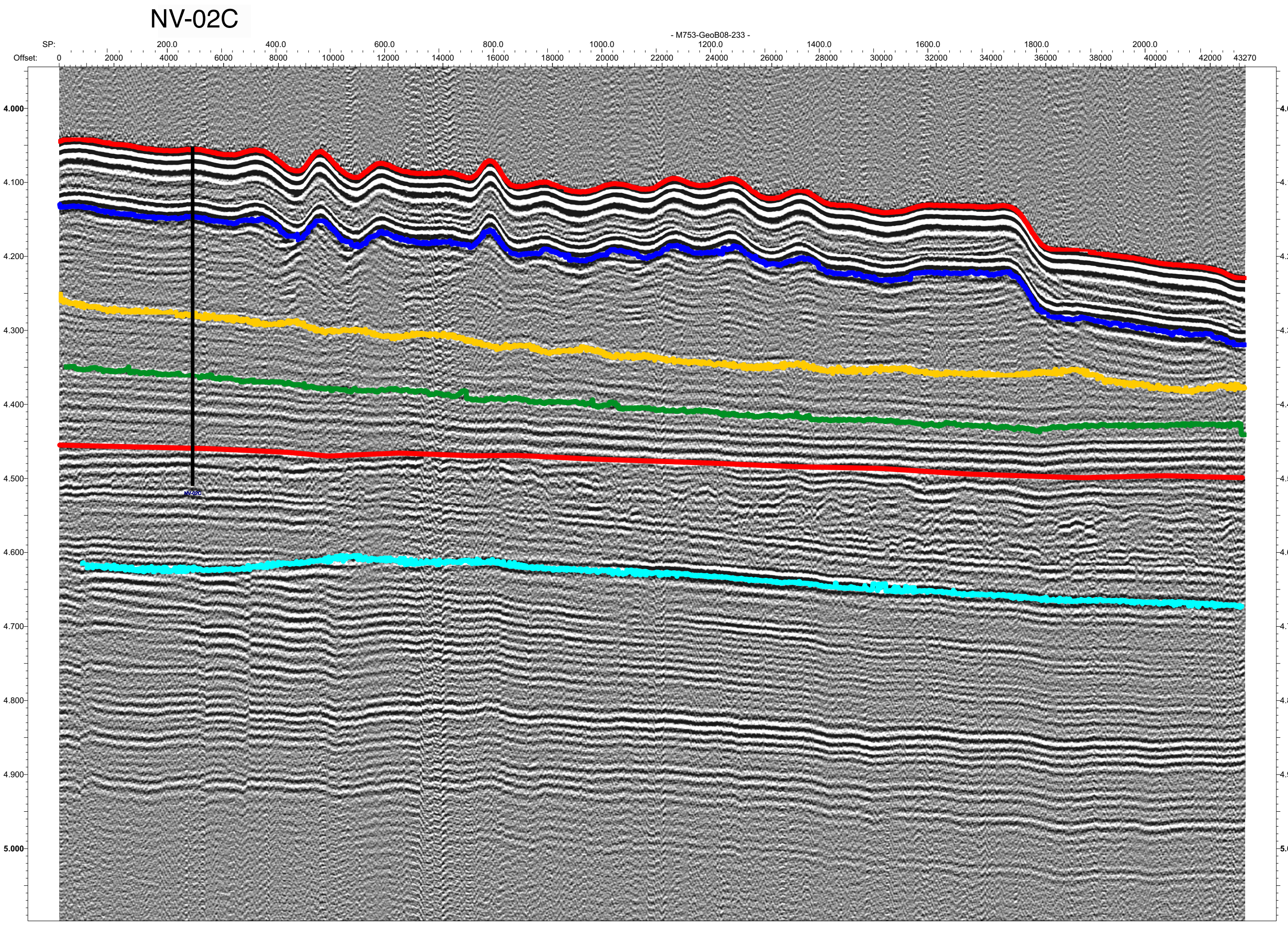


Figure AF14. Seismic Line GeoB08-235 with location of Site NV-02C.

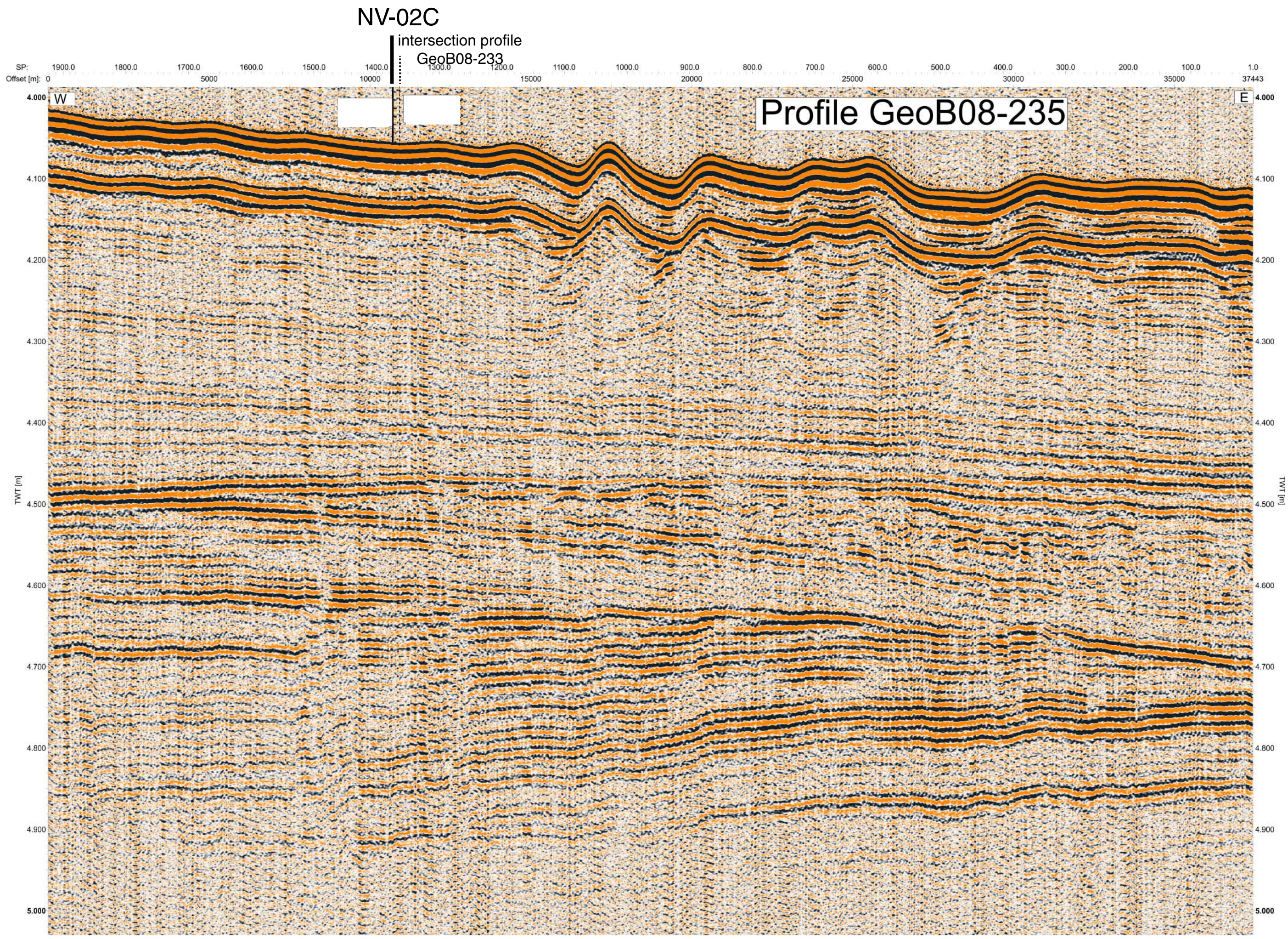


Figure AF15. Bathymetry and seismic track line for the APT sites showing Sites APT-01B, APT-04A, and APT-05A.

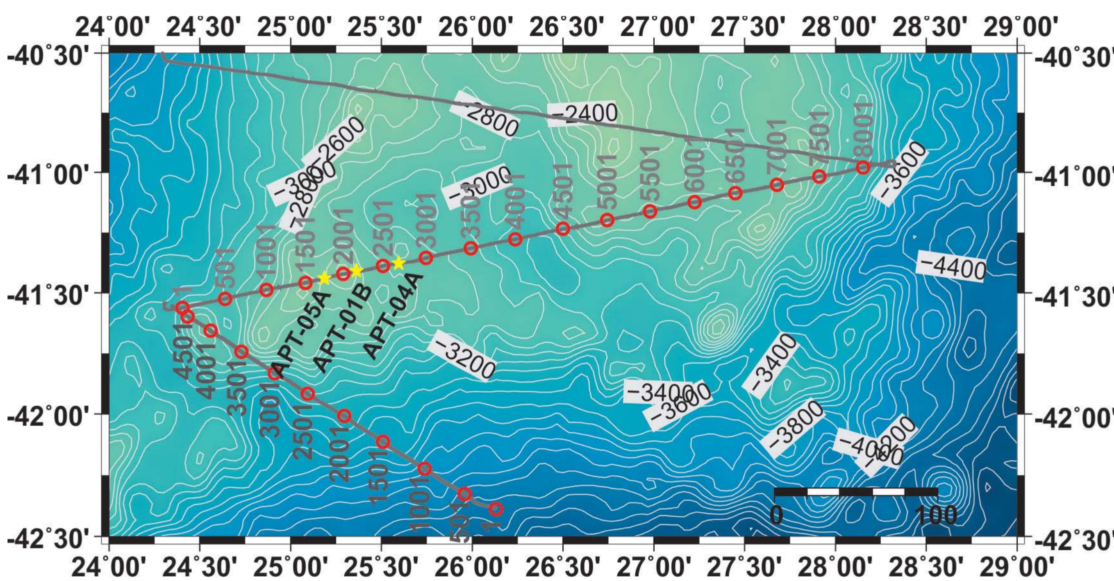


Figure AF16. Seismic Line AWI-98014 displaying locations of Sites APT-01B, APT-04A, and APT-05A, (B) with and (A) without interpretation.

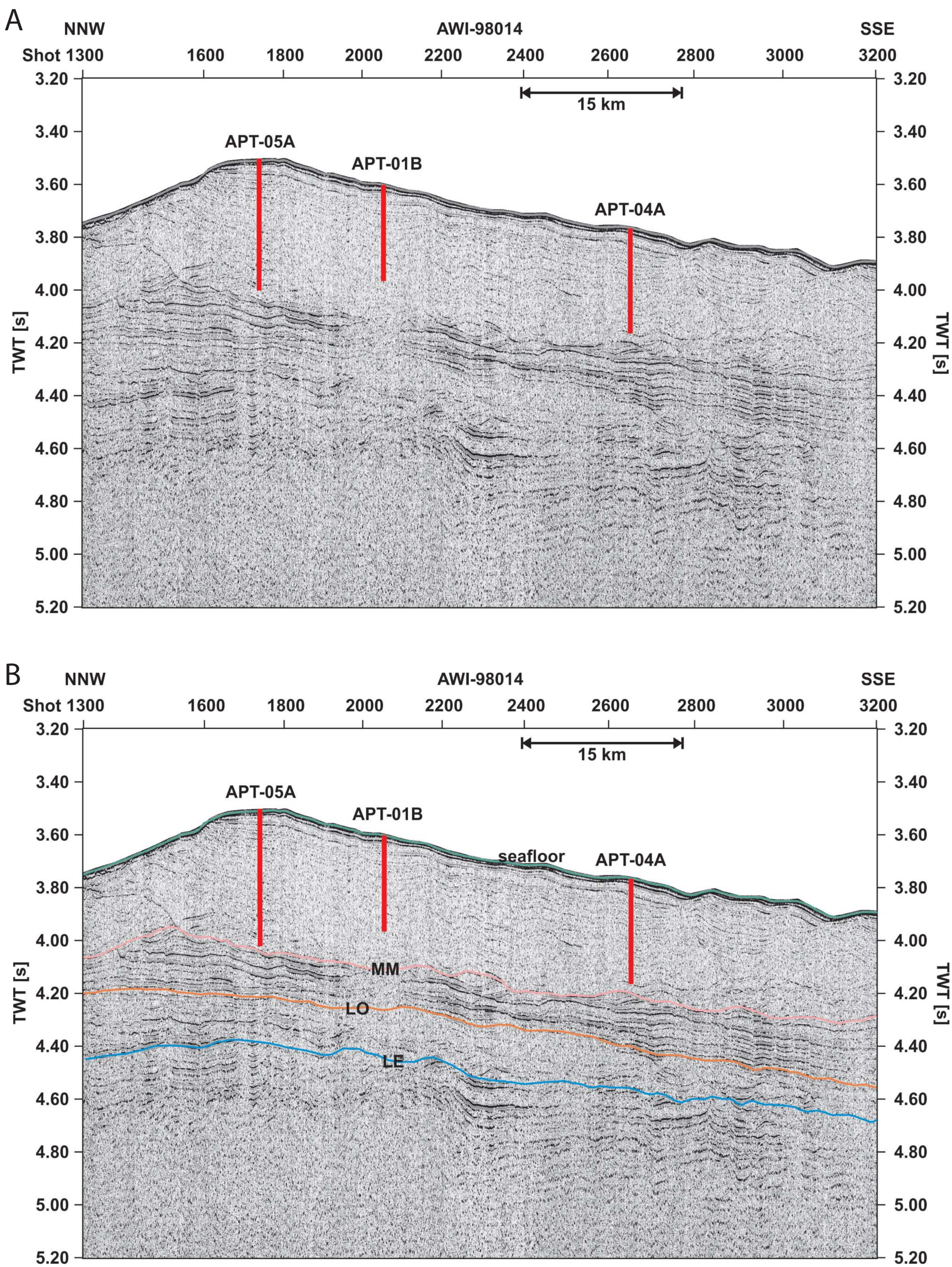


Figure AF17. (A) Seismic line track map with locations of Sites CAPE-01C, CAPE-02A, CAPE-02B, and CAPE-03B and (B) bathymetry along the track lines.

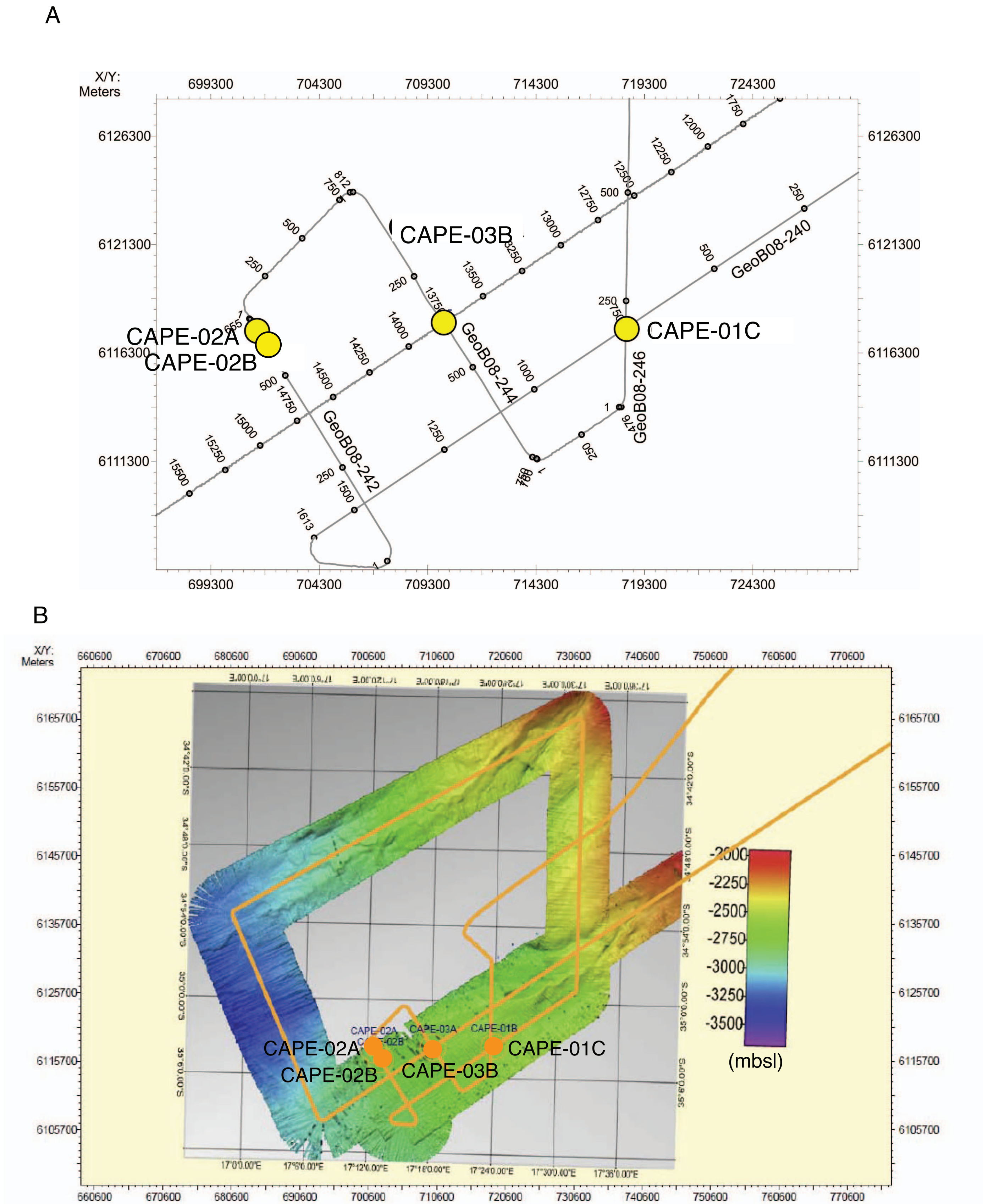


Figure AF18. Seismic Line GeoB08-240 displaying location of Site CAPE-01C.

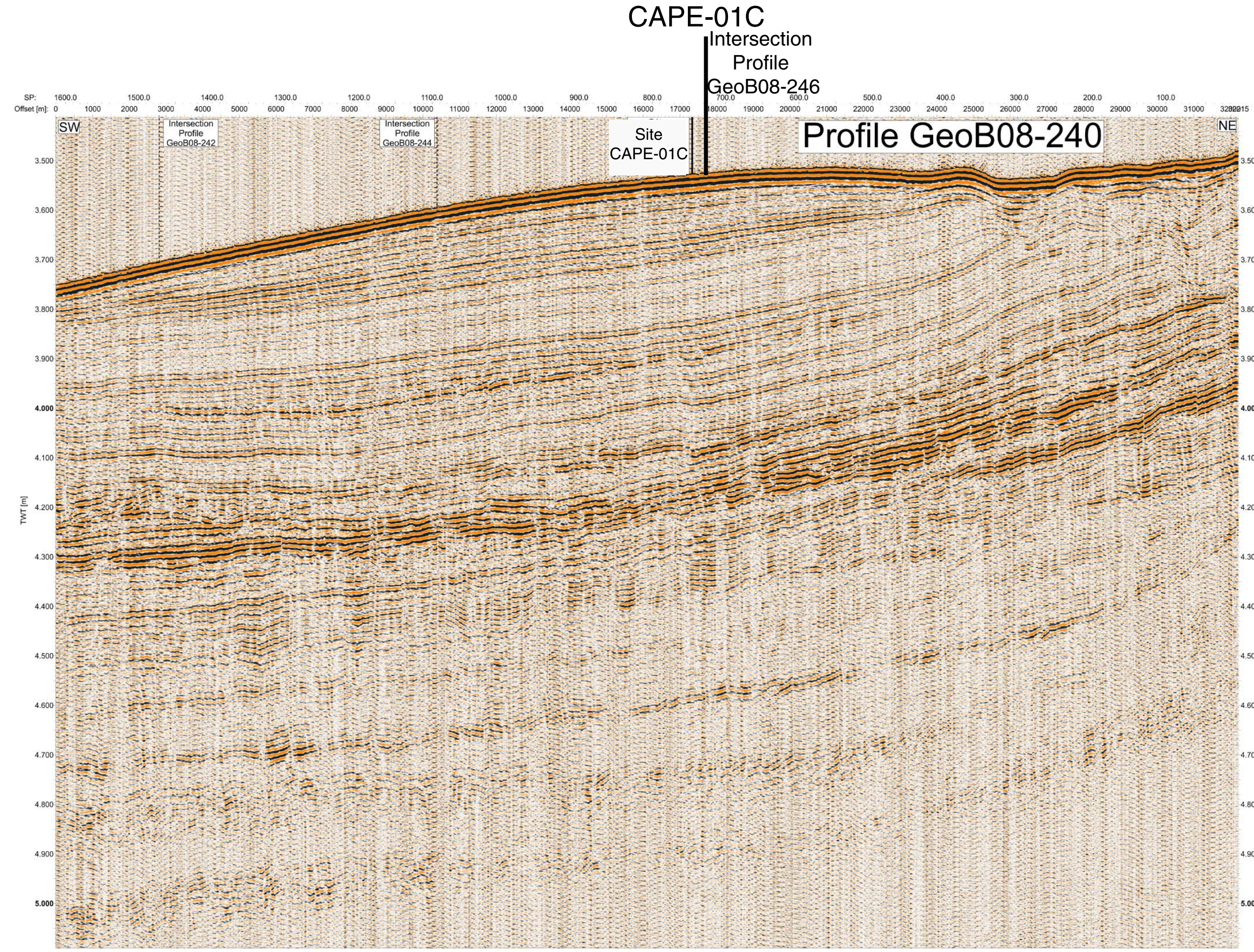


Figure AF19. Seismic Line GeoB08-240 displaying location of Site CAPE-01C and depth of penetration.

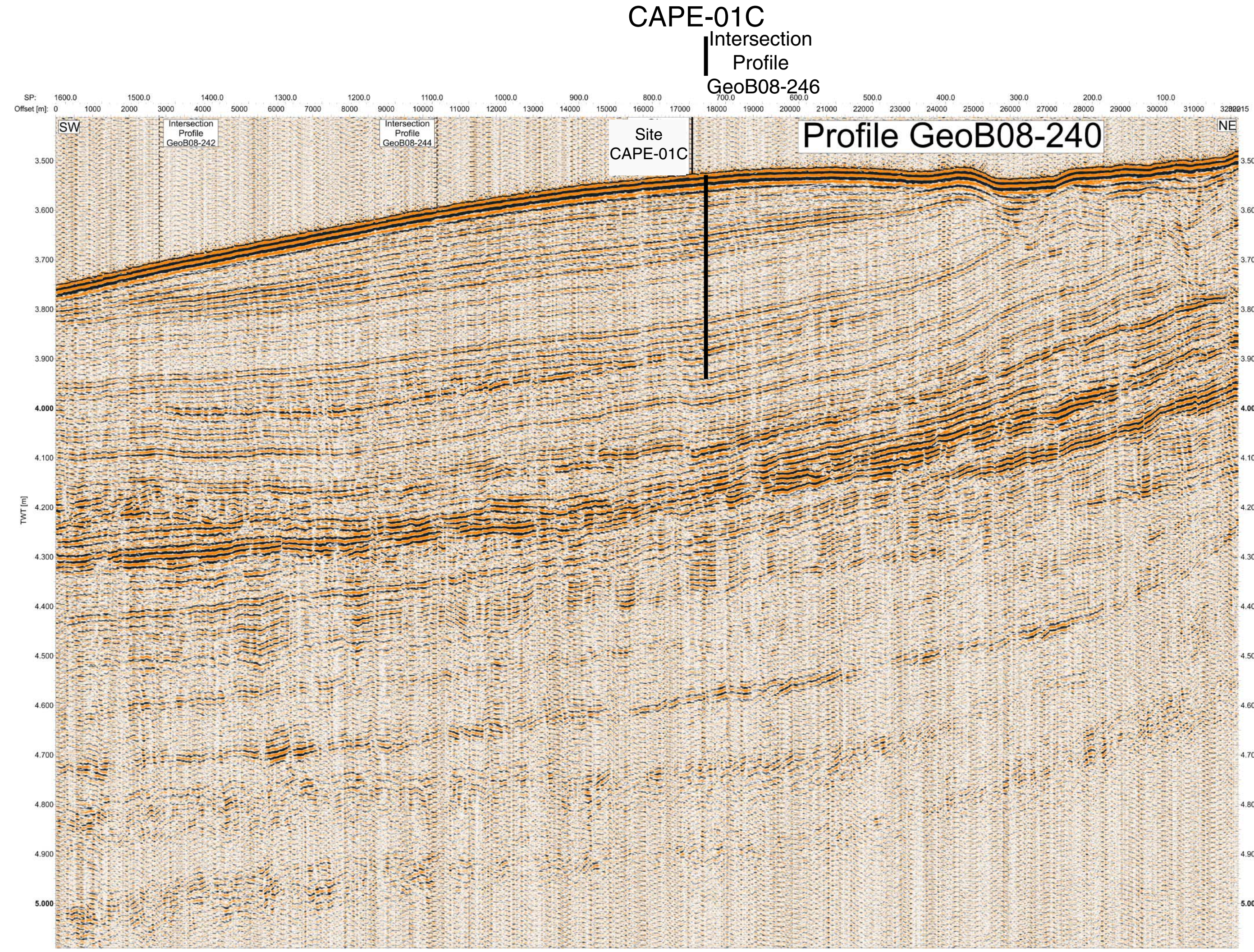


Figure AF20. Seismic Line GeoB08-195 with position of Site ZAM-04B.

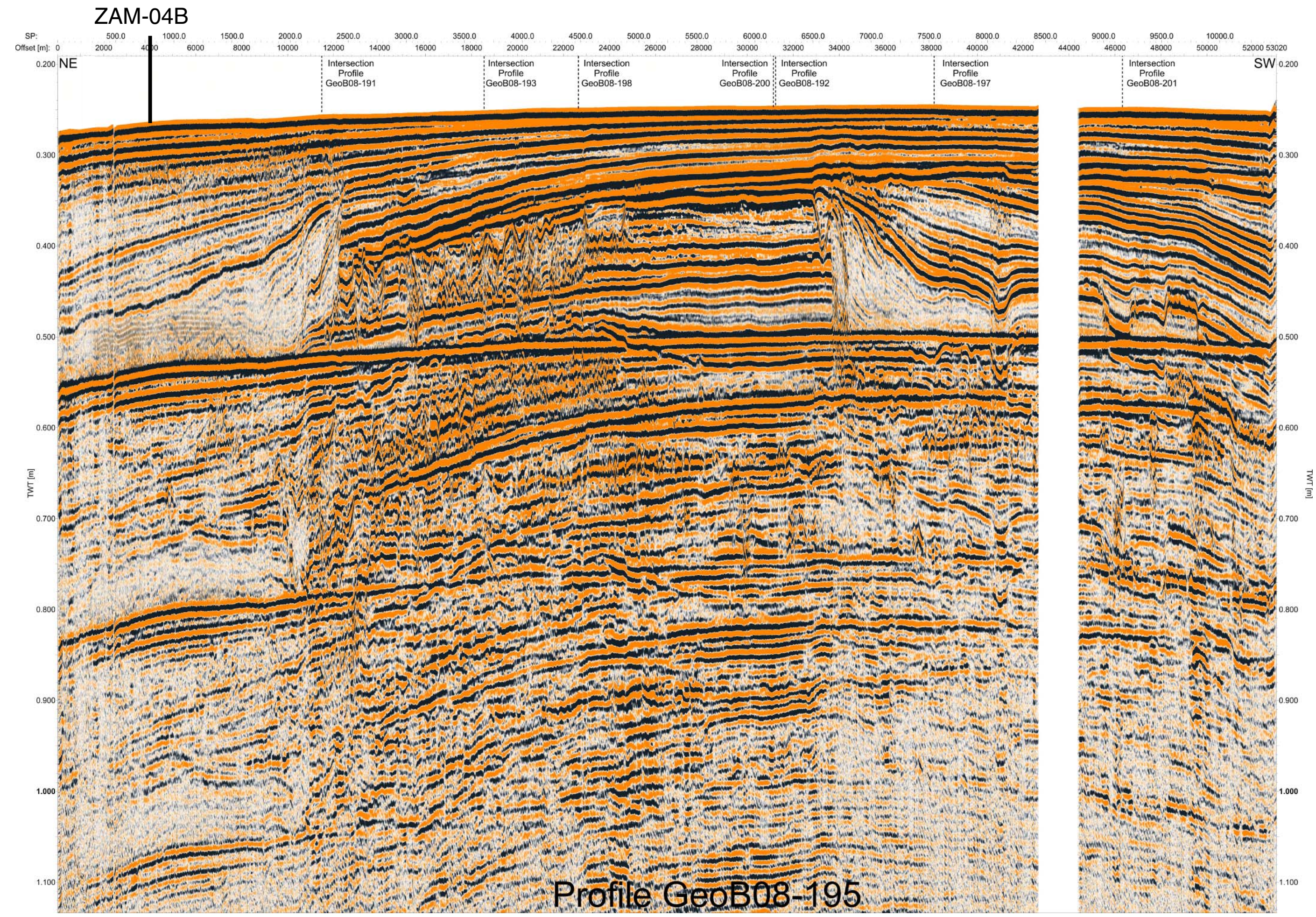


Figure AF21. Seismic Line GeoB08-195 with position of Site ZAM-04B and penetration depth.

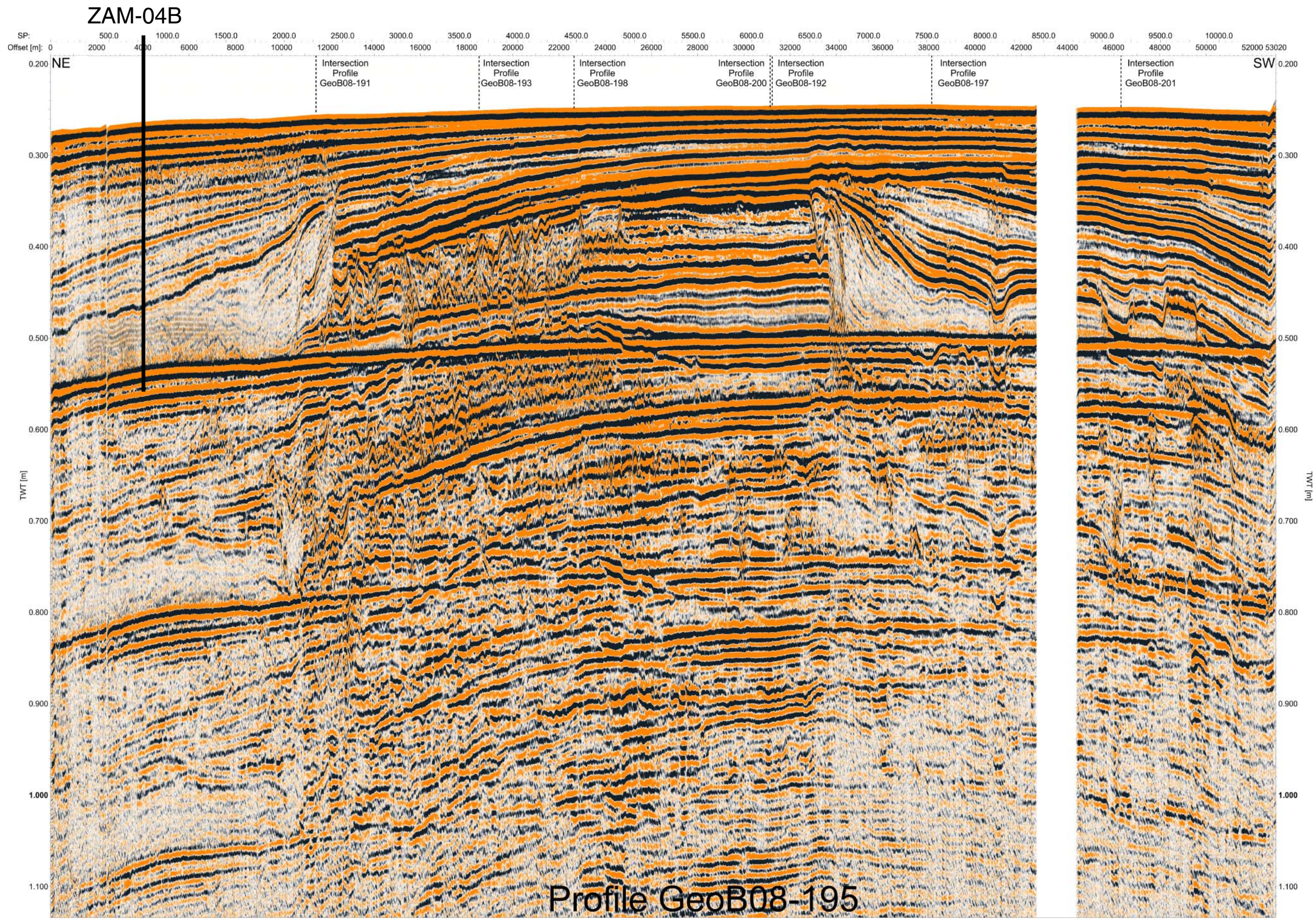


Figure AF22. Seismic Line GeoB08-200 with position of Site ZAM-01B.

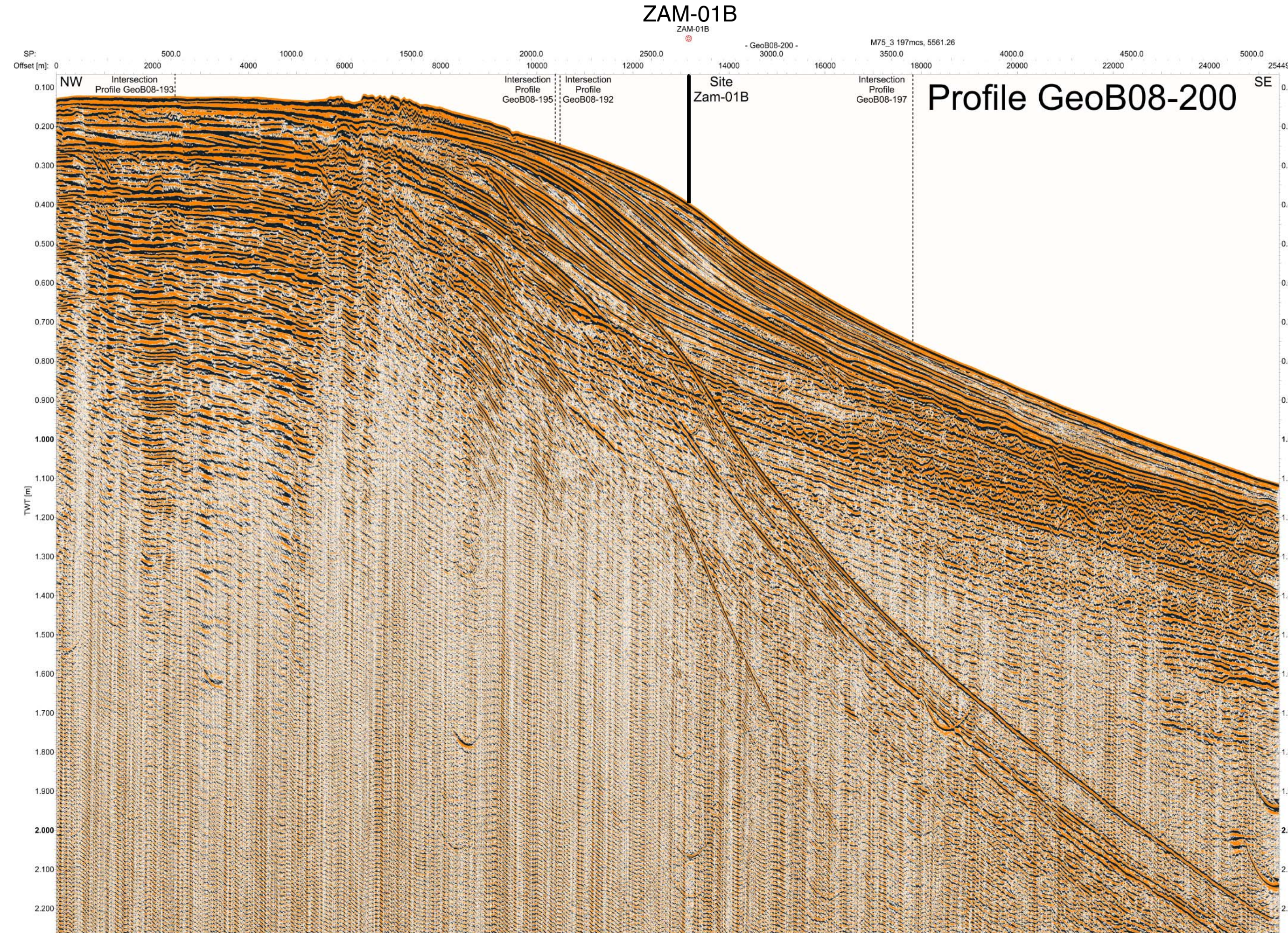


Figure AF23. Seismic Line GeoB08-200 with position of Site ZAM-01B and penetration depth.

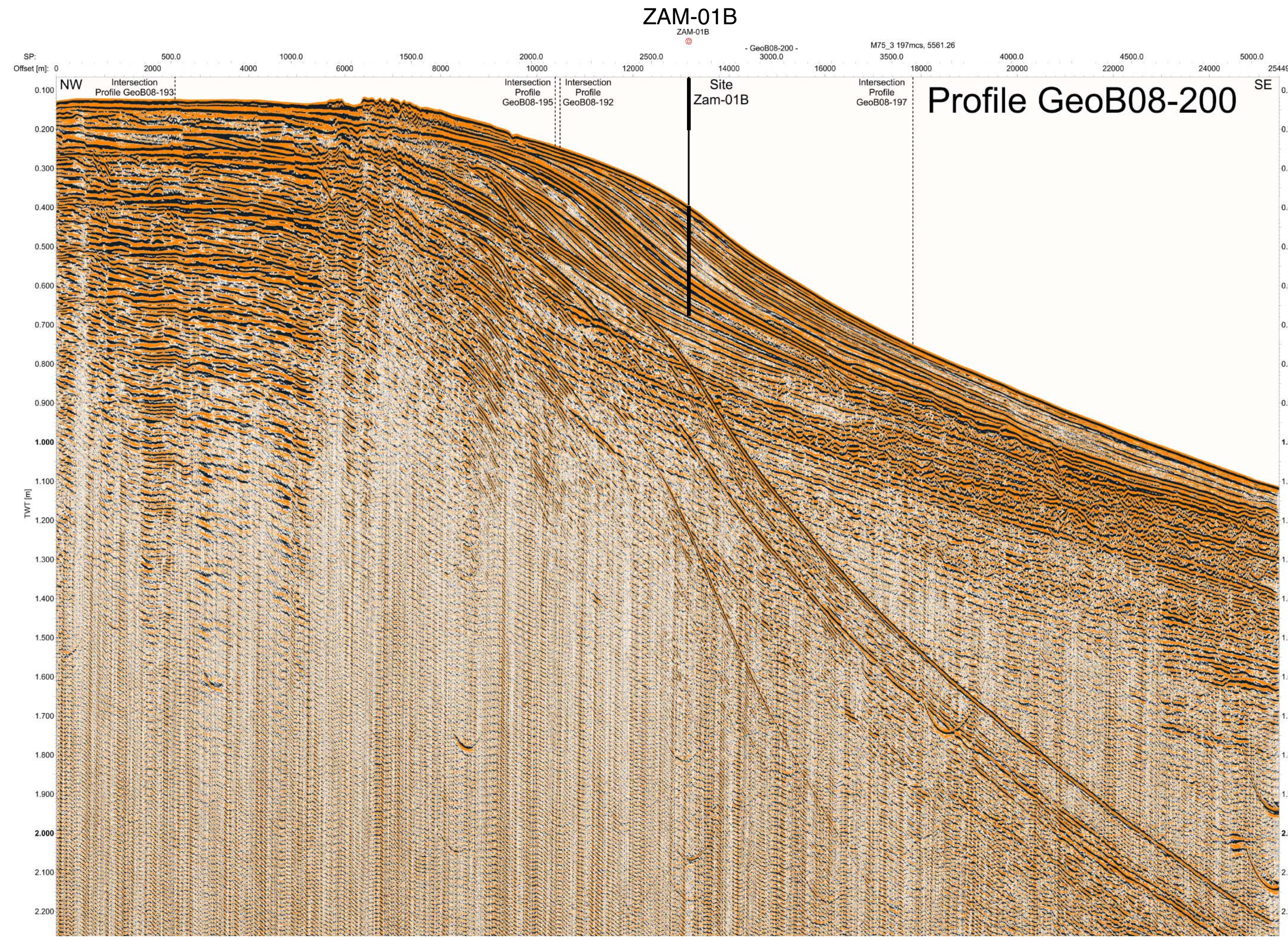
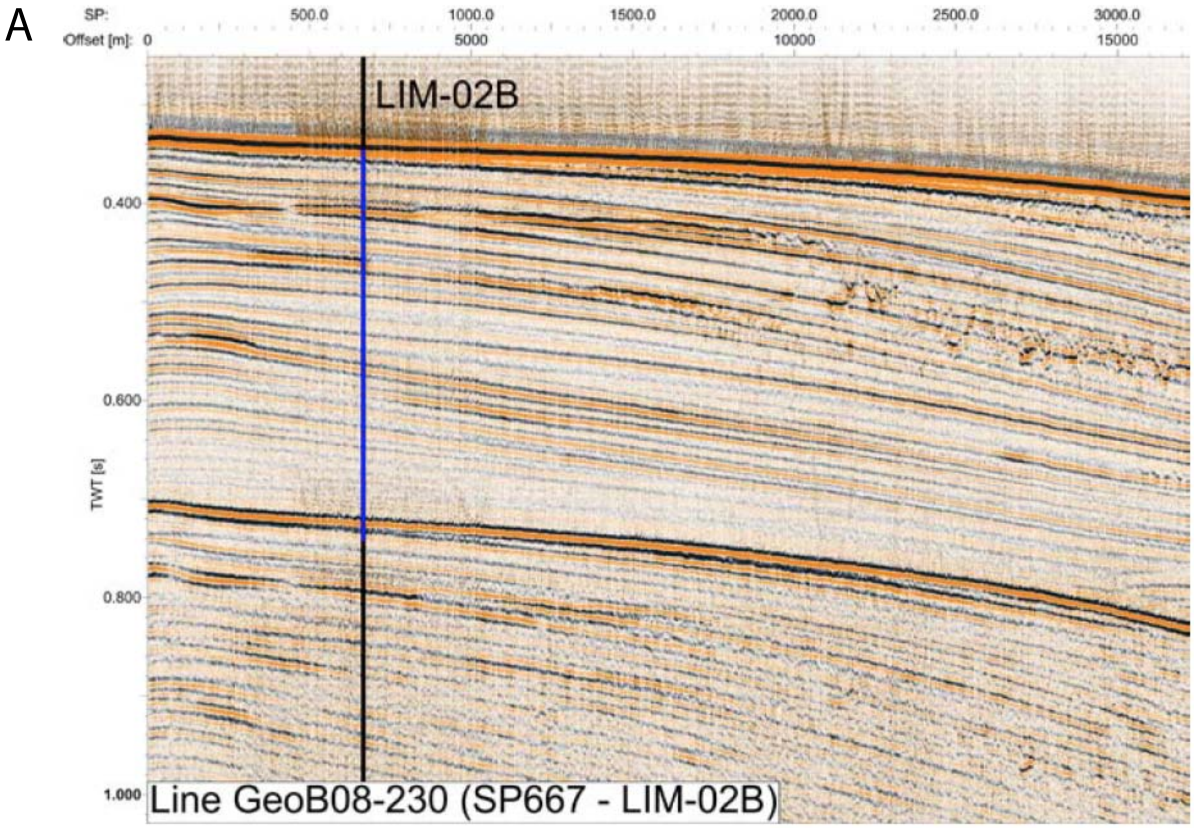


Figure AF24. Seismic crossing Lines (A) GeoB08-230 and (B) GeoB05-014 with location of Site LIM-02B and depth of penetration in blue.



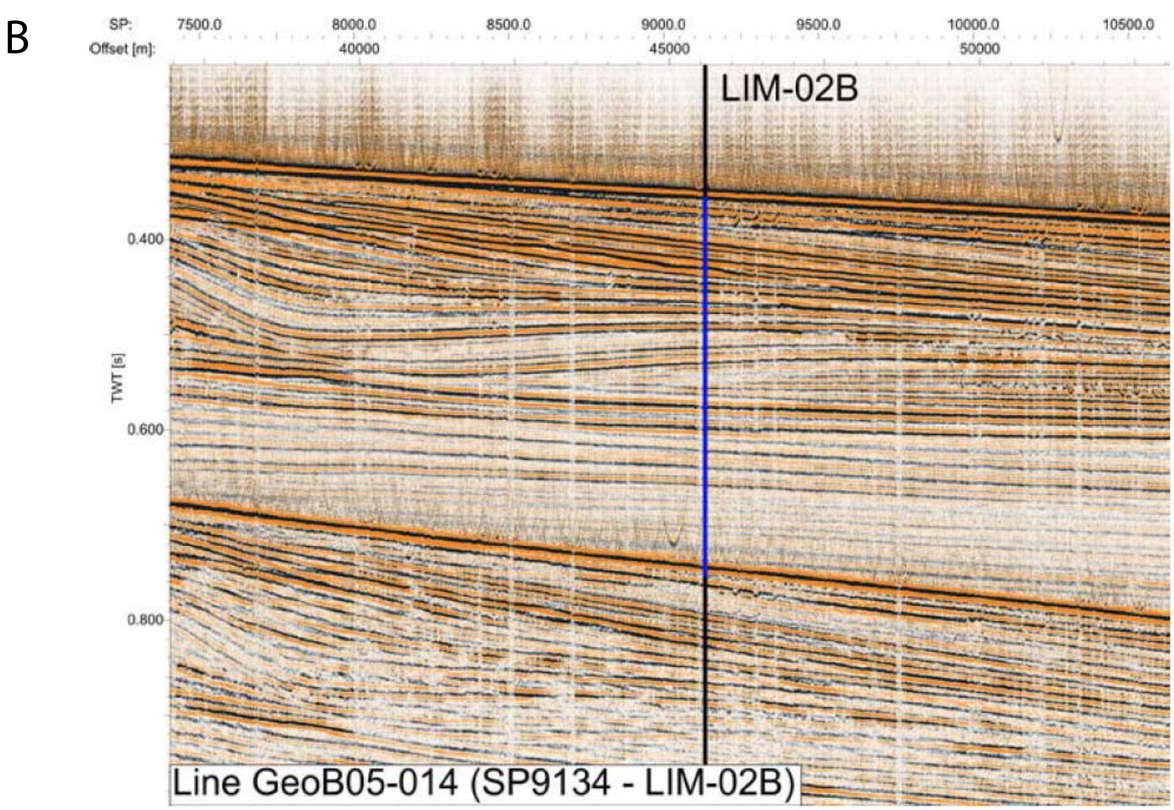


Figure AF25. Seismic Line GeoB08-236 displaying location of Site CAPE-03B.

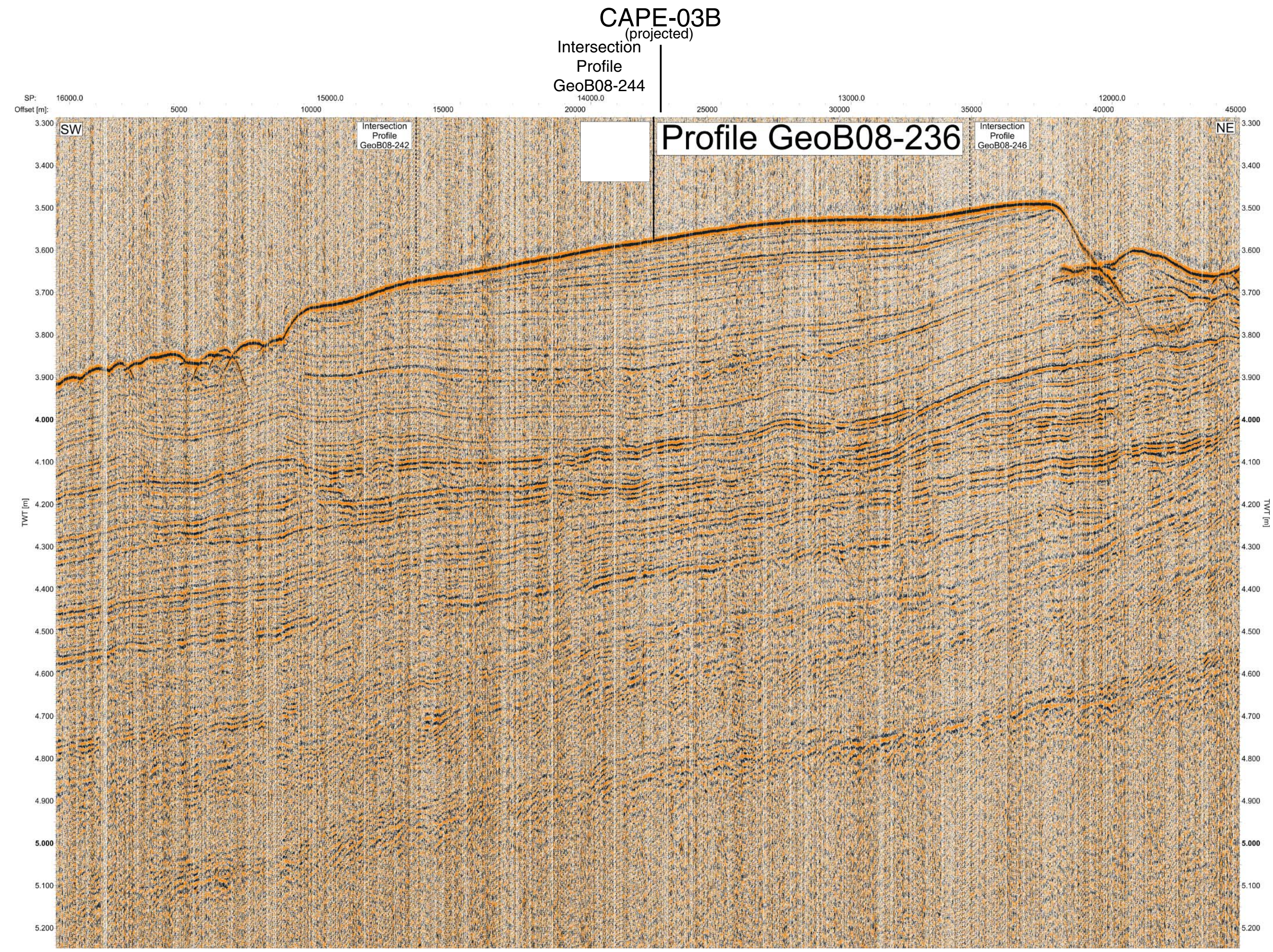


Figure AF26. Crossing Line GeoB08-244 displaying location of Site CAPE-03B and depth of penetration.

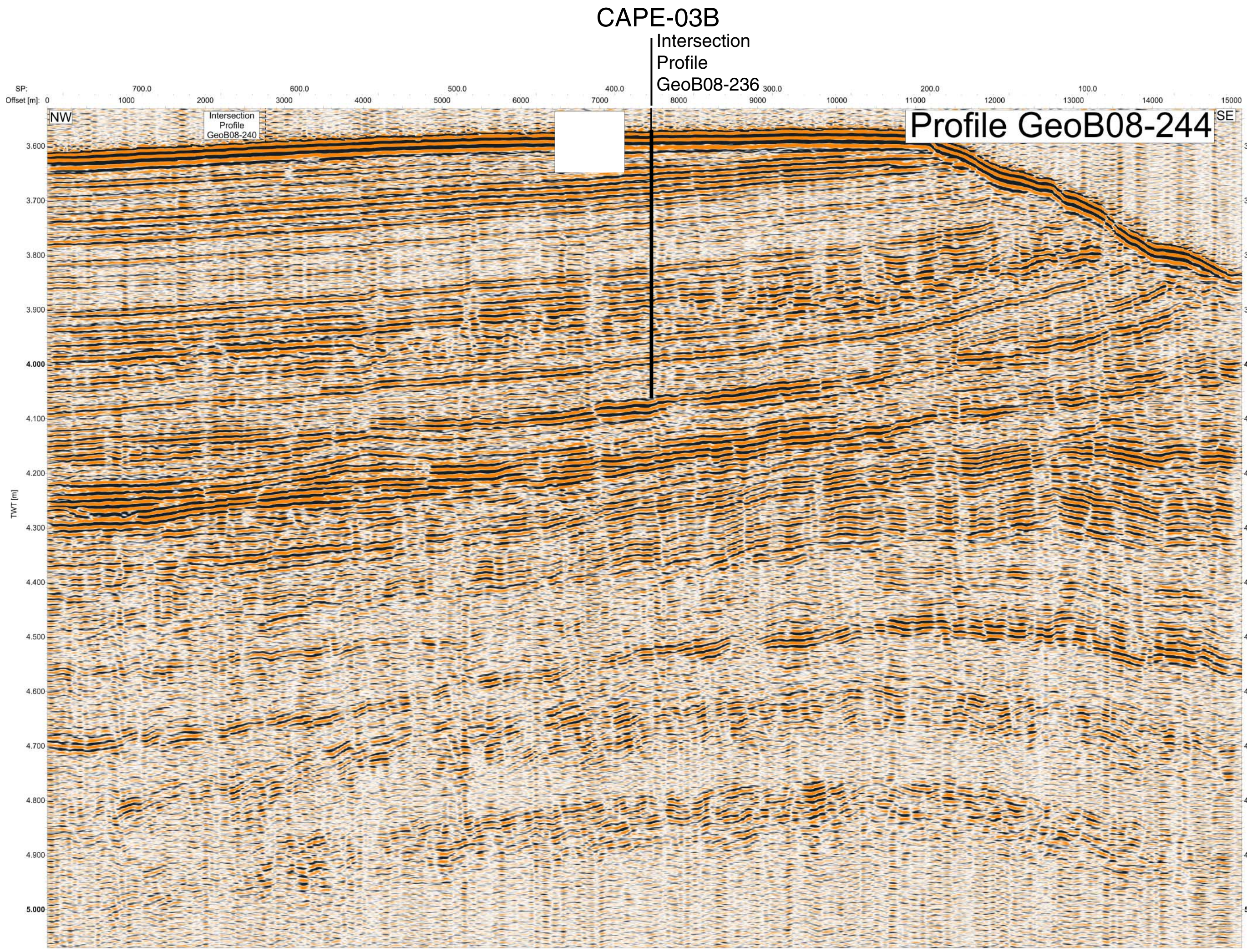


Figure AF27. Crossing Line GeoB08-244 displaying location of Site CAPE-03B.

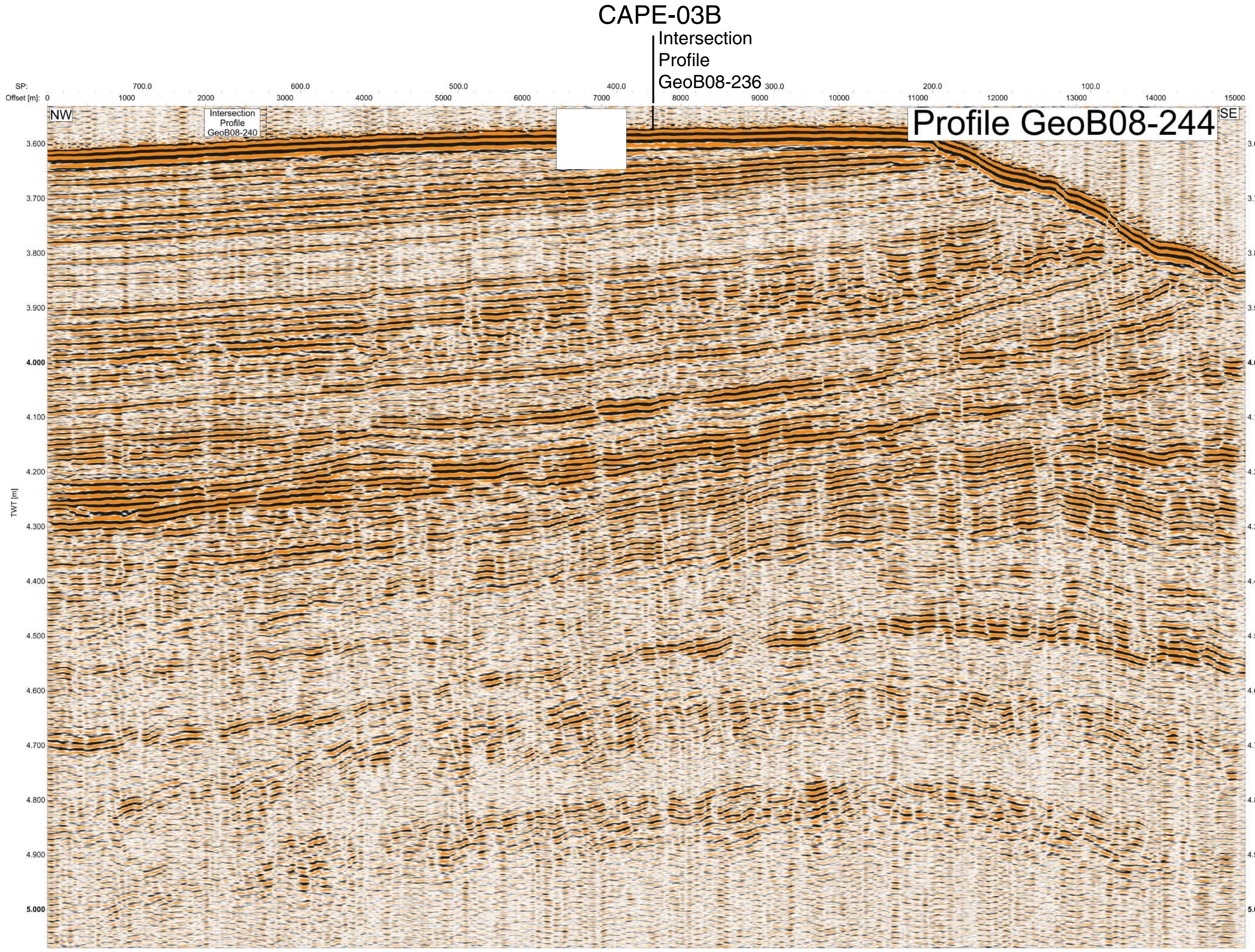


Figure AF28. Seismic Line GeoB08-236 displaying location of Site CAPE-03B and depth of penetration.

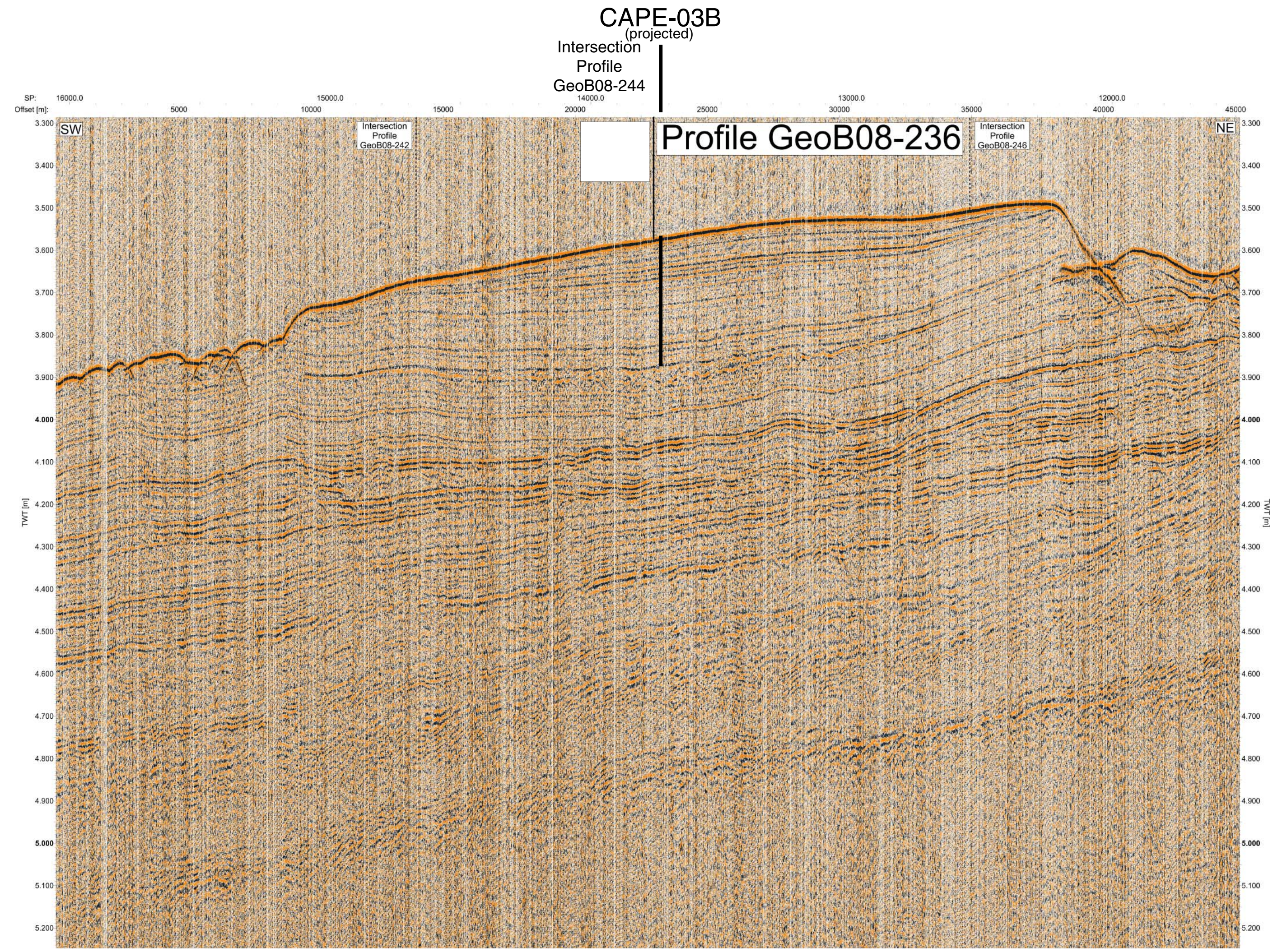


Figure AF29. Seismic Line GeoB08-242 displaying location of Sites CAPE-02A and CAPE-02B.

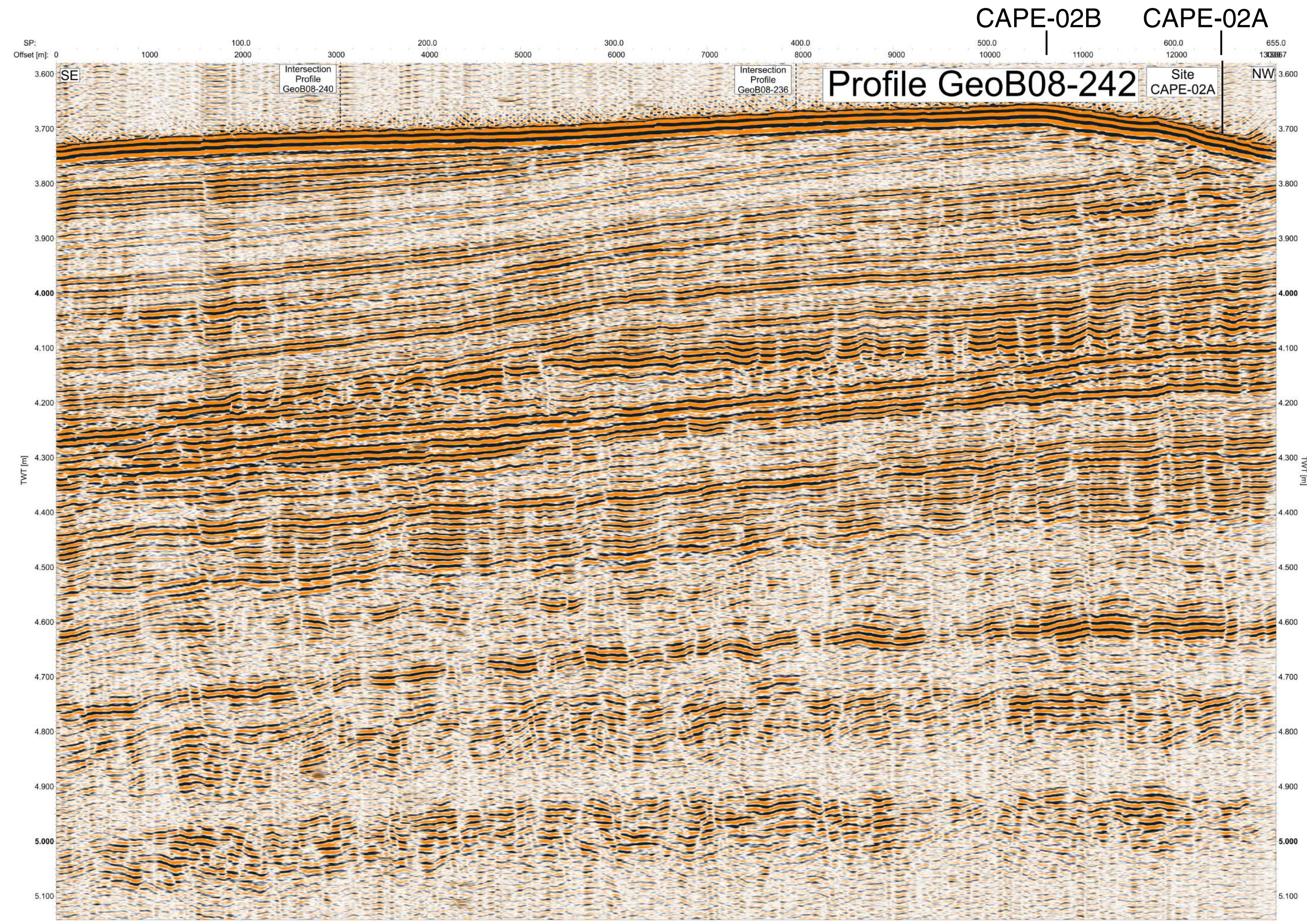
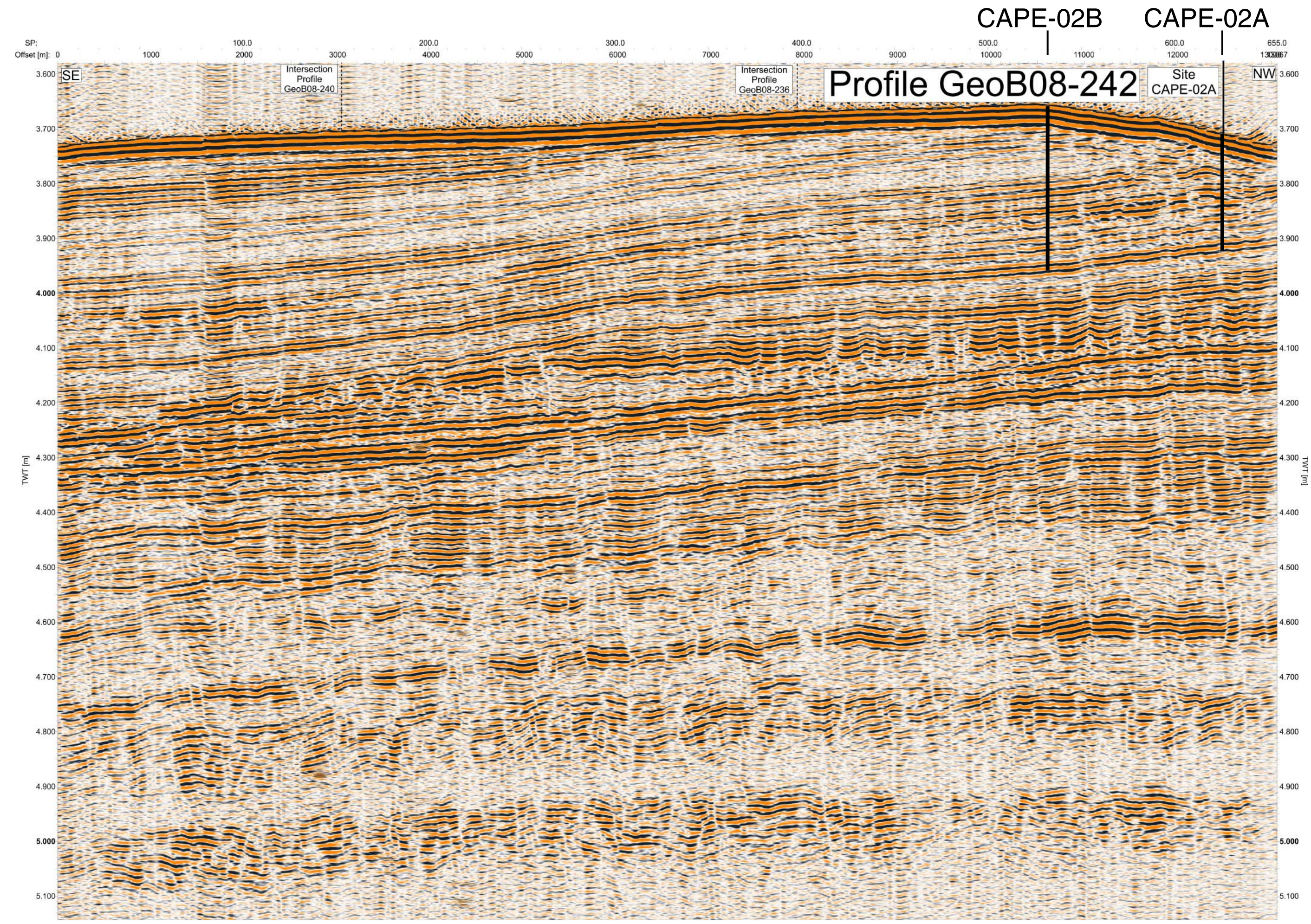


Figure AF30. Seismic Line GeoB08-242 displaying location of Sites CAPE-02A and CAPE-02B and depth of penetration.



Expedition scientists and scientific participants

The current list of participants for Expedition 361 can be found at **http://iodp.tamu.edu/scienceops/expeditions/southern_african_climates.html**