OCEAN DRILLING PROGRAM

LEG 207 SCIENTIFIC PROSPECTUS

DEMERARA RISE: EQUATORIAL CRETACEOUS AND PALEOGENE PALEOCEANOGRAPHIC TRANSECT, WESTERN ATLANTIC

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PUBLISHER'S NOTES

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This Scientific Prospectus is based on precruise JOIDES panel discussions and scientific input from the designated Co-chief Scientists on behalf of the drilling proponents. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-chief Scientists and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon the approval of the Director of the Ocean Drilling Program in consultation with the Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

ABSTRACT

The best examples in the geologic record of rapid (1-k.y. to 1-m.y. timescale) wholesale extinctions linked to massive perturbations of the global carbon cycle and extreme changes in the Earth's climate come from the Cretaceous and Paleogene periods (e.g., oceanic anoxic events [OAEs] and the Late Paleocene Thermal Maximum [LPTM]). Little is known about the underlying causes and effects of these critical events in Earth history, in large part because of the lack of modern high-resolution paleoceanographic records from this time interval, particularly from tropical regions that are so important in driving global ocean-atmospheric circulation. Ocean Drilling Program Leg 207 drilling on Demerara Rise is designed to fill these gaps in our understanding by recovering continuous samples from expanded sections at shallow burial depths of Cretaceous- and Paleogene-age deep-sea sediments that contain records of these extreme events.

During Leg 207, we plan to drill a series of sites representing a mid-Cretaceous and Paleogene paleoceanographic transect on Demerara Rise (Surinam margin, western Atlantic). The Demerara Rise is ideal for this purpose because the target sediments (1) crop out on the seafloor, (2) exist with good stratigraphic control in expanded unlithified sections, (3) contain spectacularly well-preserved microfossils, and (4) were deposited within the core of the tropics in a proximal location to the equatorial Atlantic gateway. The four primary drill sites are located in a depth transect that falls in present water depths of 1895–3215 m. The sites have been imaged with a grid of high-resolution multichannel seismic reflection lines supplemented by existing industry lines with stratigraphic control from Deep Sea Drilling Project (DSDP) Site 144, industry well Demerara A2-1, and gravity cores of Paleogene sediments from *Meteor* cruise 49/4.

DSDP Site 144 was spot cored toward the escarpment in a highly condensed section and recovered sequences of dark clays and shales correlative to at least three Cretaceous OAEs plus a further 150-m-thick sequence of upper Paleocene to lower Oligocene carbonate ooze. These sections thicken inboard, and records of at least five OAEs (OAE-1b, -1c, -1d, -2, and -3) can probably be penetrated by transect drilling on the Demerara Rise with good potential for recover of the LPTM and Eocene/Oligocene boundary. The drilling strategy for Leg 207 will be to recover continuous sections by multiple coring at each site and logging to maximize the potential for high-resolution investigations. The proposed transect of Cretaceous and Paleogene cores will be used to evaluate, at high resolution, the following:

1. The history of multiple Cretaeous OAEs in an equatorial setting and thereby test competing hypotheses for their causes and climatological effects (particularly in relation to rapid emission and draw-down of greenhouse gases);
2. The detailed response of oceanic biotic communities across a range of paleowater depths to extreme perturbations in the geochemical carbon cycle and global climate;
3. Short- and long-term changes in greenhouse forcing and tropical sea-surface temperature response;
4. Key Paleogene events of biotic turnover and/or inferred climate extremes, particularly the LPTM and the Eocene/Oligocene boundary; and
5. The role of the equatorial Atlantic gateway opening in controlling paleoceanographic circulation patterns, OAEs, and cross-equatorial ocean heat transport into the North Atlantic.

OVERVIEW OF SCIENTIFIC OBJECTIVES

The best examples in the geologic record of rapid (1-k.y. to 1-m.y. timescale) wholesale extinctions linked to massive perturbations of the global carbon cycle and extreme changes in Earth's climate come from the Cretaceous and Paleogene Periods (e.g., oceanic anoxic events [OAEs] and the Late Paleocene Thermal Maximum [LPTM]). Little is known about the underlying causes and effects of these critical events in Earth history, however. To a significant extent, these gaps in our understanding arise because of a lack of modern high-resolution paleoceanographic records from ocean drill sites, particularly from the tropics, that are so important in driving global ocean-atmospheric circulation. Deep ocean drilling can access expanded sections of Cretaceous- and Paleogene-age deep-sea sediments on the Demerara Rise (Fig. F1), fulfilling priorities of the Ocean Drilling Program (ODP) Extreme Climates Program Planning Group and Long Range Plan. The Demerara Rise represents an ideal drilling target for this purpose because the target sediments (1) crop out on the seafloor, (2) exist with good stratigraphic control in expanded unlithified sections, (3) contain spectacularly well-preserved microfossils, and (4) were deposited within the core of the tropics in a proximal location to the equatorial Atlantic gateway.

Four primary drill sites (with six alternate sites) have been selected on the northern margin of Demerara Rise (Figs. F1, F2, F3). The sites are located in a depth transect (present water depths of 1895–3215 m) along a grid of high-resolution multichannel seismic reflection lines supplemented by existing industry lines (Fig. F2), with stratigraphic control from Deep Sea Drilling Project (DSDP) Site 144, industry well Demerara A2-1, and gravity cores of Paleogene sediments from *Meteor* cruise 49/4.

DSDP Site 144 was spot cored toward the escarpment in a highly condensed section. Yet even here, Demerara Rise preserves a highly expanded (~150 m thick) sequence of dark clays and shales correlative to at least three Cretaceous OAEs plus a further 150-m-thick sequence of upper Paleocene to lower Oligocene carbonate ooze. These sections thicken inboard, and records of at least five OAEs (OAE-1b, -1c, -1d, -2, and -3) can probably be penetrated by transect drilling on the Demerara Rise with good potential for the LPTM and Eocene/Oligocene boundary. The proposed transect of Cretaceous and Paleogene cores will be used to evaluate, at high resolution, the following:

1. The history of multiple Cretaeous OAEs in an equatorial setting and thereby test competing hypotheses for their causes and climatological effects (particularly in relation to rapid emission and draw-down of greenhouse gases);
2. The detailed response of oceanic biotic communities across a range of paleowater depths to extreme perturbations in the geochemical carbon cycle and global climate;
3. Short- and long-term changes in greenhouse forcing and tropical sea-surface temperature response;
4. Key Paleogene events of biotic turnover and/or inferred climate extremes, particularly the LPTM and the Eocene/Oligocene boundary; and
5. The role of equatorial Atlantic gateway opening in controlling paleoceanographic circulation patterns, OAEs, and cross-equatorial ocean heat transport into the North Atlantic.

GEOLOGIC HISTORY OF DEMERARA RISE

The Demerara Rise is a prominent submarine plateau located at ~5°N off the coasts of Surinam and French Guyana (Figs. F1, F3). The rise stretches ~380 km along the coast and is ~220 km wide from the shelf break to the northeastern escarpment, where water depths increase rapidly from 1000 to >4500 m. The plateau lies in shallow water (~700 m), but the northwestern margin is a gentle ramp that reaches depths of 3000 to 4000 m. Much of the plateau is covered by 2 to 3 km of sediment. This sedimentary cover thins near the northeastern escarpment and exposes the lower stratigraphy of the sediment column and underlying basement at water depths of 3000 m to >4500 m. In contrast, the gentle ramp on the northwest margin is covered by a nearly uniform drape of pelagic sediment down to water depths >4000 m.

The Demerara Rise is built on rifted continental crust of Paleozoic and early Mesozoic age. Tectonic reconstructions of the equatorial Atlantic place the Demerara Rise just south of Dakar, Senegal, prior to rifting of Africa from South America (Fig. F4). The South American margin in the vicinity of the Demerara Rise was one of the last areas in contact with West Africa during opening of the equatorial Atlantic (Fig. F4). Barremian basaltic volcanics have been recovered in industry wells from the Demerara Rise, suggesting that rifting began in the early Cretaceous. A piston core taken by Koninklijke/Shell penetrated Barremian–Aptian shales 2 meters below seafloor (mbsf) on the northeast escarpment, and Jurassic sandstone was dredged in the same area (Fox et al., 1972).

The first known marine sediments on the Demerara Rise are Neocomian in age, and the northern edge of the plateau is thought to have subsided rapidly and reached water depths of nearly 2 km by late Cenomanian time (Arthur and Natland, 1979). Upper Albian sediments are mostly green claystones with interbedded black shales. The Cenomanian to Santonian sequence consists almost exclusively of laminated black shale with occasional stringers of limestone. The black shale is a principal source rock for oil production in coastal French Guyana and Surinam and has total organic carbon contents of up to 6–8 wt% in industry wells near the middle of the plateau. Apparently, upwelling conditions persisted over the Demerara Rise well into the Late Cretaceous. Campanian to Paleogene sediments are calcareous oozes and chalks. Sediment drifts formed along the top of the northeastern escarpment in the Eocene and Oligocene, but all of the Cenozoic cover thins or pinches out at the escarpment, exposing Cretaceous deposits. Pronounced thickening of all of these units inboard indicates that a relatively complete Paleogene sequence is preserved on Demerara Rise. A prominent submarine channel system developed in the early Miocene. The channeled surface is unique in the seismic stratigraphy of the Demerara Rise (Fig. F5) and can be traced over the northwestern surface of the plateau. The channels carried sediment east to west over the flank of the plateau and into feeder channels for a submarine fan that formed northwest of the Demerara Rise. The channel system was short-lived, and most of the Neogene sediments (hemipelagic and pelagic deposits) are thin or absent from the distal portions of the plateau.

DSDP Site 144 was drilled in 1970 during Leg 14 on the outermost edge of Demerara Rise (water depth = 2957 meters below sea level [mbsl]; maximum depth of penetration = 327 mbsf). Results from this site confirm the complete absence of Neogene sediments on the Demerara Rise escarpment. Instead, Oligocene foraminiferal nannofossil oozes crop out at the seafloor and are underlain by a shallowly buried succession of mid-Cretaceous through Eocene sediments (Fig. F5). Basal sediments are of late Aptian age, and these are overlain by Albian through Maastrichtian strata (Fig. F5). The Cretaceous sequence is unconformably overlain by lower Paleocene through middle Eocene sediments, and these are, in turn, unconformably overlain by lower Oligocene sediments (Fig. F5). No chert is present anywhere in the section.

In the three decades that have elapsed since DSDP Leg 14, the paleoceanographic significance of the sedimentary record at Site 144 has not gone unnoticed (e.g., Berger and von Rad, 1974; Barron, 1983; Arthur et al., 1990; Thurow et al., 1992). The Cretaceous sediments at Site 144 are particularly notable in this regard because they consist of an expanded sequence of laminated black shales (now thought to be correlative to OAEs-1b, -2, and -3) and homogenous olive-green pelagic oozes to carbonaceous claystones that are similar to Aptian and Albian lithologies from Blake Nose (ODP Leg 171B) and the Tethyan Umbria Marche Basin (Norris and Wilson, 1998; Erbacher et al., 2001). These dominantly clay-rich Albian through Santonian sediments, like the overlying Upper Cretaceous and Paleogene oozes and marls, yield well-preserved carbonate microfossils when subjected to the same gentle desegregation procedures that are routinely applied to Neogene samples. Examination under binocular microscope shows that the tests of these foraminifers are glassy in appearance and that their chambers are free of calcite infilling. Scanning electron microscopy reveals the preservation of detailed wall and aperture structures (Fig. F6).

It has long been appreciated that ancient calcareous fossils from shallowly buried clay-rich lithologies can display remarkable primary textural structure. Recent work on Cretaceous foraminifers from Blake Nose (ODP Leg 171B) has shown that such fossils are also remarkably well preserved with respect to their stable isotope geochemistry. This fact significantly increases the potential for developing reliable paleoecological, -oceanographic, and -climatological records for the Cretaceous (Norris and Wilson, 1998; Erbacher et al., 2001; Wilson and Norris, 2001; Huber et al., 2002). Therefore, we have generated new stable isotope data from multiple planktonic species in the upper Cenomanian sediments from Site 144 (Fig. F7). Results indicate that these foraminifers are also geochemically well preserved. Downcore records are noise-free, showing small but consistent interspecies offsets in $\delta^{13}C$ and $\delta^{18}O$ values (~–3.5 to –4.0‰ PDB) that are consistent with predictions for tropical sea-surface temperatures during the so-called mid-Cretaceous greenhouse.

DETAILED SCIENTIFIC OBJECTIVES

Oceanic Anoxic Events

OAEs represent major disruptions to the ocean system defined by massive deposition of organic carbon in marine environments (Schlanger and Jenkyns, 1976; Jenkyns, 1980; Arthur et al., 1990). Despite the fundamental role that OAEs are widely hypothesized to have played in the evolution of Earth's climatic and biotic history, very little is really known about the causes and effects of these events. Arguably, between two and six OAEs occurred during the mid- to Late Cretaceous (OAE-1a through OAE-1d, OAE-2, and OAE-3) (Jenkyns, 1980; Arthur et al., 1990, Erbacher et al., 1997) (Fig. F8), and these are particularly important because they have left records not merely in shallow seas but also in the deep oceans.

Records of $\delta^{13}C$ from the Western Interior, the English Chalk, and Italian Scaglia appear to confirm the initial designation of OAE-3 for the late Coniacian, but current resolution of Atlantic records is insufficient to determine the existence of additional events in the late Turonian through Santonian (Jenkyns, 1980; Jenkyns et al., 1994). Similarly, until recently, comparatively little was known about the Albian OAEs (OAE-1b through OAE-1d), but two new studies demonstrate the potential to improve constraints on the origin of different OAEs when diagenetically uncompromised microfossils become available from modern ocean drilling. Data from ODP Site 1049 suggest that pronounced water column stratification instigated OAE-1b (Erbacher et al., 2001), whereas records from nearby Site 1052 indicate that OAE-1d was triggered by the total collapse of upper ocean stratification, intense vertical mixing, and high oceanic productivity (Wilson and Norris, 2001). These antipodal hypotheses for the proximal causes of two OAEs within the same stage emphasize the utility of targeting sections that we know to contain records of multiple OAEs.

The two most prominent mid- to Upper Cretaceous black shale events are the late early Aptian Selli Event (OAE-1a; ~120 Ma) and the Cenomanian/Turonian boundary, Bonarelli Event (OAE-2; ~93.5 Ma) (Fig. F6). Both OAE-1a and OAE-2 have sedimentary records in all ocean basins (Arthur et al., 1985, 1988, 1990; Bralower et al., 1994; Thurow et al., 1992), and the Aptian event is now known to have been truly cosmopolitan; its sedimentary expression extended even to the extremely shallow waters of mid-Pacific atolls (Jenkyns and Wilson, 1999). These findings and recent improvements to $\delta^{13}C$ records from classic European sections (both in outcrop and drill core) and the mid-Cretaceous seawater $^{87}Sr/^{86}Sr$ curve reveal three important factors concerning the possible origins of OAEs (Bralower et al., 1997; Menegatti et al., 1998; Erba et al., 1999):

1. The response of the oceanic reservoir to increased sedimentary burial of organic carbon (as determined by the inferred increase in seawater $\delta^{13}C$) lags significantly behind black shale deposition during the Selli Event.
2. The onset of black shale deposition is associated with an extreme, short-lived negative $\delta^{13}C$ excursion and carbonate dissolution spike that have been attributed to rapid greenhouse gas release (possibly methane as is hypothesized for the LPTM).
3. The foregoing events are associated with the onset of a pronounced decline in global seawater $^{87}Sr/^{86}Sr$ to its least radiogenic value in the past 125 m.y. (a second post-Jurassic minimum occurs around the time of OAE-2), suggesting a link between OAEs and oceanic plateau emplacement (Jones et al., 1994; Sinton and Duncan, 1997; Kerr, 1998) (Fig. F8).

The global occurrence of laminated sediments and a variety of geochemical records demonstrate that the response of the carbon cycle during OAE-2 was somehow related to dysoxic to euxinic conditions at the sediment/water interface (e.g., Sinninghe et al., 1998). However, the cause and dimensions of O_2-deficiency remain unclear and controversial. The substantial positive $\delta^{13}C$ excursion of seawater at the time of OAE-2 (Scholle and Arthur, 1980; Schlanger et al., 1987; Jenkyns et al., 1994) has also been attributed to increased global oceanic productivity and increased rates of C_{org} burial. This process of sedimentary sequestration of C_{org} is hypothesized to act as a rapid negative feedback mechanism for global warming via drawdown of atmospheric carbon dioxide (Arthur et al., 1988; Kuypers et al., 1990).

The condensed section at DSDP 144 contains black carbonaceous claystones and shales correlative to at least three Cretaceous OAEs. Records of at least five OAEs (OAE-1b, -1c, -1d, -2, and -3) probably can be penetrated by transect drilling on the Demerara Rise. The following scientific questions will be addressed by drilling this transect:

1. What is the history of OAEs in the tropical Atlantic as recorded on Demerara Rise? For example, was OAE-3 restricted to the upper Coniacian or composed of multiple subevents analogous to OAE-1?
2. What was the duration and vertical extent of specific OAEs in the tropical Atlantic? Results from Demerara Rise could be used in conjunction with high-resolution records for OAE-2 from the shallow-water Tarfaya Basin (Kuhnt et al., 2001) to test (a) the predictions of the oxygen minimum zone model and (b) what role, if any, is played by equatorial divergence in OAE-forcing.
3. How does the type of C_{org} differ (a) between different OAE intervals and (b) between these and non-OAE intervals? The proposed transect would provide an opportunity to examine the constraints that can be applied using modern geomicrobiological techniques.
4. What were the proximal and underlying causes of Cretaceous OAEs? In particular, it is important to determine whether carbon-cycle perturbations are the instigators or merely the consequence of OAEs. The location of Demerara Rise would also allow the competing roles of gateway opening, plateau emplacement, and the hydrological cycle to be evaluated.
5. Are hypothesized increases in productivity during Cretaceous OAEs real? Current models of OAEs rely heavily on bulk carbonate $\delta^{13}C$ records from epicontinental sea-land sections where preservation of microfossils is generally poor. Well-preserved microfossils from Demerara Rise would provide a way to test these records and their conventional interpretations by allowing the production of new types of data sets (e.g., $\Delta\delta^{13}C$).

6. What mechanism(s) are responsible for the lead and lag effects observed in existing records between the onset of C_{org} burial and the geochemical response (increase in seawater $\delta^{13}C$)? The Demerara Rise transect could address the following two competing hypotheses: (a) globally significant C_{org} burial began earlier elsewhere (e.g., core of the tropics) than has hitherto been appreciated and (b) some unknown factor acted to buffer seawater $\delta^{13}C$ values during C_{org} burial.
7. What evidence (e.g., negative $\delta^{13}C$ excursions and depth-transect records of changes in the carbonate compensation depth [CCD]) exists to support the hypothesis that OAEs were driven by the sudden release of greenhouse gases (e.g., CH_4, as hypothesized for the LPTM)?
8. Currently, a wide range of hypotheses invoke changes in ocean circulation and/or stratification to explain OAEs, but virtually no reliable geochemical data exist to constrain changes in the basic physical properties (temperature and salinity) of the water masses involved. These competing hypotheses could be tested via $\delta^{18}O$ and trace element records using well-preserved microfossils from Demerara Rise.

Biotic Turnover

The tropics are widely viewed as an environment in which physiochemical factors and thus biotic compositions are inherently stable. Yet many low-latitude species have low environmental tolerances, thereby suggesting that relatively small climate changes may result in a substantial biological response (Stanley 1984). The so-called Cretaceous and Paleogene greenhouse was characterized by a series of significant marine and terrestrial biotic turnovers. Most of these events seem to be linked to major changes in Earth's climate (Eocene–Oligocene transition and LPTM), paleoceanography, and/or the geochemical carbon cycle (Cretaceous OAEs and mid-Maastrichtian Event). Many of these events also produced synchronous turnovers in both terrestrial and marine biotas. The causes of most of these turnovers are poorly known because of the absence of expanded sections in the deep sea, where paleontological and isotopic studies can be carried out at high temporal resolution.

The biotic turnovers of the mid-Cretaceous OAEs (OAE-1b, -1d, and -2) are broadly comparable to one another even if the detailed causal factors are thought to have been different (Leckie, 1987; Erbacher and Thurow, 1997; Premoli Silva et al., 1999). A faunal crisis in nannoconids is well documented in the Aptian (Erba, 1994). Similarly, the early Albian OAE-1b strongly influenced the evolution of both planktonic foraminifers and radiolarians, as did the other OAEs. Some events not only influenced planktonic groups but also benthic foraminifers, ammonites, bivalves, and even angiosperms, and OAE-2 ranks as one of the eighth largest mass extinctions in Phanerozoic Earth history (Sepkoski, 1986). Extension of the oxygen minimum zone and a rapid eutrophication of the oceans has been linked to extinction and a subsequent radiation of plankton and benthos alike (e.g., Hart, 1980; Caron and Homewood, 1983; Kaiho et al., 1994; Erbacher et al., 1996; Leckie, 1989). $\delta^{13}C$ excursions around three events (OAE-1b, -1d, and -2) are interpreted in terms of increases in oceanic productivity, and this mechanism has been invoked to explain wide-scale carbonate platform drowning events in the Tethyan realm (Erbacher and Thurow, 1997; Weissert et al., 1998). In contrast, results from the Pacific suggest that high tropical sea-surface temperatures rather than eutrofication were responsible for platform drowning (Wilson et al., 1998; Jenkyns and Wilson, 1999). Cretaceous OAEs and extreme climates of the Paleogene (Cretaceous/Tertiary [K/T] boundary, LPTM, and middle to late Eocene refrigeration) led to profound changes in plankton and benthos in the oceans (Thomas, 1998; Aubry, 1998). The following questions will be addressed using well-preserved Demerara Rise microfauna:

1. Are leads and lags discernible (on the scale of ~10 k.y. or more) in the pattern of turnover between different groups of plankton and benthos that could elucidate the nature of gradual shifts in climate around a turnover pulse?
2. Are some species present only during transient climate shifts, and if so, how does their ecology (judged from faunal and isotopic data) compare with closely related species before and after the climatic anomaly? Answers could address (a) the rate of evolutionary response to climatic transients, (b) the magnitude or type of events needed to prompt evolutionary response, and (c) the extent to which species can accommodate environmental change by shifts in ecology rather than evolution (or extinction).
3. Are biotic changes permanent, or are major evolutionary changes offset from the transient climate shift? For example, the K/T extinction was abrupt, but the subsequent pattern of rediversification occurred over several million years. The long recovery appears to reflect structural changes in ecosystems wrought by the mass extinction (e.g., D'Hondt et al., 1998).
4. Are particular taxonomic groups more susceptible to extinction or radiation during turnovers?
5. Do different events (such as the various OAEs) generate predictable patterns of turnover within and between taxonomic groups? For example, thermocline dwelling species and those with complex life histories are believed to be particularly susceptible to extinction (and subsequent radiation) during OAEs (e.g., Hart, 1980; Caron and Homewood, 1983; Leckie, 1987), but these hypotheses have not been tested in detail with stable isotopic data.

Tropical Sea-Surface Temperatures and Greenhouse Forcing

A wide range of biotic observations suggest that substantially higher mid-latitude and polar temperatures relative to today prevailed during certain intervals of Earth history (e.g., mid-Cretaceous and early Paleogene), with tropical temperatures throughout the past ~150 m.y. probably at least as warm as today (Adams et al., 1990; Crowley and North, 1991). $\delta^{18}O$ paleothermometry in deep-sea foraminiferal calcite supports the existence of these past warm climates (Fig. F9). These data show that deep and surface waters in the Cretaceous Antarctic during these intervals were significantly warmer than today (e.g., ~15°C for sea-surface temperatures [SSTs]) (Huber et al., 1995). In contrast, broadly contemporaneous SSTs estimated in this way for the tropics are generally no warmer and sometimes much cooler (mininum of ~12° to 18°C) than today (Shackleton, 1984; Barrera, 1994; D'Hondt and Arthur, 1996). Such cool tropical SSTs contradict not only biotic observations but also basic theories of tropical ocean-atmosphere dynamics (Crowley, 1991). Attempts to simulate Cretaceous climates using numerical general circulation models (GCMs) have consistently demonstrated that (1) high levels of atmospheric CO_2 (four times present) are needed to explain the warm polar SSTs derived from $\delta^{18}O$ paleothermometry, and (2) this level of greenhouse forcing also yields increases in tropical SSTs beyond those indicated by $\delta^{18}O$ data sets (e.g., Manabe and Bryan, 1985; Barron, 1995; Bush and Philander, 1997; Poulsen et al., 1999). Explanations for the apparent paradox of the cool-tropical greenhouse fall into two basic categories: (1) models of past warm climates fail to account adequately for polar ocean and/or atmospheric heat transport, and (2) tropical $\delta^{18}O$ SST estimates are misleading (Zachos et al., 1994; Crowley and Zachos, 2000).

Many artifacts plague existing records of tropical SST, including their extremely low resolution, misidentification of true surface-dwelling species of foraminifers, and the susceptibility of epipelagically secreted calcite to early diagenetic alteration in favor of artificially low SSTs (Douglas and Savin, 1975; Killingley, 1983; Schrag et al., 1995). Recent studies demonstrate that ancient carbonates (even highly metastable minerals) can be remarkably well preserved and yield $\delta^{18}O$ SSTs for the tropics that are significantly warmer than those provided by diagenetically suspect material (Pearson and Shackleton, 1995; Wilson and Opdyke, 1996; Norris and Wilson, 1998). These studies show that foraminifers recovered from sections with shallow burial depths and/or clay-rich lithologies display excellent textural preservation and include epipelagic fauna yielding tropical $\delta^{18}O$ SSTs that match or, in some cases, exceed those measured today, thereby suggesting a thermal response to greenhouse forcing in the tropics.

The concept of a greenhouse mid- to Late Cretaceous period is well supported by models of Earth's tectonic history. These models indicate that the mid- to Late Cretaceous was a time of exceptional rates of seafloor spreading and intraplate volcanism. This pulse in global oceanic crustal production is hypothesized to have caused increases in the levels of atmospheric carbon dioxide and global sea levels via increases in global oceanic ridge volumes, magmatic outgassing, and metamorphic decarbonation reactions (Schlanger et al., 1981; Larson, 1991; Berner, 1994). Fundamental problems, however, remain in terms of our understanding of these Cretaceous environments and their Paleogene equivalents. For example, the timing of maximum rates of crustal cycling and inferred carbon dioxide levels significantly pre-dates Cretaceous climatic optima as perceived from existing paleothermometric records (e.g., Larson, 1991; Clarke and Jenkyns, 1999). This discrepancy suggests that additional factors to the geochemical carbon cycle may play an important role in determining Cretaceous climate (e.g., the hydrologic cycle). Furthermore, new high-resolution bulk carbonate $\delta^{18}O$ records from classic land sections in Italy reveal large positive excursions that have been interpreted in terms of short glaciations superimposed on the middle of the Cretaceous greenhouse (Stoll and Schrag, 2000). Sedimentological and biotic records show no support for this hypothesis, but these records are of insufficient temporal resolution to provide a categorical test. Similarly, our highest-resolution long-term $\delta^{18}O$ record from deep-sea sites for the Cretaceous comes from diagenetically altered bulk carbonate and has a temporal resolution of ~1 sample/200 k.y. (Clarke and Jenkyns, 1999). The best existing corresponding record from separates of planktonic foraminiferal calcite is also diagenetically suspect (it comes from chertified deeply buried chalks in the Pacific) and is of very low resolution (<1 sample/m.y.; Aptian through Santonian) (Barrera, 1994).

Results from DSDP Site 144 indicate that Demerara Rise sediments contain well-preserved microfossils of mid-Cretaceous to Oligocene age. The following scientific questions will be addressed using well-preserved microfossils from the Demerara Rise transect:

1. What is the history of changes in atmospheric CO_2 levels from mid-Cretaceous to Paleogene time? Well-preserved microfossils from Demerara Rise would provide an ideal means to evaluate this question using exciting new proxies (e.g., Pearson and Palmer 1999).
2. What is the history of tropical SSTs in the tropical Atlantic? The presence of Demerara Rise within the core of the tropics throughout the entire Cretaceous and Paleogene provides a way to evaluate the relative strength of greenhouse forcing over long time periods. It is important to establish whether the persistent problem of tropical overheating in simulations of past warm climates is an artifact of poor SST records or the result of the existence of some tropical thermostatic regulator.
3. What evidence is there for rapid ocean warming associated with extreme perturbations in the geochemical carbon cycle (e.g., Cretaceous OAEs and LPTM)? High-resolution records from Demerara Rise across these events would also provide a way to test the hypothesis that C_{org} burial during OAEs acted as a negative feedback for global warming.
4. Are hypothesized mid-Cretaceous glaciations real? Answers to this question have important consequences to (a) the long-standing problem of the mechanism responsible for perceived changes in global sea level prior to the icehouse and (b) our understanding of the stability of greenhouse climates.

Paleogene Events

The Paleogene record is rife with critical boundaries that offer significant opportunities for understanding the dynamics of greenhouse gas release, warm climate stability, biotic turnover associated with climate transitions, and extraterrestrial impacts. For example, the early Eocene warm period (~50–53 Ma) is the most extreme interval of global warming in the past ~80 m.y., but little is known about the number of hyperthermals within it, the range of temperatures, or their effects on biotic evolution (Thomas and Zachos, 1999). The Eocene warm period is succeeded by a long shift toward the lower temperatures and increased ice buildup of the late Eocene and Oligocene (Fig. F9), whose history and consequences for ocean circulation, carbon cycling, and biotic evolution are only vaguely understood. Finally, extraterrestrial impacts in the early middle Eocene and the late Eocene offer the opportunity to study the climatological and biotic effects of impacts that were too small to precipitate global mass extinctions but were large enough to have engendered global changes in climate. Below we discuss two events that have a particularly good likelihood of being preserved on Demerara Rise.

Late Paleocene Thermal Maximum

The transient global warming near the end of the Paleocene is one of the best candidates for greenhouse warming in the geologic record. A growing body of evidence implicates a massive release of greenhouse gases into the atmosphere and ocean as a cause for ~5°–7°C warming in the Southern Ocean and subtropics, a 35%–50% extinction of deep-sea benthic foraminifers, and widespread carbonate dissolution in the deep oceans record (e.g., Zachos et al. 1993; Koch et al. 1995; Dickens et al. 1997). Recent studies utilizing high-resolution stable isotope analyses (Bains et al. 1999) and orbitally tuned chronologies (Norris and Röhl 1999) suggest that carbon release occurred in a series of short steps (lasting a few thousand years) punctuated by catastrophic shifts in $\delta^{13}C$ and ocean temperature. Although these new data support the idea that the carbon may have been sourced from methane hydrate reservoirs, considerable uncertainty remains about how the carbon was released, what triggered the different phases of release, and what the biotic and climatological response to the input of large amounts of greenhouse gas.

It is unknown whether there are complete records of the late Paleocene on Demerara Rise, but there are good indications that a well-preserved LPTM could be recovered. DSDP 144 spot cored through 50 m of late Paleocene calcareous ooze. A nearly 40-m coring gap between the upper Paleocene and middle Eocene oozes allows for up to ~90 m of Paleocene strata at DSDP Site 144. DSDP 144 was drilled where the Paleogene section is greatly condensed near the northern escarpment of Demerara Rise, but a relatively expanded (~300–400 m thick) sequence of Paleocene and Eocene chalk and ooze is present inboard of the escarpment. Furthermore, seismic data suggest that Paleogene sediment drifts exist along the northern escarpment where we propose to drill.

Eocene–Oligocene Transition

The Eocene/Oligocene boundary represents an important point in the transition from the greenhouse world of the Cretaceous and early Paleogene into the late Paleogene–Neogene icehouse. The Eocene–Oligocene transition appears to record a dramatic growth in Antarctic ice sheets, but the rarity of complete sections across the boundary have limited our understanding of the dynamics of this important step in to the modern icehouse world (Miller et al., 1991). This transition is marked by a large rapid increase in the in benthic foraminiferal calcite $\delta^{18}O$ record in earliest Oligocene time (Oi-1) (Fig. F9). This excursion was first ascribed to a 5°C temperature drop associated with the onset of thermohaline circulation, but more recently, Oi-1 has been associated with the onset of continental ice accumulation on Antarctica. This conclusion is in accord with a recent Mg/Ca paleothermometry record developed for benthic foraminifers, which shows no significant change corresponding to Oi-1 (Lear et al., 2000). On this basis it has been hypothesized that a lack of moisture available for snow precipitation on Antarctica rather than excess warmth prevented ice accumulation immediately prior to this time. However, our most complete records of the Eocene/Oligocene boundary come from mid-latitude sites (DSDP 522 and ODP 744). Low-latitude records of the Eocene–Oligocene transition and the Oligocene–Miocene transition are needed to fully evaluate the competing roles played by global cooling and ice growth in the transition from the Cretaceous greenhouse into the Neogene icehouse.

The Demerara Rise is known to have expanded records of the early Oligocene to early Miocene at shallow burial depth. A widespread network of submarine channels on the outer Demerara Rise is of early Miocene age. Oligocene strata were recovered in both DSDP 144 and industry well Demerara A2-1. Dating the channeled surface, which does not cut deeply into underlying strata, is important to understand the transient change in climate and sediment supply that produced the submarine channels. The presence of lower Oligocene ooze in DSDP 144 suggests that a much more expanded record of the Oligocene, and possibly the upper Eocene, may be present in the Paleogene sediment drifts present along the northern escarpment.

Equatorial Atlantic Gateway Opening, Oceanic Circulation, and Heat Transport

The opening of the equatorial Atlantic gateway was driven by the separation of Africa and South America and is widely hypothesized to have had a significant effect on both oceanic circulation patterns and heat transport over wide areas of the Cretaceous Atlantic. Yet, the timing of the opening of this gateway remains poorly constrained. Based on the biogeographic distribution of foraminifers and cephalopods, a shallow-water passage is thought to have been initiated between the North and South Atlantic oceans at some time during the Albian (Moullade and Guerin, 1982; Förster, 1978; Wiedmann and Neugebauer, 1978; Moullade et al., 1993). Results from ODP Leg 159 on the eastern side of the equatorial Atlantic gateway suggest that a strong relationship existed between stepwise deepening and widening of the gateway and black shale deposition on the west African margin from the Albian to the Turonian (Wagner and Pletsch, 1999). Cessation of black shale deposition in the Upper Cretaceous is interpreted to result from increasingly vigorous circulation between the North and South Atlantic, hence marking the transition from a Mesozoic longitudinal circulation system through the Tethyian and the central Atlantic oceans to a more Cenozoic-like oxidizing latitudinal circulation pattern through the Atlantic gateway.

Analysis of the subsidence history of Demerara Rise will contribute to interpretations of the history of the opening of the equatorial Atlantic gateway. High-resolution sampling of distinct time slices across a range of paleowater depths will help to constrain the following questions:

1. What were the timings of the establishment of oceanographically significant through-flow in the equatorial Atlantic gateway (i.e., the onset of through-flow of upper intermediate and deeper water masses)? Results will help to determine the paleoceanographic consequences of connecting the previously restricted South Atlantic to the North Atlantic–Tethyian realm.
2. What was the specific role played by the equatorial Atlantic gateway in controlling the development of Cretaceous black shale deposition? By comparing the high-resolution multiple

OAE records from Demerara Rise with earlier DSDP mapping it will be possible to evaluate whether this gateway merely controlled OAE sedimentation in the more restricted South Atlantic or whether its influence extended to the tropical North Atlantic–Tethys.

3. What is the long-term history of cross-equatorial heat transport into the North Atlantic? The Demerara Rise is positioned in an ideal location to sample meriodonal circulation and delivery of heat northward from Cretaceous to Oligocene time (Fig. F1).

SEISMIC STRATIGRAPHY OF DEMERARA RISE

Four to five seismic reflectors can be distinguished on the outer Demerara Rise; these are labeled as reflectors O, A, B, B′, and C. The reflectors have been dated by correlation to industry well Demerara A2-1, DSDP Site 144, and gravity cores taken during cruise M49-4 (Fig. F5).

Reflector O

Where present, Reflector O marks the base of a thin veneer of Quaternary clay-rich carbonate oozes (no more than a few tens of meters thick; see line GeoB01-208). Reflector O is underlain by a package of mostly thin layers indicated by a group of distinctive reflectors of different strength. Toward the distal end of Demerara Rise, reflectors are anastoming and partly missing, presumably caused by erosion events (e.g., lines GeoB01-217, GeoB01-211, and GeoB01-212). Correlation of industry well Demerara A2-1 with line GeoB01-204 suggests a Miocene age for this package.

Reflector A

Reflector A is produced by an erosional surface of latest Oligocene to early Miocene age as dated by industry well Demerara A2-1 and a *Meteor* 49-4 gravity core taken from an outcrop of Reflector A on line GeoB01-215. The reflector is more or less uniformly dipping to the northwest in the eastern part of Demerara Rise (see lines GeoB01-211 and GeoB01-212). The roughness of Reflector A increases toward the northwest and northeast of Demerara Rise. There, deeply incised channels indicate extensive erosion into the Paleogene sedimentary sequence (see lines GeoB01-215, GeoB01-216, GeoB01-204, and GeoB01-219). Channels dip to the northwest, north, and northeast toward the slopes of Demerara Rise.

Reflector A pinches out on the northern slopes of Demerara Rise where sediments older than this reflector crop out. It is difficult to trace Reflector A along the shallow dipping western slope of Demerara Rise to proposed Site DR-3C. Line GeoB01-221 shows a package of branching reflectors that probably correlates with Reflector A and indicates the presence of several Oligocene outcrops.

Reflector B

Reflector B is the first prominent reflector below the erosional surface marking Reflector A and marks the top of a Santonian to Cenomanian black shale sequence. In general, Reflector B dips uniformly to the northwest. This reflector is present in all lines except one and downdips along Line GeoB01-217, where its absence appears to reflect local extreme downcutting associated with the erosive event denoted by Reflector A.

Reflector B′

Reflector B′ is a relatively weak reflector and is thought to represent the top of a package of Albian to Barremian marls and claystones underlying the mid-Cretaceous black shales.

Reflector C

Reflector C is strong and reflects the angular unconformity between Barremian/Aptian marine claystones and underlying synrift sediments. This prominent reflector is the deepest in the set of reflectors and a distinct feature in all seismic lines.

Tectonics

Extensional faults are present throughout the investigated area. Simple horst and graben structures (e.g., line GeoB01-208) with tilted blocks and extensional faults (e.g., lines GeoB01-213 and GeoB01-204) can be observed. The faults are related to Atlantic drifting and gravitational extension in the studied area. The general strike of the faults is northeast-southwest. The major fault in line GeoB01-213 can be traced to other lines such as GeoB01-204, GeoB01-219, and BeoB01-217.

OPERATIONAL PLAN

Drilling site locations were selected on the basis of seismic reflection profiles and results from DSDP Site 144. Sites were chosen based on the following criteria: (1) thick sediment packages that include the intervals of interest and (2) a range of paleodepths to provide depth transects for the mid-Cretaceous to Paleogene section. Four sites are primary targets, and six alternate sites are provided for contingency planning.

Seismic

A 20-nmi-long northwest-southeast seismic reflection line is planned when first arriving on Demerara Rise to provide a crossline over proposed Site DR-3C, intersecting existing line GeoB01-221, and ending at line GeoB01-215. This line is oriented in the dip direction across the proposed site, as none presently exists. It will tie into two existing strike lines to provide closure to the seismic stratigraphic correlations.

Site Locations

The drilling program includes a total of four primary sites (DR-8B, DR-3C, DR-5B, and DR-2) and six alternate sites (DR-1B, DR-3, DR-4B, DR-6B, DR-6C, and DR-7B), spanning water depths from 1895 to 3215 m (for the primary sites). Paleogene to mid-Cretaceous sediments will be sampled at all primary sites. Site DR-2 should include a 300-m-thick Neogene succession. A thin veneer of Quaternary ooze is expected at each site. Site details and drilling order for the primary sites are presented in Table T1. Table T2 contains priorities and details of the alternate sites.

The primary Sites DR-8B, DR-3C, and DR-5B will be multi-advanced piston coring/extended core barrel (APC/XCB) cored to refusal or to the maximum proposed depth of penetration (Table T1). Site DR-2 will be multi-APC/XCB cored and rotary core barrel (RCB) cored to a total depth of 970 mbsf. Depths of maximum penetration of all proposed sites is based on a safe elevation above the estimated depth of Reflector C (see "Seismic Stratigraphy of Demerara Rise"). Interval velocities are not known, so a checkshot experiment is planned at the first site to allow for recalculation of these depth estimates. Multiple coring at each site will ensure 100% recovery of the stratigraphic column. Given the nature of sediments recovered at DSDP Site 144 and interpretation of the seismic reflection profiles, no geologic conditions are expected to provide drilling problems.

Alternate Drilling Strategy

Alternate drilling sites have been provided as contingency for unforeseen problems with any of the existing primary sites. The intent is to sample similar sections as proposed for the primary sites but at different locations. They are proposed as alternates because they are viewed as less than ideal from interpretation of the seismic reflection profiles (e.g., the sections of interest are more deeply buried, the target sections are not as thick as at the primary sites, or nearby slumping or faulting draws into question the competency of the stratigraphic section).

Logging Plan

Logging operations are scheduled to take place at all of the primary sites (DR-8B, DR-3C, DR-5B and DR-2). The two standard ODP tool string configurations will be deployed. The triple combination (triple combo) tool string logs formation resistivity, density, porosity, natural gamma ray, and borehole diameter, and will be run first, followed by the Formation MicroScanner (FMS)-Sonic tool string, which provides an oriented 360° resistivity image of the borehole wall, logs of formation acoustic velocity, natural gamma ray, and borehole diameter. The Lamont-Doherty Earth Observatory (LDEO) high-resolution Multisensor Gamma Tool (MGT) will be deployed on the top of the triple combo tool string and run on a separate pass at all of the primary sites. In addition, the Well Seismic Tool (WST) is scheduled for use at primary Sites DR-2 and DR-8B. This tool will be used to undertake a checkshot survey, providing accurate traveltime data for calibrating the velocity logs.

The main aims of the leg are the recovery of Paleogene and Cretaceous fossiliferous oozes and chalks and Cretaceous black shales. Borehole logging will provide continuous in situ measured physical properties, which can be used to assess the physical, chemical, and structural characteristics of the formation. Even in the event of complete core recovery, the expansion of sediments resulting from elastic strain recovery requires core data to be depth-shifted (compressed), which can be accomplished by depth matching core multisensor-track (MST) data (density, porosity, and gamma ray) to equivalent log data using the Sagan core-log integration program. The situation is reversed when incomplete core recovery occurs. The recovery of black shale intervals may be problematic, but they should be clearly identifiable using the natural gamma, density, and porosity logs. The continuous logs of density, porosity, gamma ray, and resistivity are readily amenable to cyclostratigraphic analysis, which can identify the influence of orbital forcing on climate cycles evident in sedimentary deposits. Formation density and velocity profiles (derived by splicing core and log data) will be calibrated using the checkshot surveys and used to produce formation acoustic impedance profiles, depth/time models, and synthetic seismograms. The synthetic seismograms provide a direct link between the depth domain core data and the time domain seismic data, allowing the accurate location, dating, and interpretation of the reflectors seen in the regional seismic data. Further details on tools and their application can be found on the LDEO Borehole Research Group (BRG) website: http://www.ldeo.columbia.edu/BRG/.

SAMPLING STRATEGY

General

Much of the Paleogene and Cretaceous core material to be recovered during Leg 207 will be retrieved by APC and XCB coring, generally by triple coring. No archive halves (permanent or temporary) will be sampled aboard ship, and the permanent archive will be designated postcruise. Sampling of the recovered cores will be subject to the rules described in the ODP Sample Distribution Policy (http://www-odp.tamu.edu/publications/policy.html). Sampling for high-resolution isotopic, sedimentologic, and micropaleontologic studies will be conducted after construction of the spliced composite section. High-resolution sampling requests are anticipated for most sites. Sampling schedules will be worked out to optimize stratigraphic coverage and minimize duplication. Geochemical sampling, which calls for larger volumes, will be conducted on material from the third hole if it would otherwise interfere with first-pass micropaleontology and sedimentology sampling. Where appropriate, U-channel sampling for high-resolution paleomagnetic studies will be conducted postcruise from the temporary archive half along the composite sampling splice.

Sampling for whole-round samples (e.g., physical properties, interstitial water, etc.) will be undertaken so as not to interfere with stratigraphically sensitive sampling sequences and to take advantage of available continuous nondestructive measurements where possible.

Ultra-High-Resolution Sites

Should particularly thinly laminated sediments be encountered or some other factor necessitate it, detailed very high resolution sampling may be approved. The sampling allocation committee (SAC) will determine details of the sampling pattern in such instances.

Sampling Timetable

Detailed sampling of cores from a given site will proceed only after a composite stratigraphy is constructed from cores from the two or more holes drilled at the site. The splice will be constructed, and the stratigraphic information will be distributed to the scientific party in advance of postcruise sampling to facilitate planning and scientific collaboration. Requests to sample on board, for pilot studies or for projects requiring lower stratigraphic resolution, will be considered by the SAC.

Archives

The archive-half cores (permanent and temporary) for all holes will not be sampled aboard ship, and the permanent archive will be designated postcruise.

Critical Intervals

Critical intervals include the Eocene/Oligocene, Paleocene/Eocene, Cretaceous/Tertiary, and Cenomanian/Turonian boundaries and the Albian Oceanic Anoxic Events 1d, 1c, and 1b. The biostratigraphic definitions of the critical intervals will be established by shipboard paleontologists and the SAC at the beginning of the cruise. When these intervals are recovered, only toothpick samples will be taken initially to provide age control. Once this control has been obtained, the SAC will develop a sampling plan in consultation with interested scientists. This sampling will be carried out during a postcruise sampling party. Whole-round samples in these intervals will only be taken once biostratigraphic control is obtained.

Final Comment

All sampling for Leg 207 and the final sampling plan, will be approved by the SAC, consisting of the Co-Chief Scientists (Erbacher and Mosher), Staff Scientist (Malone), and the Curator (or his representative). The initial sampling plan will be preliminary and may be modified during the cruise, depending upon actual material recovered and collaborations that may evolve between scientists.

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TABLE CAPTIONS

Table T1. Primary site operational plan and time estimates.

Table T2. Alternate site operational plan and time estimates.

FIGURE CAPTIONS

Figure F1. Area of Leg 207 operations on the Demerara Rise, showing positions of seismic tracklines, DSDP Site 144, and industry exploration well site Demerara A2-1.

Figure F2. Seismic grid shot during survey *Meteor* 49-4 (solid lines) with industry multichannel tracklines (dashed lines) over the Demerara Rise, with proposed Leg 207 drill site locations (primary sites in bold).

Figure F3. Detailed bathymetry of Demerara Rise with positions of the proposed Leg 207 drill sites. Primary sites are indicated by larger (red) type. GeoB4013 is a gravity core taken during the *Meteor* 49-4 expedition.

Figure F4. Global paleogeographic reconstruction of the Late Cretaceous showing the position of the Demerara Rise in the early South Atlantic.

Figure F5. Seismic stratigraphy of MCS line GeoB01-220 at the location of DSDP Site 144 and proposed Site DR-8B. See text for details of seismic stratigraphic intepretation. Stratigraphy and core recovery at Site 144 is also shown. CDP = common depth point.

Figure F6. Scanning electron micoscropy photos of planktonic foraminifers from late Cenomanian black shales of DSDP 144. Note the perfect preservation.

Figure F7. Stable isotope data from DSDP 144-4, 144-3, and 144-2, showing small but consistent interspecies offsets. This observation demonstrates the potential to generate modern high-resolution records from the Demerara Rise cores.

Figure F8. Mid-Cretaceous oceanic anoxic events (OAE) and patterns of faunal turnover. Shown also are secular changes in seawater strontium and carbon isotope composition and estimated ages for oceanic plateau emplacement (from Leckie et al., in press).

Figure F9. Global deep-sea isotopic record compiled from numerous DSDP and ODP sites (Huber et al., 1999; Norris et al., 2001; Zachos et al., 2001). LPTM = late Paleocene Thermal Maximum, CO = Climatic Optimum. Modified from Kroon et al. (2002).

Table T1. Primary site operational plan and time estimates.

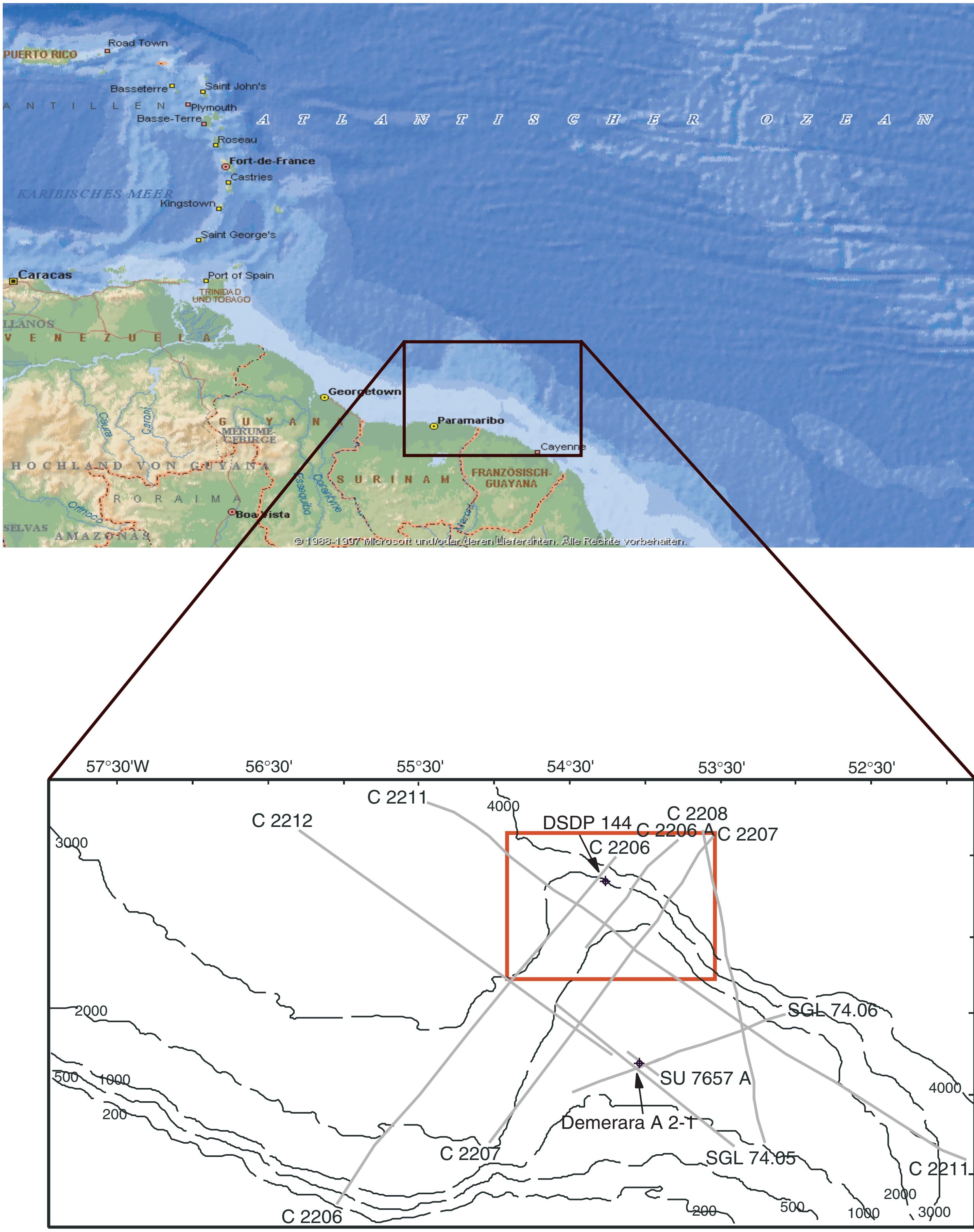
Proposed site	Latitude/ Longitude	Water depth (m)	Operation description	Transit (days)	Coring (days)	Logging (days)
			Transit 349 nmi from Bridgetown, Barbados, to Site DR-3C	1.5		
			Seismic survey over Site DR-3C	0.3		
DR-8B	9°27.23'N 54°20.52'W	2950	Hole A: APC/XCB to 280 mbsf		1.8	
			Logging: triple combo, FMS, checkshot survey*			1.6
			Hole B: APC/XCB to 280 mbsf		1.6	
			Hole C: APC/XCB to 280 mbsf		1.8	
			Site DR-8B operations time subtotal:		5.2	1.6
			Transit 23.2 nmi from Site DR-8B to Site DR-3C	0.1		
DR-3C	9°26'N 54°44'W	3215	Hole A: APC/XCB to 485 mbsf		3.3	
			Hole B: APC/XCB to refusal (~485 mbsf)		3.0	
			Hole C: APC/XCB to refusal (~485 mbsf)		3.2	
			Logging: triple combo, FMS*			1.4
			Site DR-3C operations time subtotal:		9.5	1.4
			Transit 32.6 nmi Site DR-3C to Site DR-5B	0.2		
DR-5B	9°18'N 54°12'W	2340	Hole A: APC/XCB to refusal (~500 mbsf)		2.8	
			Hole B: APC/XCB to refusal (~500 mbsf)		2.7	
			Logging: triple combo, FMS*			1.4
			Site DR-5B operations time subtotal:		5.5	1.4
			Transit 16.9 nmi Site DR-5B to Site DR-2	0.1		
DR-2	9°5'N 54°1'W	1895	Hole A: APC/XCB to refusal (~500 mbsf)		2.8	
			Hole B: APC/XCB to refusal (~500 mbsf)		2.7	
			Hole C: Drill to ~500 mbsf, RCB 500–970 mbsf		4.7	
			Logging: triple combo, FMS, checkshot survey*			2.4
			Site DR-2 operations time subtotal:		10.2	2.4
			Transit 2956.4 nmi from Site DR-2 to Rio de Janeiro, Brazil	11.6		
			Transit and onsite time subtotals:	13.8	30.5	6.8
			Leg 207 primary site operational days total:		51.0	

Note: * = Logging times include hole preparation. APC/XCB = advanced piston coring/extended core barrel, RCB = rotary core barrel. Triple combo = triple combination tool string, FMS = Formation MicroScanner tool string.

Table T2. Alternate site operational plan and time estimates.

Alternate site	Latitude/ Longitude	Water depth (m)	Operations description	Coring (days)	Logging (days)
DR-1B	8°57.7'N	1610	Hole A: APC/XCB to refusal (~500 mbsf)	2.4	
	54°7'W		Hole B: APC/XCB to refusal (~500 mbsf)	2.4	
			Hole C: Drill to ~500 mbsf, RCB 500–1000 mbsf	5.0	
			Logging: triple combo, FMS		1.5
			Alternate Site DR-1B operations time subtotal:	9.8	1.5
DR-3	9°8'N	2080	Hole A: APC/XCB to refusal (~500 mbsf)	2.4	
	53°58'W		Hole B: APC/XCB to refusal (~500 mbsf)	2.4	
			Hole C: Drill to ~500 mbsf, RCB 500–700 mbsf	3.1	
			Logging: triple combo, FMS		1.3
			Alternate Site DR-3 operations time subtotal:	8.0	1.3
DR-4B	9°20.5'N	2800	Hole A: APC/XCB to 350 mbsf	2.3	
	54°6.2'W		Hole B: APC/XCB to refusal (~350 mbsf)	2.0	
			Hole C: APC/XCB to refusal (~350 mbsf)	2.3	
			Alternate Site DR-4B operations time subtotal:	6.6	0.0
DR-6B	9°13.6'N	2410	Hole A: APC/XCB to 485 mbsf	3.6	
	54°30.1'W		Hole B: APC/XCB to refusal (~485 mbsf)	3.4	
			Hole C: APC/XCB to refusal (~485 mbsf)	3.6	
			Logging: triple combo, FMS		1.1
			Alternate Site DR-6B operations time subtotal:	10.6	1.1
DR-6C	9°7.3'N	2460	Hole A: APC/XCB to 185 mbsf	3.8	
	54°35.5'W		Hole B: APC/XCB to refusal (~485 mbsf)	3.6	
			Hole C: APC/XCB to refusal (~485 mbsf)	3.7	
			Logging: triple combo, FMS		1.1
			Alternate Site DR-6C operations time subtotal:	11.1	1.1
DR-7B	9°3'N	1980	Hole A: APC/XCB to refusal (~500 mbsf)	2.4	
	54°19'W		Hole B: APC/XCB to refusal (~500 mbsf)	2.4	
			Hole C: Drill to ~500 mbsf, RCB 500 to 600 mbsf	3.0	
			Logging: triple combo, FMS		1.3
			Alternate Site DR-7B operations time subtotal:	7.9	1.3

Notes: APC/XCB = advanced piston coring/extended core barrel, RCB = rotary core barrel. Triple combo = triple combination tool string, FMS = Formation MicroScanner tool string.


PUERTO RICO
Road Town
Basseterre
Saint John's
ANTILLEN
Plymouth
Basse-Terre
ATLANTISCHER OZEAN
Roseau
Fort-de-France
Castries
KARIBISCHES MEER
Kingstown
Saint George's
Caracas
Port of Spain
TRINIDAD UND TOBAGO
LLANOS
VENEZUELA
Georgetown
GUYANA
MERUME-GEBIRGE
Paramaribo
Cayenne
HOCHLAND VON GUYANA
SURINAM
FRANZÖSISCH-GUAYANA
RORAIMA
Boa Vista
SELVAS
AMAZONAS
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57°30'W
56°30'
55°30'
54°30'
53°30'
52°30'
9°30' N
9°00'
8°30'
8°00'
7°30'
C 2211
C 2212
DSDP 144
C 2208
C 2206 A
C 2207
C 2206
SGL 74.06
SU 7657 A
Demerara A 2-1
SGL 74.05
C 2207
C 2206
C 2211
3000
2000
1000
500
200
4000

Figure F1

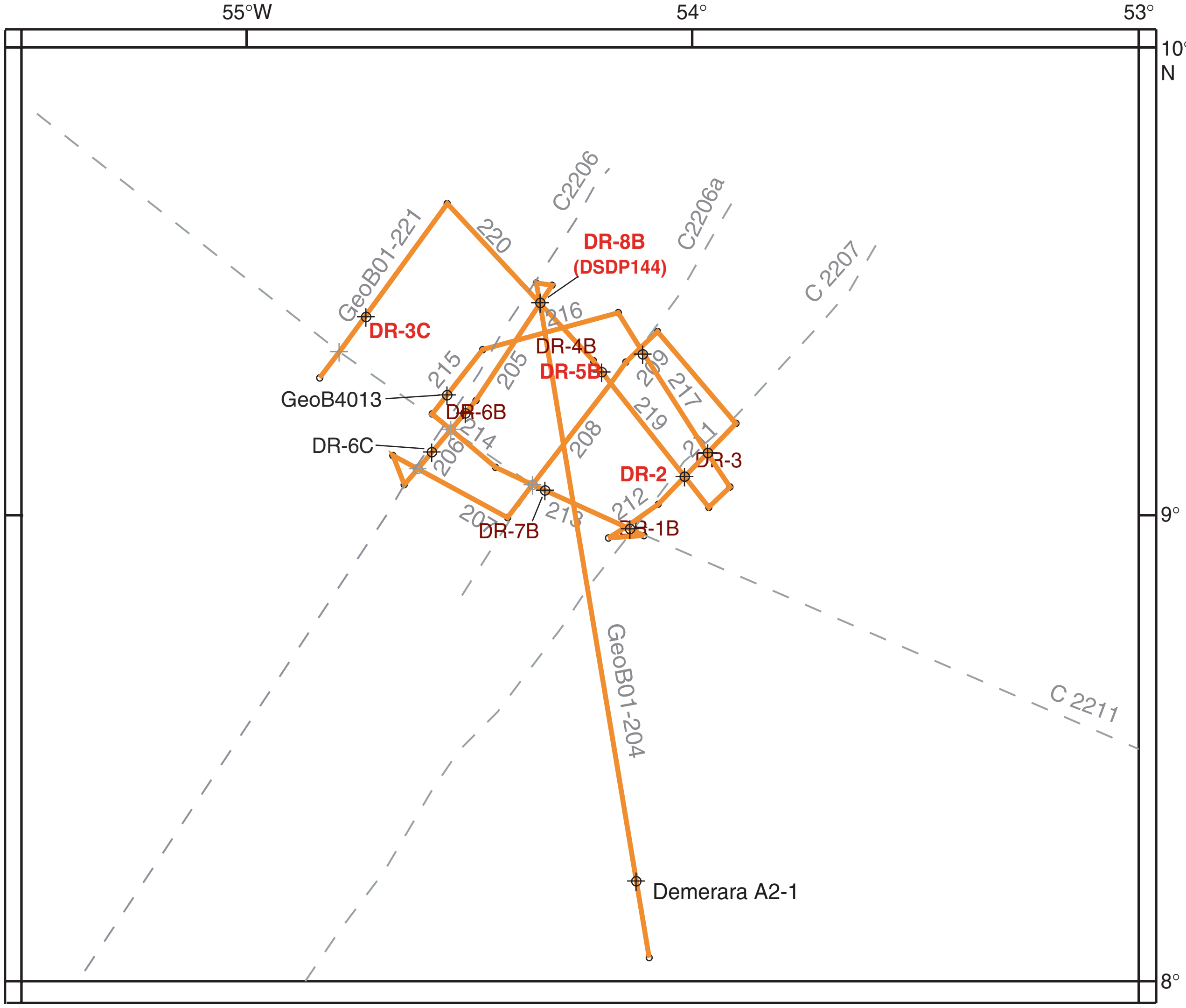

55°W
54°
53°
10° N
9°
8°
C2206
C2206a
C 2207
C 2211
GeoB01-221
GeoB01-204
220
216
215
205
214
206
208
219
217
211
212
213
DR-8B
(DSDP144)
DR-3C
DR-4B
DR-5B
DR-6B
GeoB4013
DR-6C
DR-2
DR-3
DR-1B
DR-7B
Demerara A2-1

Figure F2

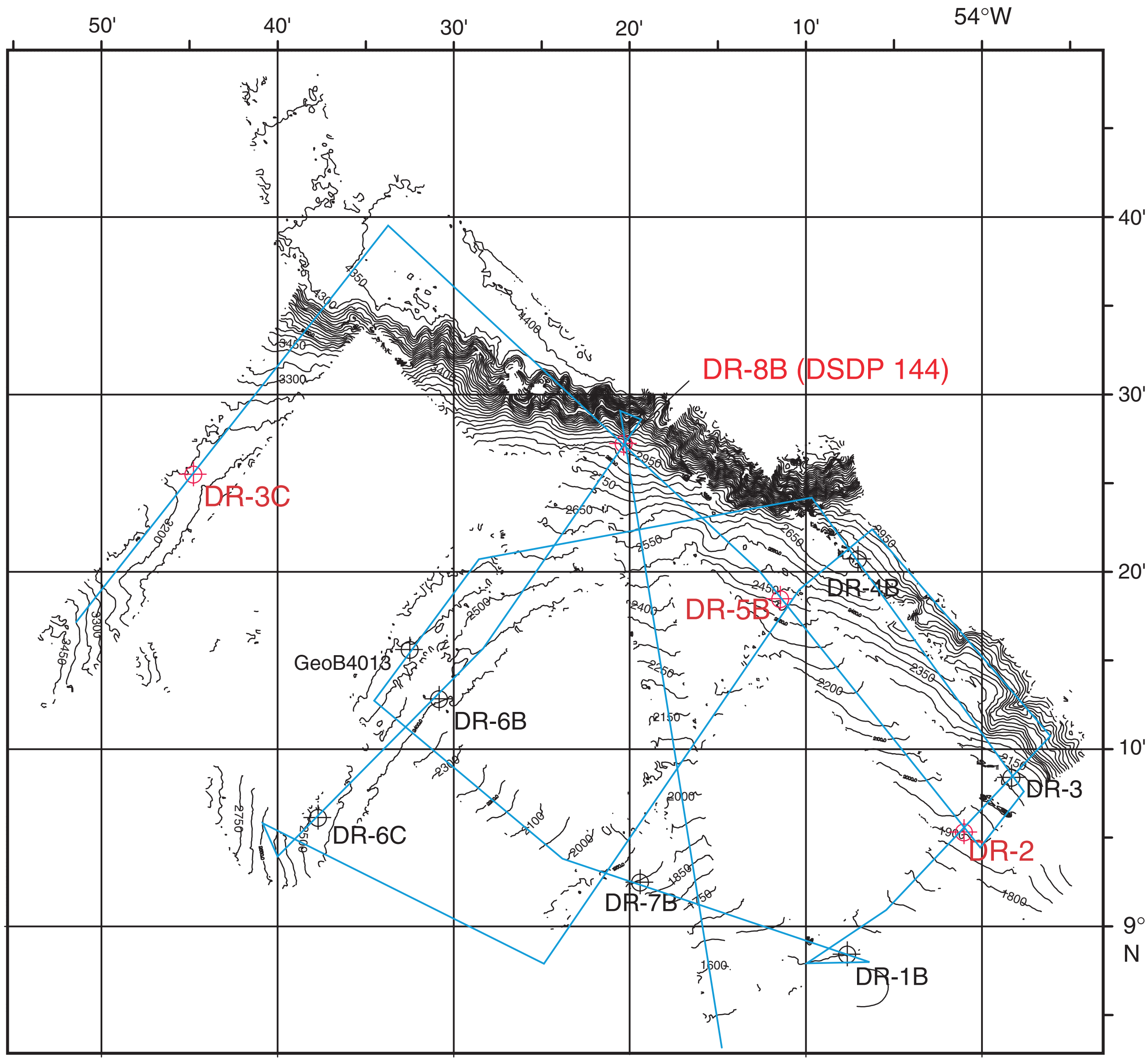
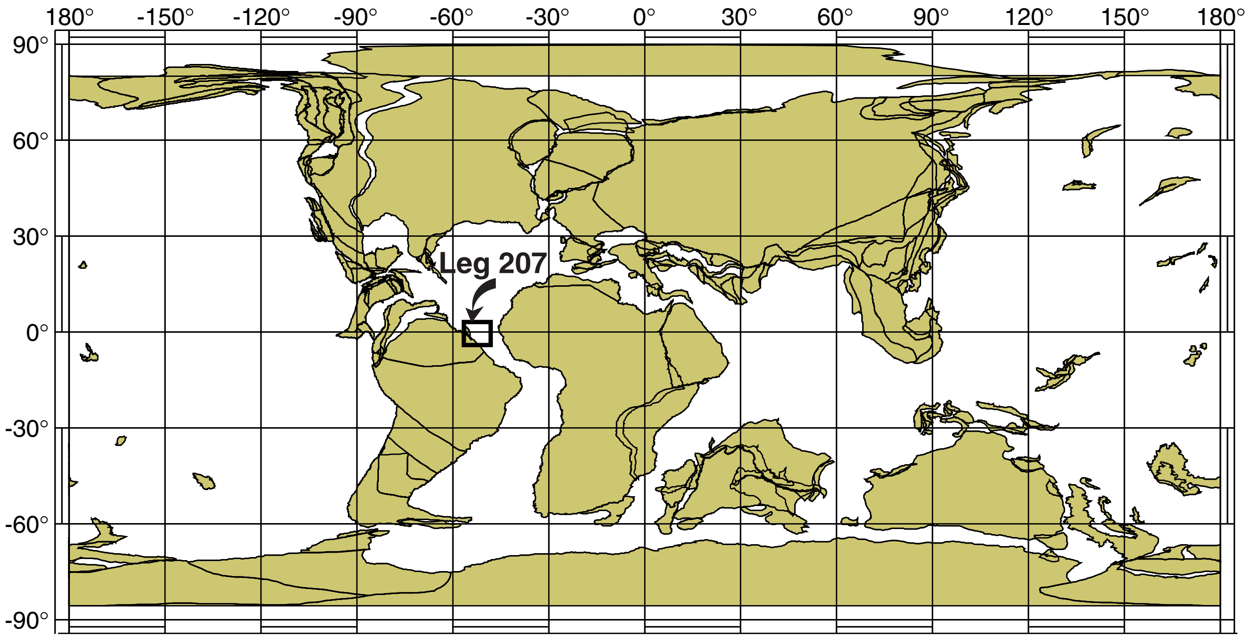

50'
40'
30'
20'
10'
54°W
40'
30'
20'
10'
9°
N
DR-8B (DSDP 144)
DR-3C
DR-5B
DR-4B
GeoB4013
DR-6B
DR-6C
DR-7B
DR-3
DR-2
DR-1B

Figure F3



90 Ma Reconstruction

Figure F4

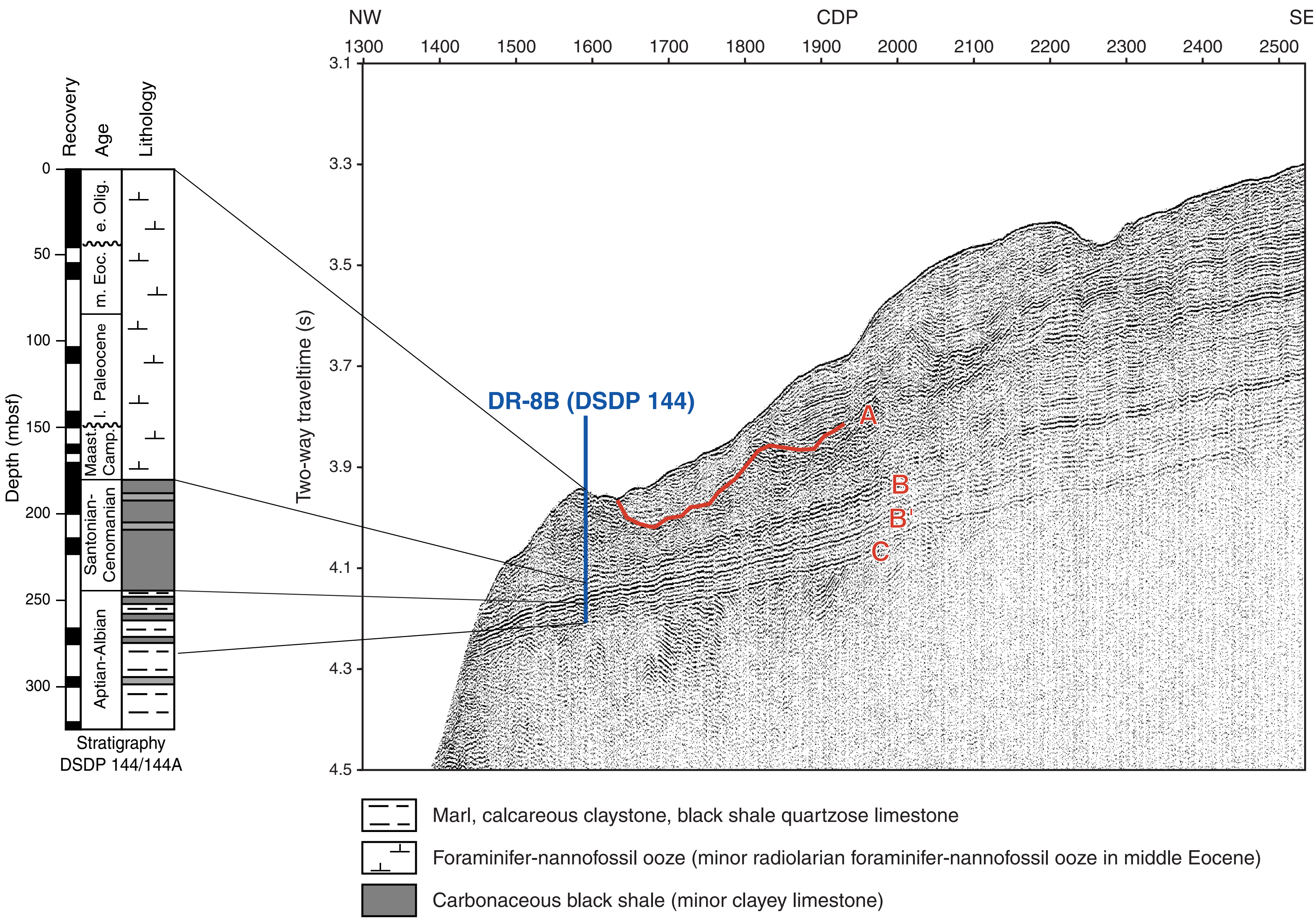

NW
CDP
SE
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
Two-way traveltime (s)
DR-8B (DSDP 144)
A
B
B'
C
Recovery
Age
Lithology
Depth (mbsf)
0
50
100
150
200
250
300
e. Olig.
m. Eoc.
Paleocene
l.
Maast.
Camp.
Santonian-
Cenomanian
Aptian-Albian
Stratigraphy
DSDP 144/144A
Marl, calcareous claystone, black shale quartzose limestone
Foraminifer-nannofossil ooze (minor radiolarian foraminifer-nannofossil ooze in middle Eocene)
Carbonaceous black shale (minor clayey limestone)

Figure F5

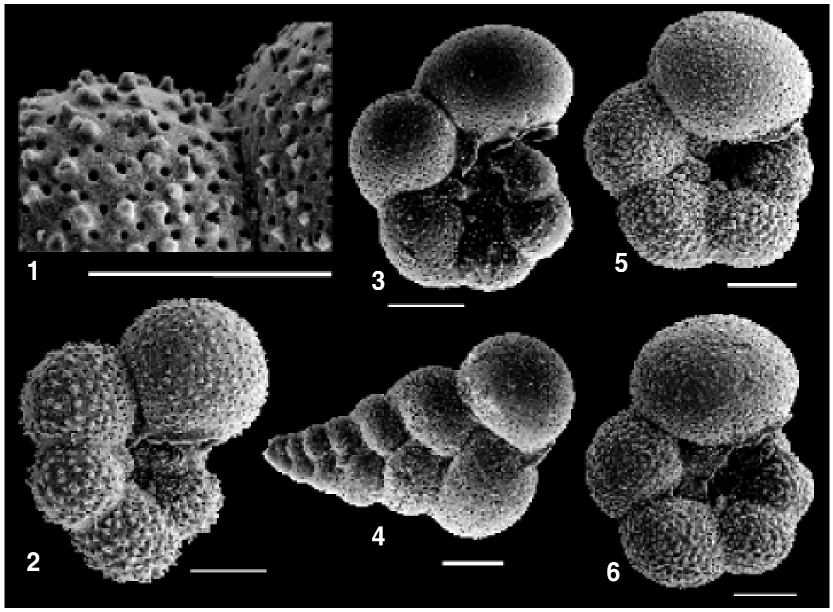


Figure F6

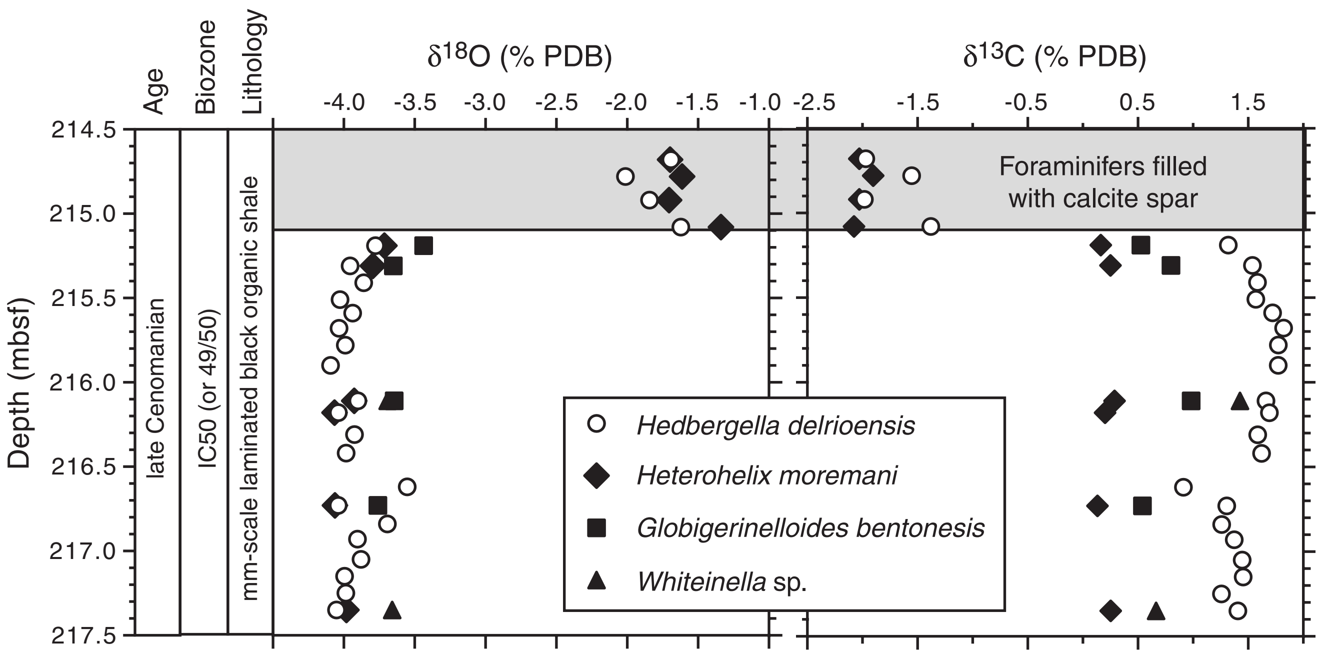

Age
Biozone
Lithology
δ18O (% PDB)
δ13C (% PDB)
-4.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-2.5
-1.5
-0.5
0.5
1.5
214.5
215.0
215.5
216.0
216.5
217.0
217.5
Depth (mbsf)
late Cenomanian
IC50 (or 49/50)
mm-scale laminated black organic shale
Foraminifers filled
with calcite spar
Hedbergella delrioensis
Heterohelix moremani
Globigerinelloides bentonesis
Whiteinella sp.

Figure F7

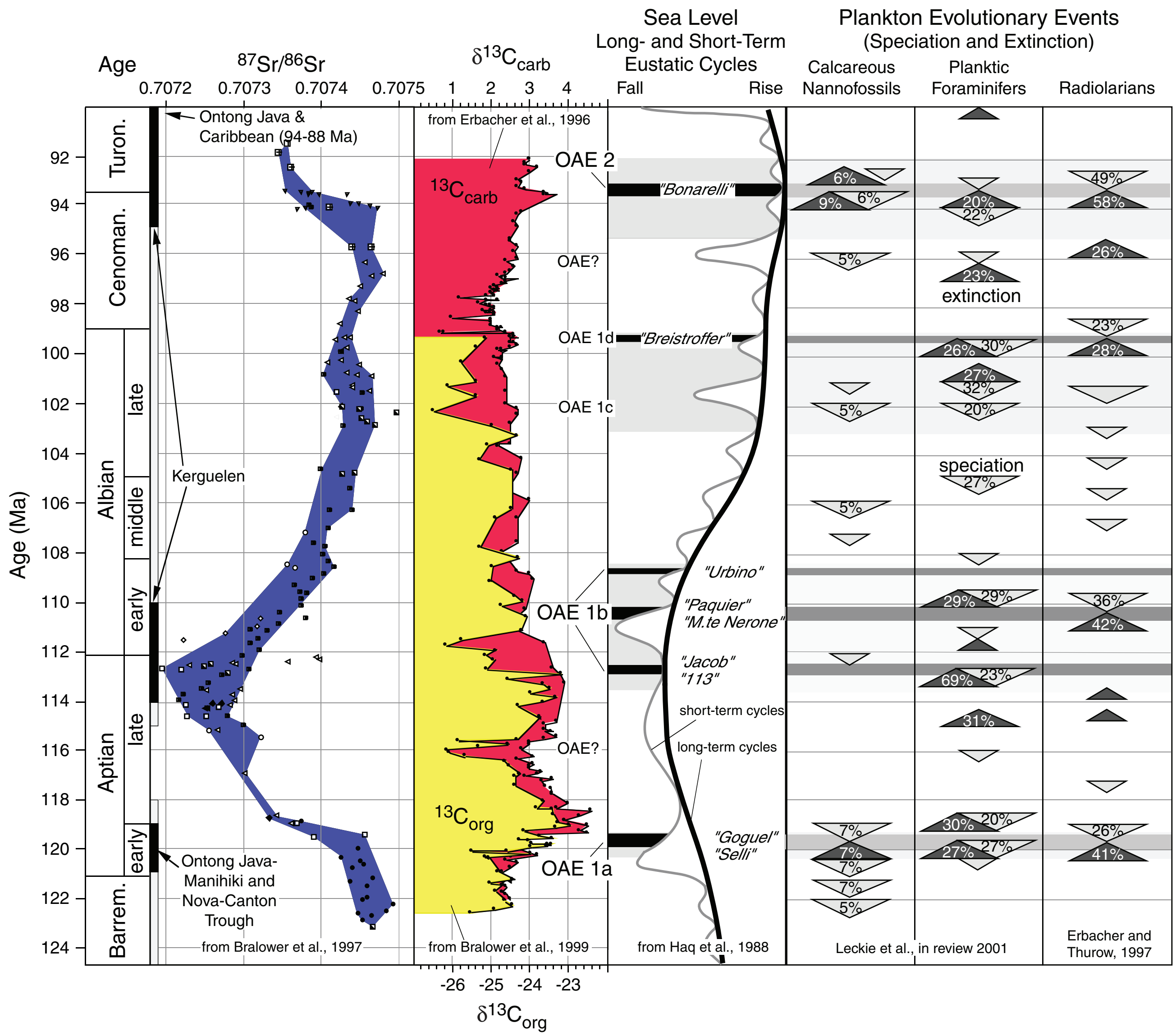

Age
^{87}Sr/^{86}Sr
0.7072
0.7073
0.7074
0.7075
δ^{13}C$_{carb}$
1
2
3
4
Sea Level
Long- and Short-Term
Eustatic Cycles
Fall
Rise
Plankton Evolutionary Events
(Speciation and Extinction)
Calcareous Nannofossils
Planktic Foraminifers
Radiolarians
Age (Ma)
Turon.
Cenoman.
Albian
Aptian
Barrem.
late
middle
early
late
early
Ontong Java & Caribbean (94-88 Ma)
Kerguelen
Ontong Java-Manihiki and Nova-Canton Trough
from Bralower et al., 1997
from Erbacher et al., 1996
^{13}C$_{carb}$
^{13}C$_{org}$
from Bralower et al., 1999
OAE 2
OAE?
OAE 1d
OAE 1c
OAE 1b
OAE?
OAE 1a
"Bonarelli"
"Breistroffer"
"Urbino"
"Paquier"
"M.te Nerone"
"Jacob"
"113"
short-term cycles
long-term cycles
"Goguel"
"Selli"
from Haq et al., 1988
extinction
speciation
Leckie et al., in review 2001
Erbacher and Thurow, 1997
-26
-25
-24
-23
δ^{13}C$_{org}$

Figure F8

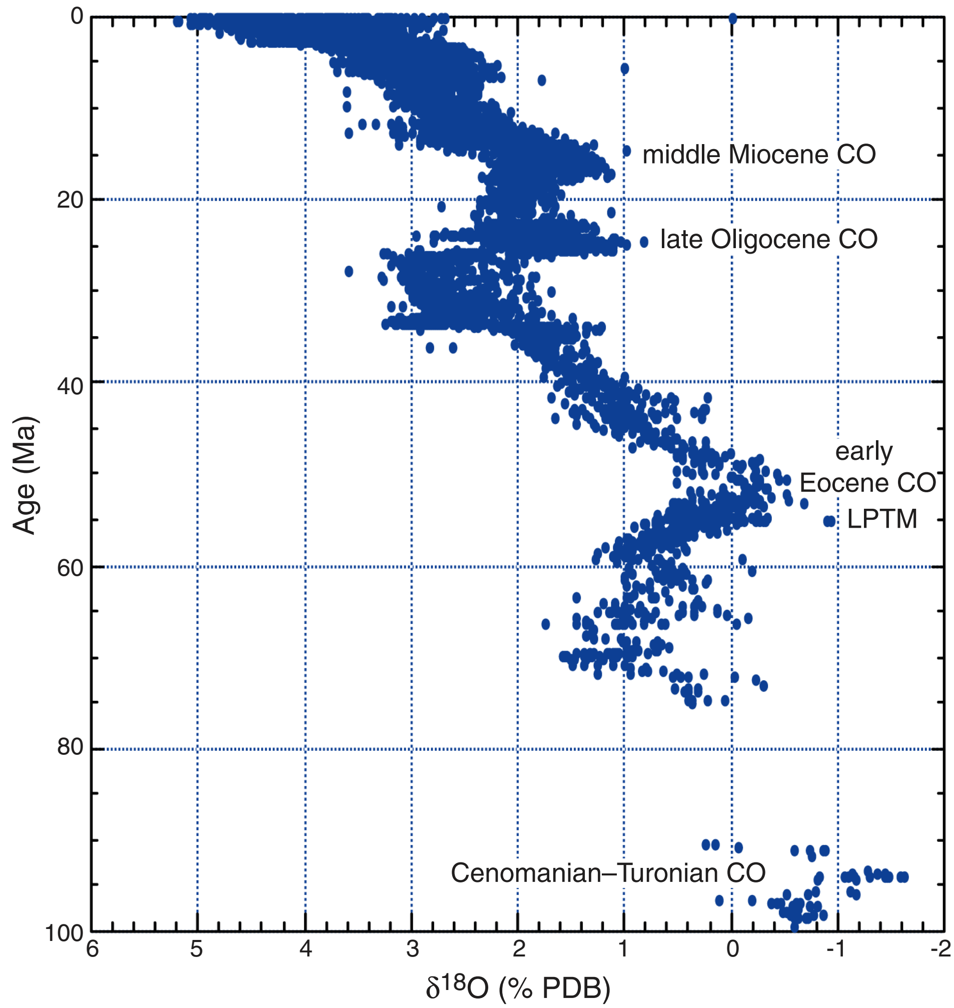

0
20
40
60
80
100
Age (Ma)
6
5
4
3
2
1
0
-1
-2
δ18O (% PDB)
middle Miocene CO
late Oligocene CO
early
Eocene CO
LPTM
Cenomanian–Turonian CO

Figure F9

Site: DR-1B

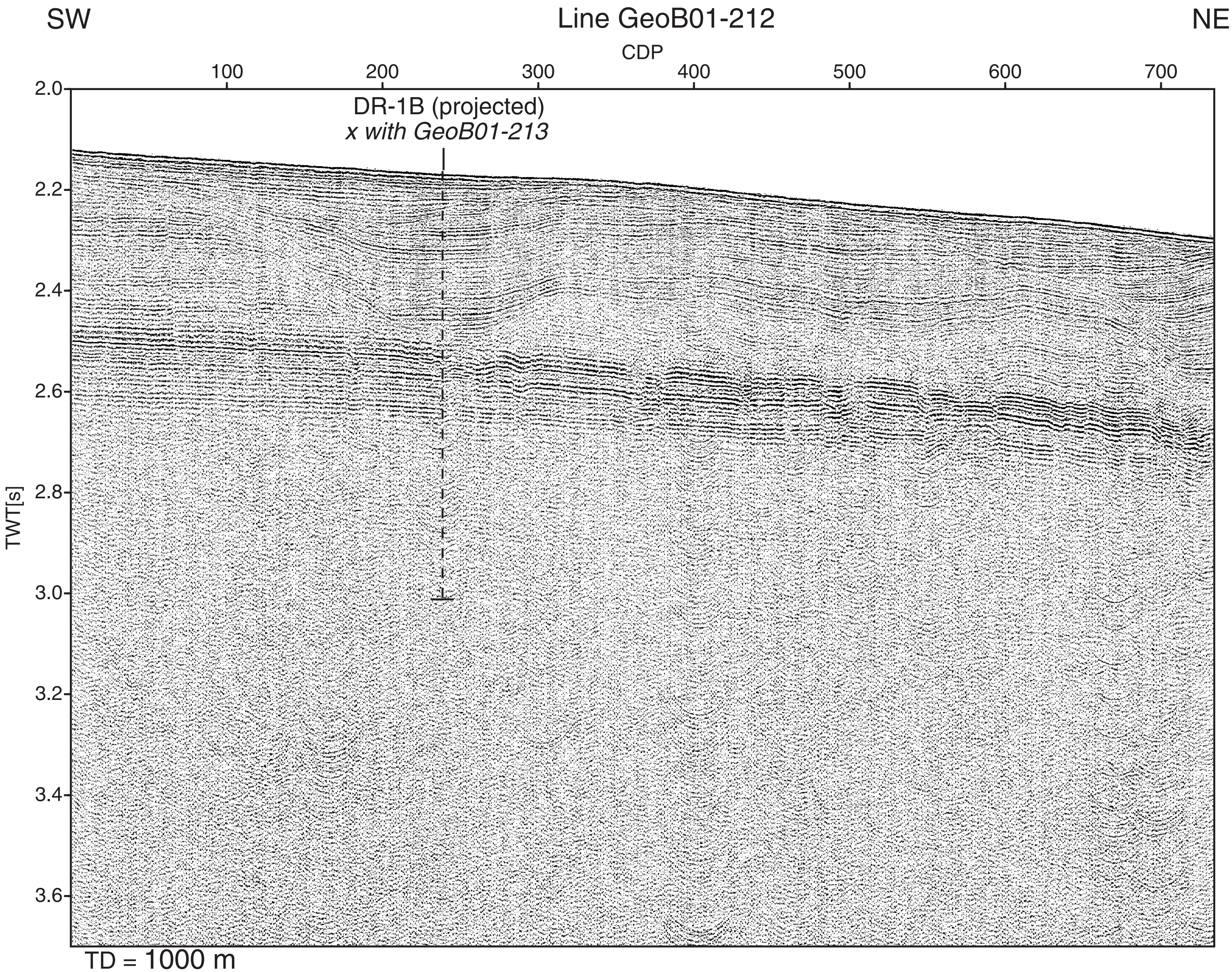
Priority: 3
Position: 8°57.7′N, 54°7′W
Water Depth: 1610 m
Target Drilling Depth: 1000 mbsf
Approved Maximum Penetration: 1000 mbsf
Seismic Coverage: Primary line GeoB01-212, crossing line GeoB01-213

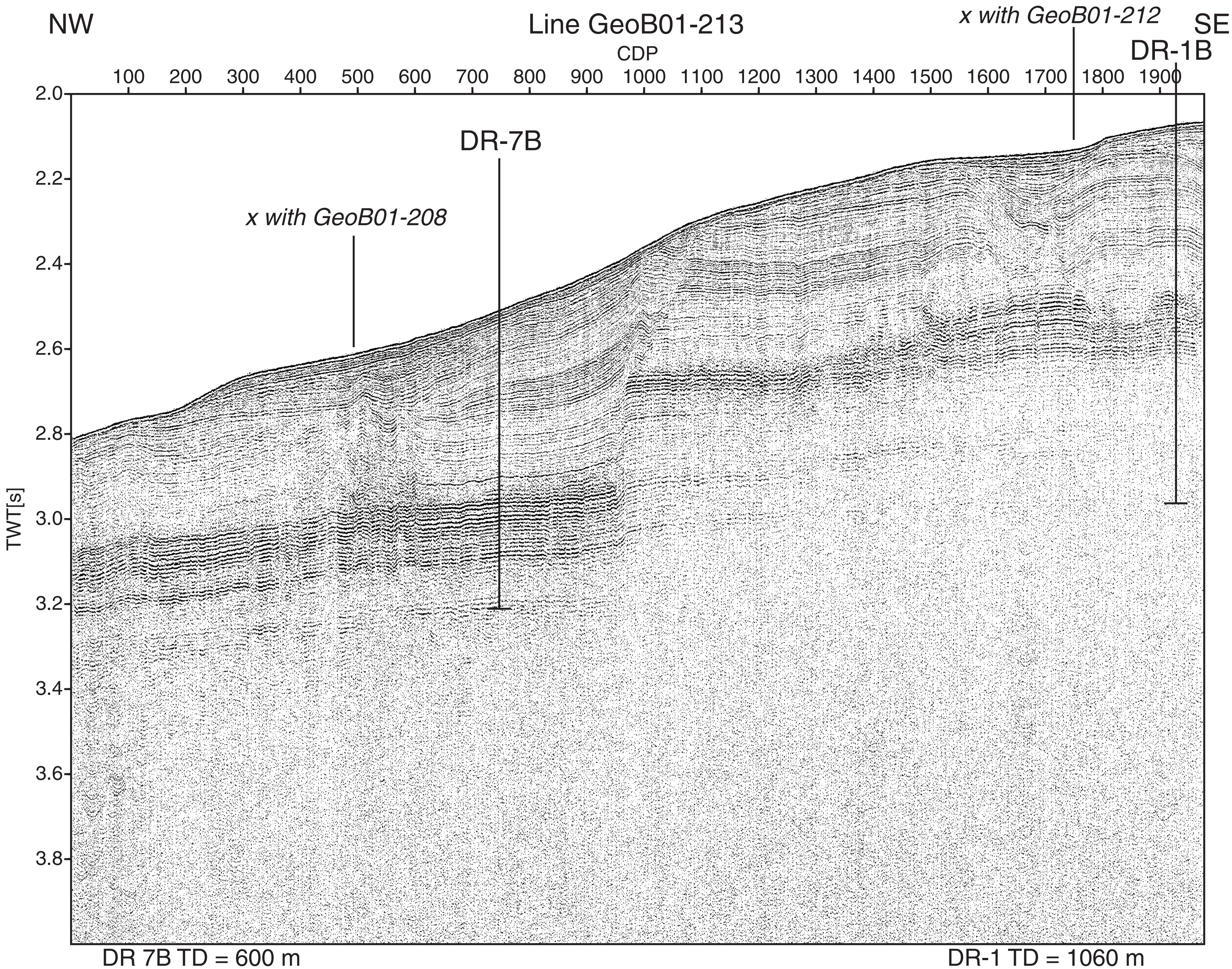
Objective: The primary objective for Site DR-1B is to sample mid-Cretaceous sediments at shallow paleowater depth (upper slope) to obtain information about the upper boundary of the oxygen minimum zone during OAEs and its fluctuation through time.

Drilling Program: Double APC/XCB to refusal, RCB from XCB refusal depth to 1000 mbsf.

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


SW
Line GeoB01-212
NE
CDP
100
200
300
400
500
600
700
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
TWT[s]
DR-1B (projected)
x with GeoB01-213
TD = 1000 m


NW
Line GeoB01-213
CDP
x with GeoB01-212
SE
DR-1B
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
TWT[s]
DR-7B
x with GeoB01-208
DR 7B TD = 600 m
DR-1 TD = 1060 m

Site: DR-2

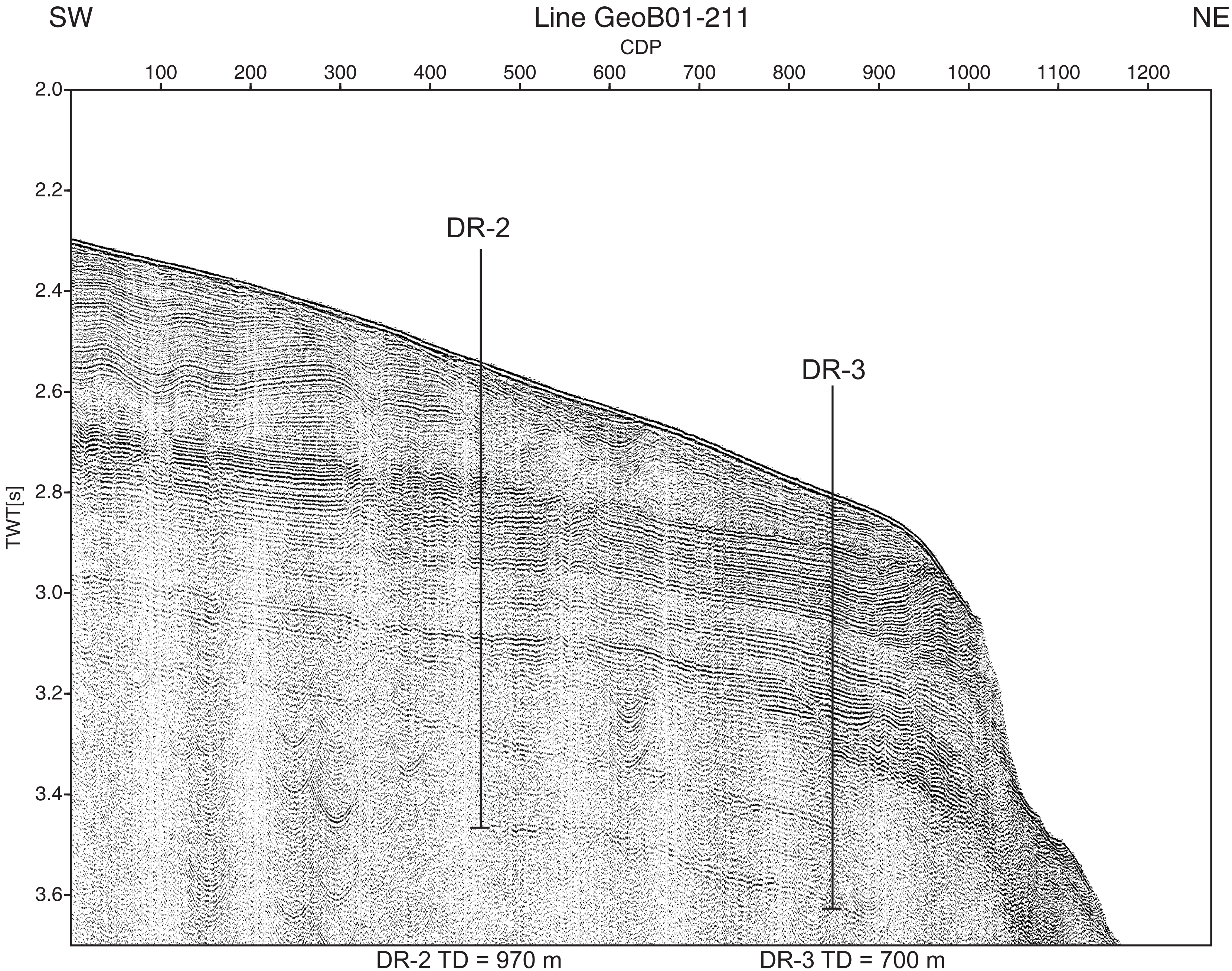
Priority: 1
Position: 9°5′N, 54°1.0′W
Water Depth: 1895 m
Target Drilling Depth: 970 mbsf
Approved Maximum Penetration: 970 mbsf
Seismic Coverage: Primary line GeoB01-211, crossing line GeoB01-219

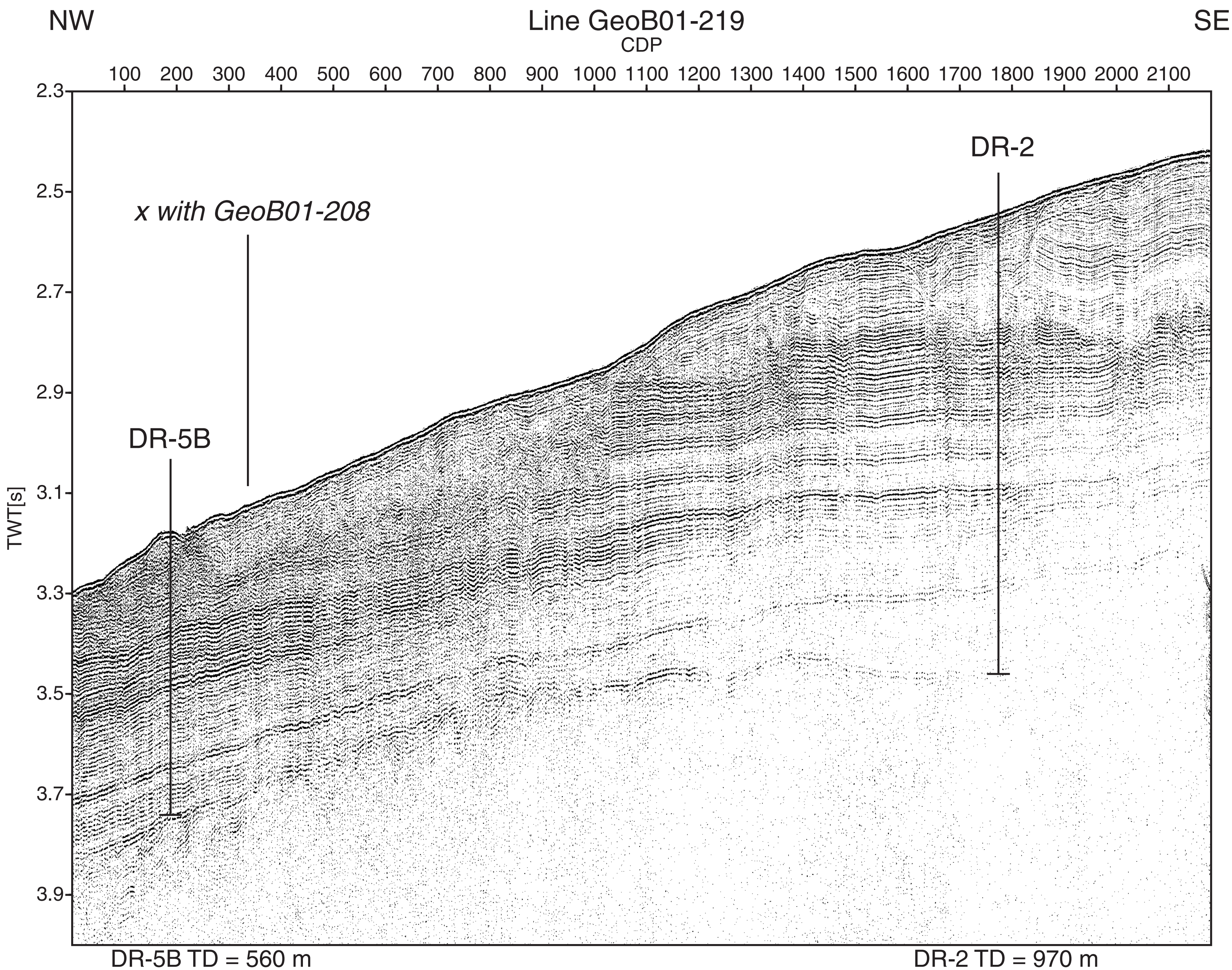
Objective: The primary objective for Site DR-2 is to sample Cretaceous sediments from the shallowest part of the depth transect.

Drilling Program: Double APC/XCB to refusal, RCB from XCB refusal depth to 970 mbsf.

Logging Program: Triple combo, FMS-sonic, and checkshot.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


SW
Line GeoB01-211
NE
CDP
100
200
300
400
500
600
700
800
900
1000
1100
1200
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
TWT[s]
DR-2
DR-3
DR-2 TD = 970 m
DR-3 TD = 700 m


NW
Line GeoB01-219
SE
CDP
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
TWT[s]
DR-2
x with GeoB01-208
DR-5B
DR-5B TD = 560 m
DR-2 TD = 970 m

Site: DR-3

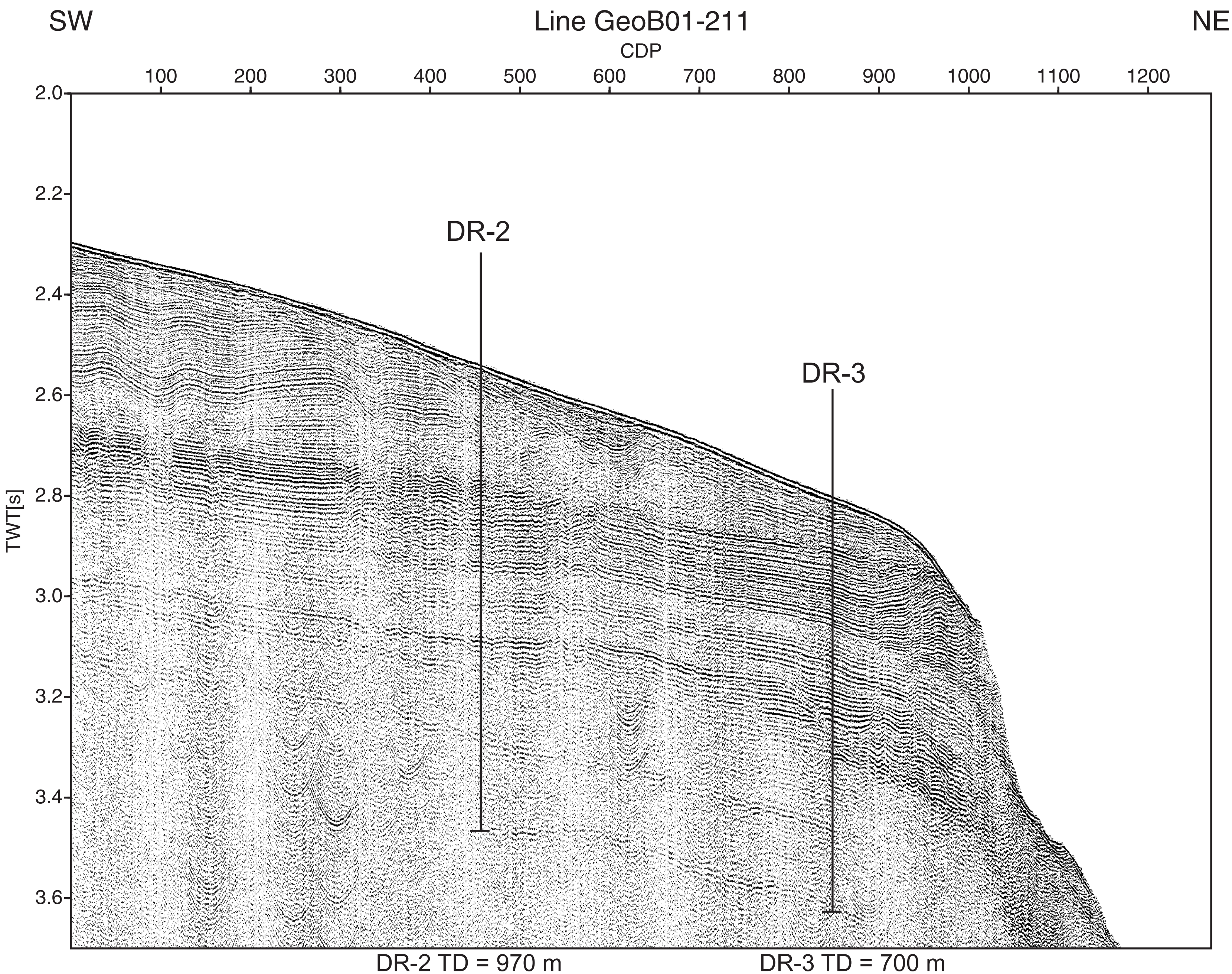
Priority: 3
Position: 9°8′N, 53°58′W
Water Depth: 2080 m
Target Drilling Depth: 700 mbsf
Approved Maximum Penetration: 700 mbsf
Seismic Coverage: Primary line GeoB01-211

Objective: Site DR-3 is an alternate located to maximize the total thickness of the black shale sequence at these water depths.

Drilling Program: Double APC/XCB to refusal, RCB from XCB refusal depth to 700 mbsf.

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.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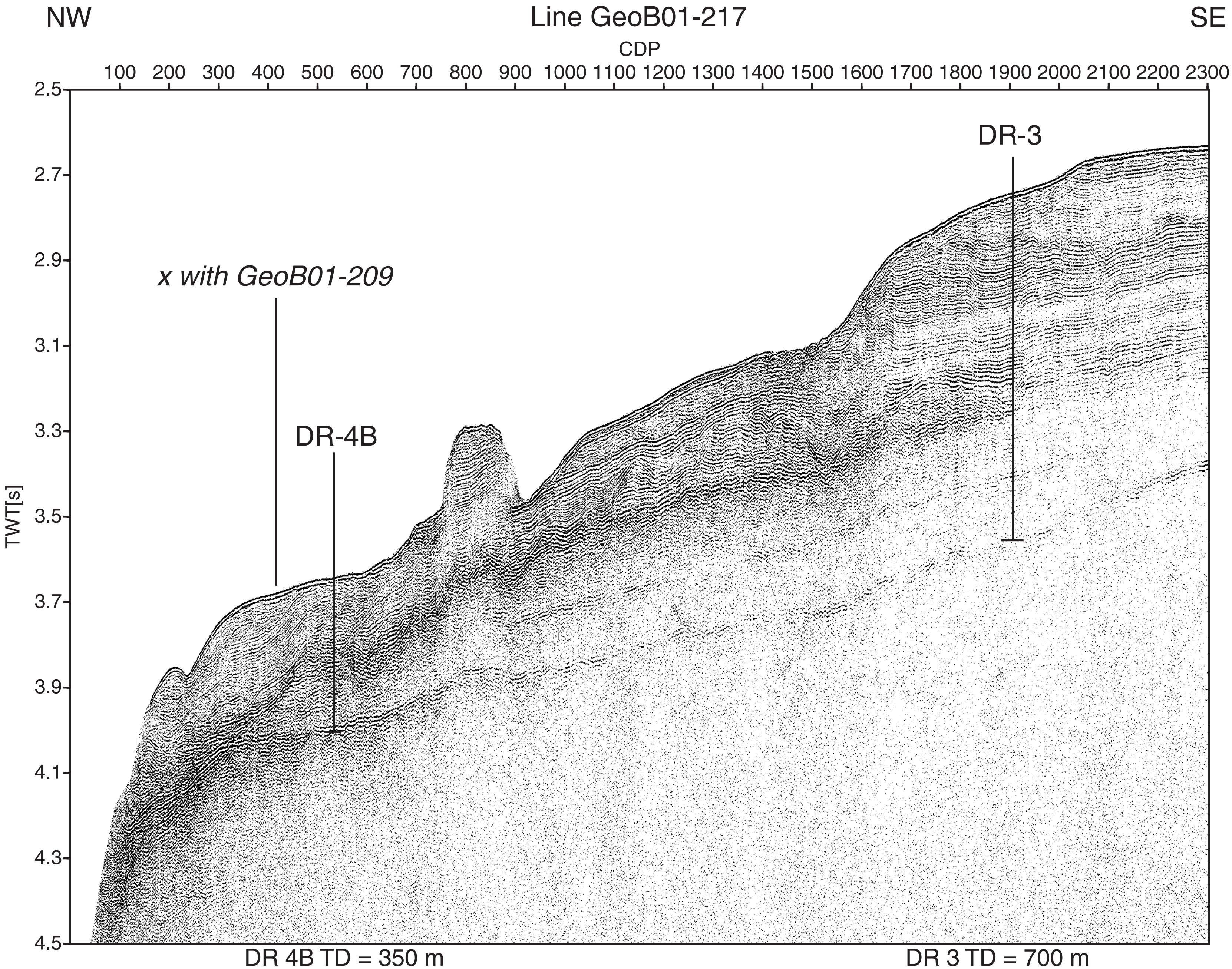
Line GeoB01-211
NE
CDP
100
200
300
400
500
600
700
800
900
1000
1100
1200
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
TWT[s]
DR-2
DR-3
DR-2 TD = 970 m
DR-3 TD = 700 m


NW
Line GeoB01-217
SE
CDP
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300
TWT[s]
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
x with GeoB01-209
DR-4B
DR-3
DR 4B TD = 350 m
DR 3 TD = 700 m

Site: DR-3C

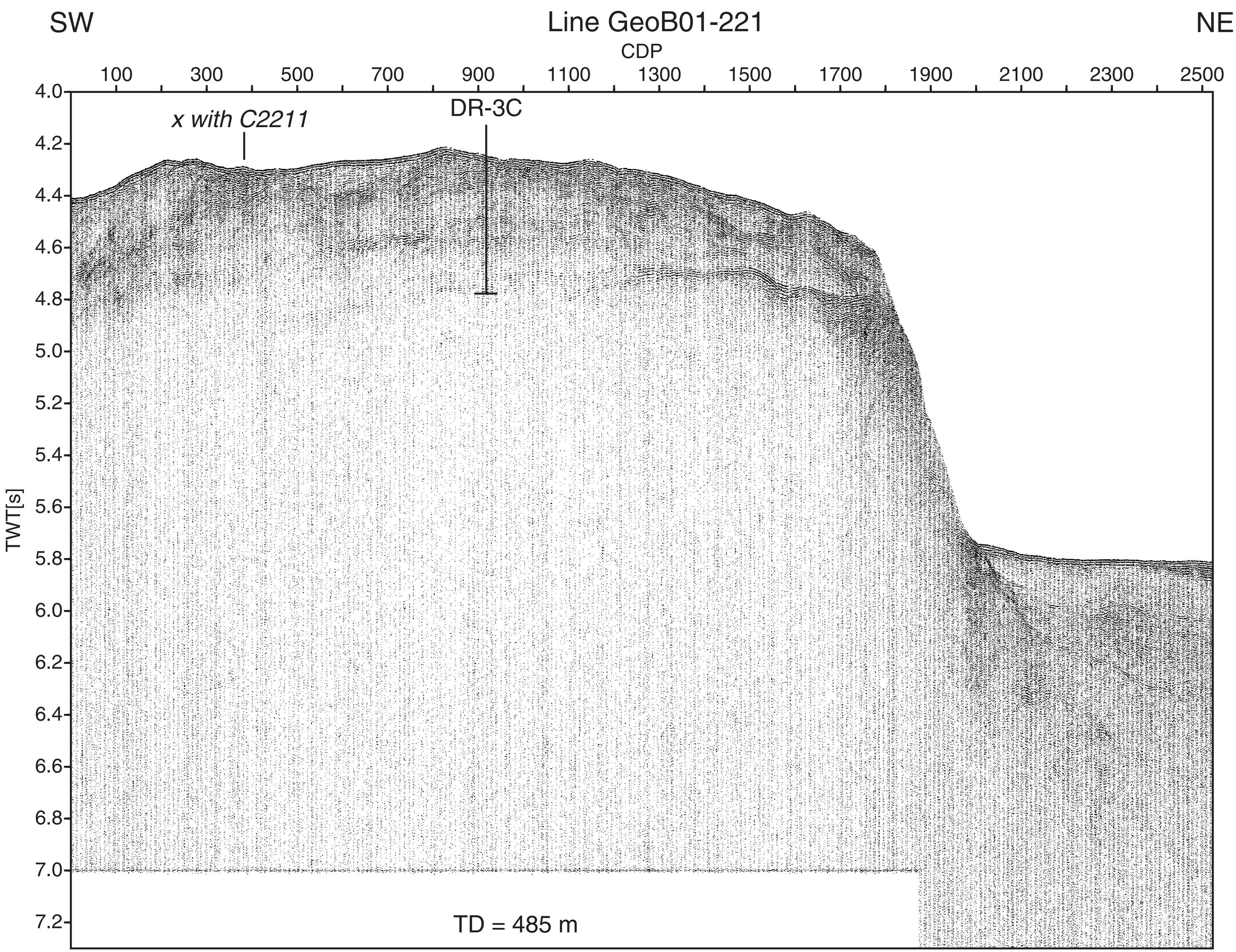
Priority: 1
Position: 9°26′N, 54°44′W
Water Depth: 3215 m
Target Drilling Depth: 485 mbsf
Approved Maximum Penetration: 485 mbsf
Seismic Coverage: Primary line GeoB01-221, crossing line C2211

Objective: Site DR-3C is located to maximize the total thickness of the black shale sequence as the deepest site in the depth transect.

Drilling Program: Triple APC/XCB to 485 mbsf.

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


SW
Line GeoB01-221
NE
CDP
100
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
TWT[s]
x with C2211
DR-3C
TD = 485 m

Site: DR-4B

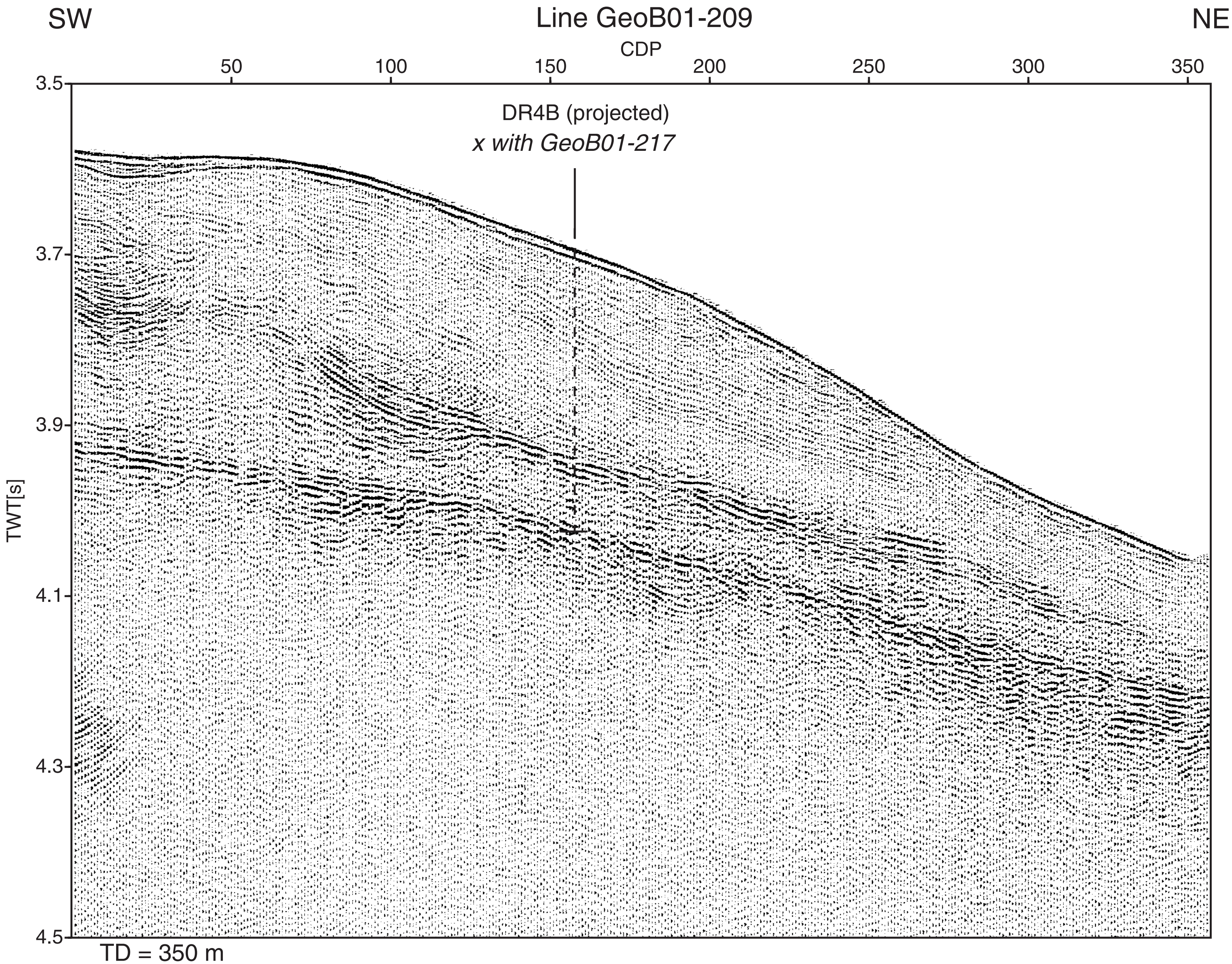
Priority: 3
Position: 9°20.5′N, 54°6.2′W
Water Depth: 2800 m
Target Drilling Depth: 350 mbsf
Approved Maximum Penetration: 350 mbsf
Seismic Coverage: Primary line GeoB01-209, crossing line GeoB01-217

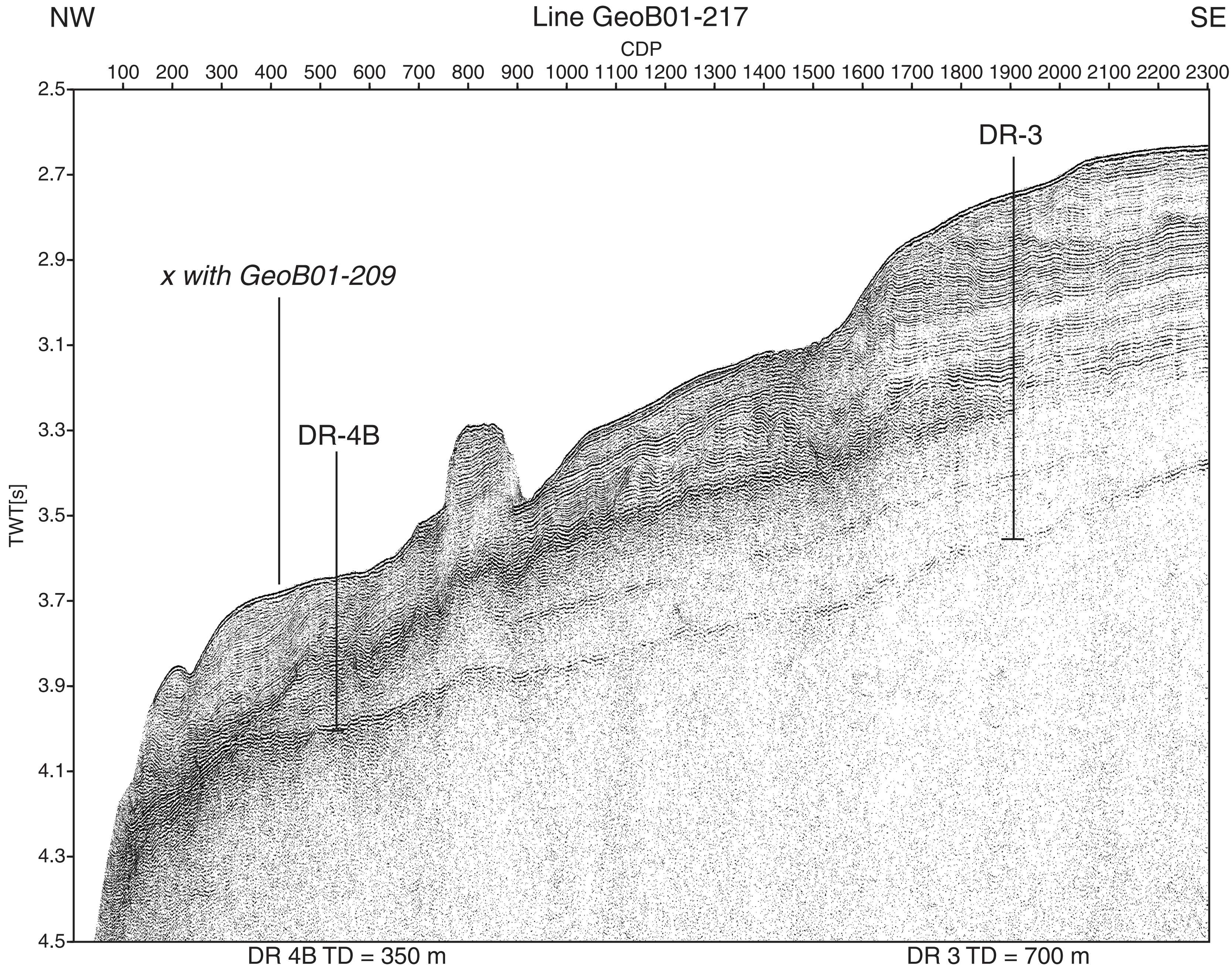
Objective: The main objective of Site DR-4B is to recover a reduced section of Oligocene to Aptian sediments serving as a comparison to deeper and shallower sites to the north and south.

Drilling Program: Triple APC/XCB to 350 mbsf.

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


SW
Line GeoB01-209
NE
CDP
50
100
150
200
250
300
350
3.5
3.7
3.9
4.1
4.3
4.5
TWT[s]
DR4B (projected)
x with GeoB01-217
TD = 350 m


NW
Line GeoB01-217
SE
CDP
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
TWT[s]
DR-3
x with GeoB01-209
DR-4B
DR 4B TD = 350 m
DR 3 TD = 700 m

Site: DR-5B

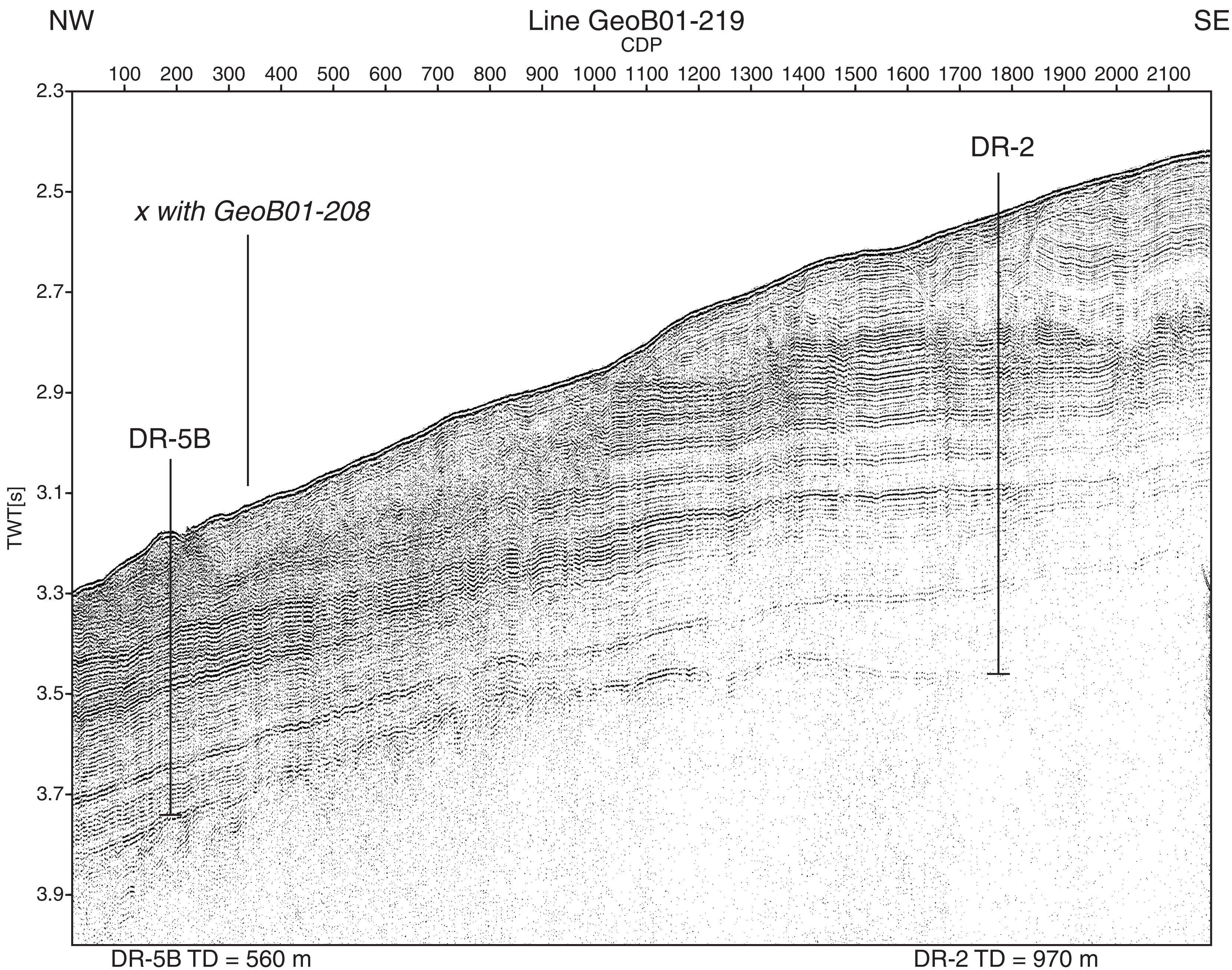
Priority: 1
Position: 9°18′N, 54°12′W
Water Depth: 2340 m
Target Drilling Depth: 560 mbsf
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: Primary line GeoB01-219, crossing line GeoB01-208

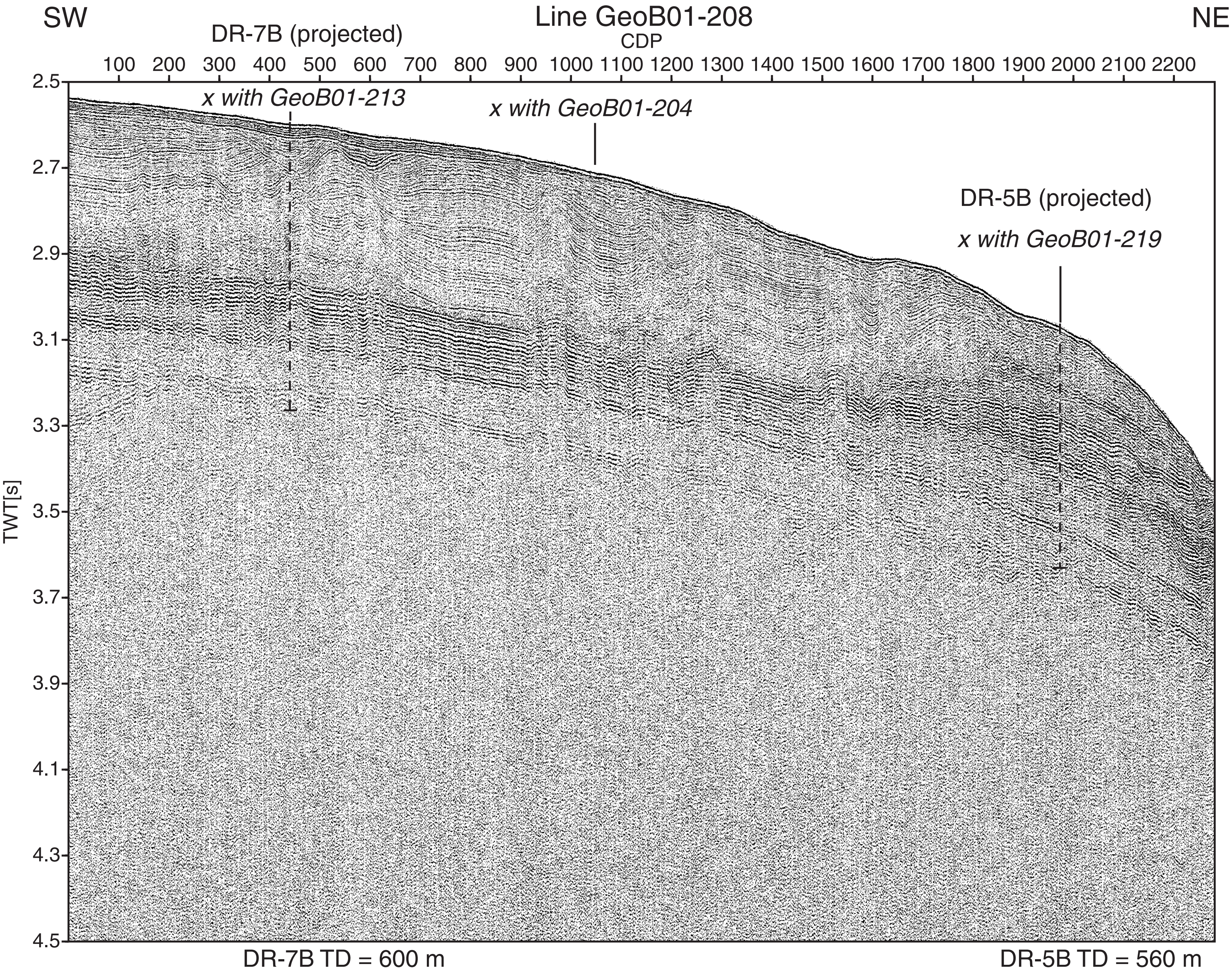
Objective: The primary objective of Site DR-5B is to recover Paleogene and Cretaceous strata at an intermediate position along the depth transect.

Drilling Program: Double APC/XCB to refusal (~560 mbsf).

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


NW
Line GeoB01-219
SE
CDP
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
TWT[s]
DR-2
x with GeoB01-208
DR-5B
DR-5B TD = 560 m
DR-2 TD = 970 m


SW
Line GeoB01-208
CDP
NE
DR-7B (projected)
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200
x with GeoB01-213
x with GeoB01-204
DR-5B (projected)
x with GeoB01-219
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
TWT[s]
DR-7B TD = 600 m
DR-5B TD = 560 m

Site: DR-6B

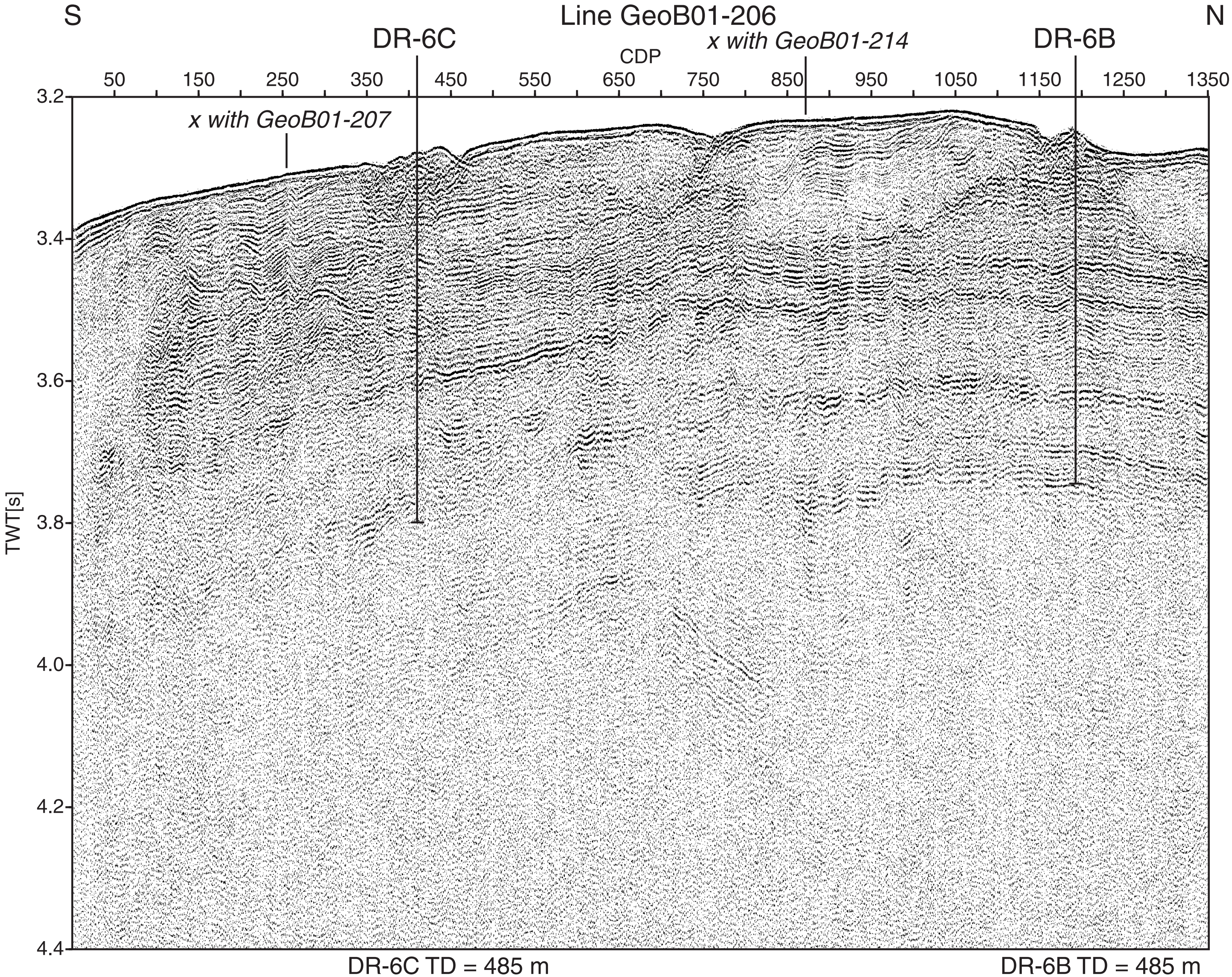
Priority: 2
Position: 9°13.6′N, 54°30.1′W
Water Depth: 2410 m
Target Drilling Depth: 485 mbsf
Approved Maximum Penetration: 485 mbsf
Seismic Coverage: Primary line GeoB01-206, crossing line GeoB01-214

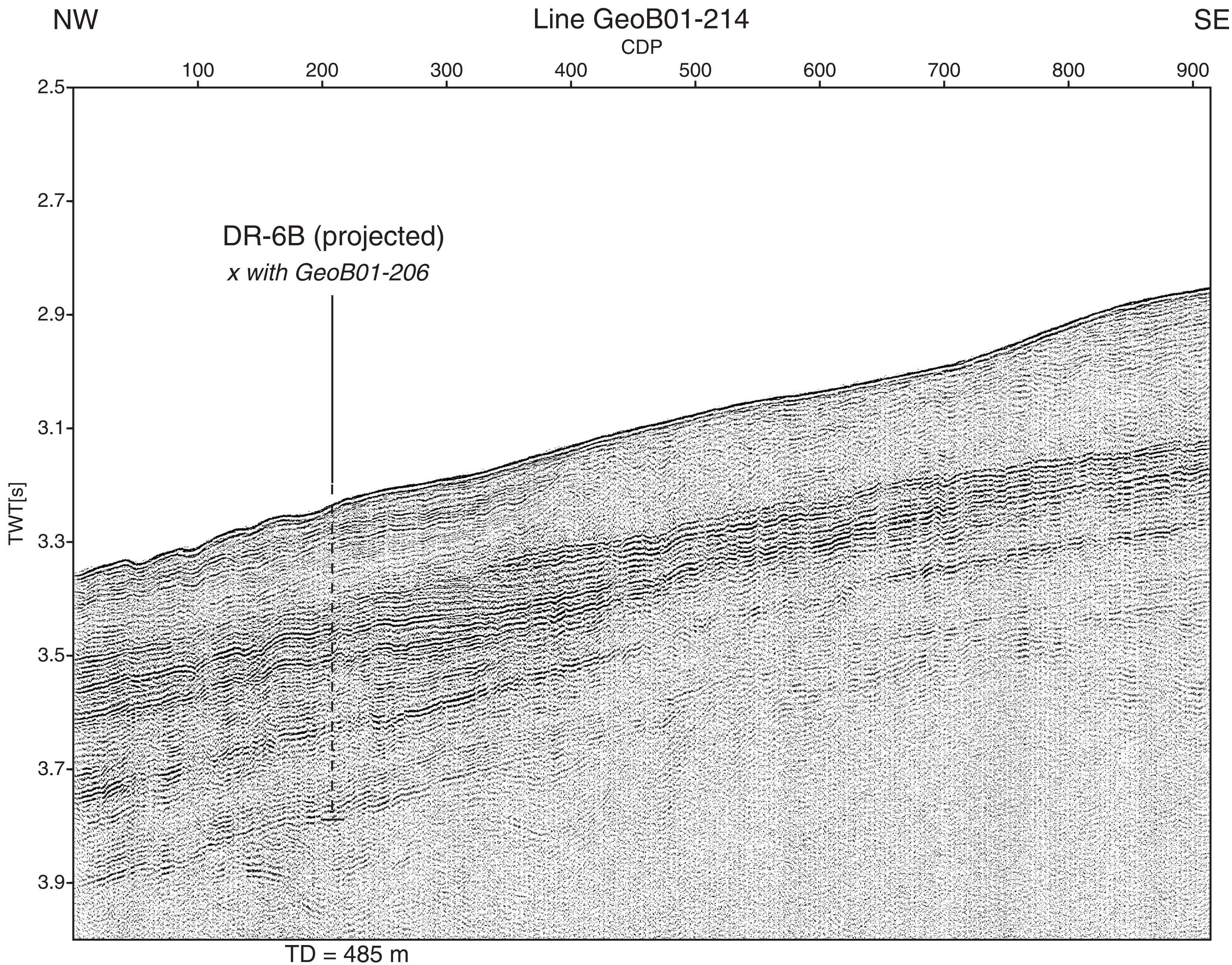
Objective: The objective of Site DR-6B is to recover shallowly buried Paleogene to Cretaceous sediments from intermediate water depths along the transect.

Drilling Program: Double APC/XCB to refusal (~485 mbsf).

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


S
Line GeoB01-206
N
DR-6C
x with GeoB01-214
DR-6B
CDP
50
150
250
350
450
550
650
750
850
950
1050
1150
1250
1350
x with GeoB01-207
TWT[s]
3.2
3.4
3.6
3.8
4.0
4.2
4.4
DR-6C TD = 485 m
DR-6B TD = 485 m


NW
Line GeoB01-214
SE
CDP
100
200
300
400
500
600
700
800
900
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
TWT[s]
DR-6B (projected)
x with GeoB01-206
TD = 485 m

Site: DR-6C

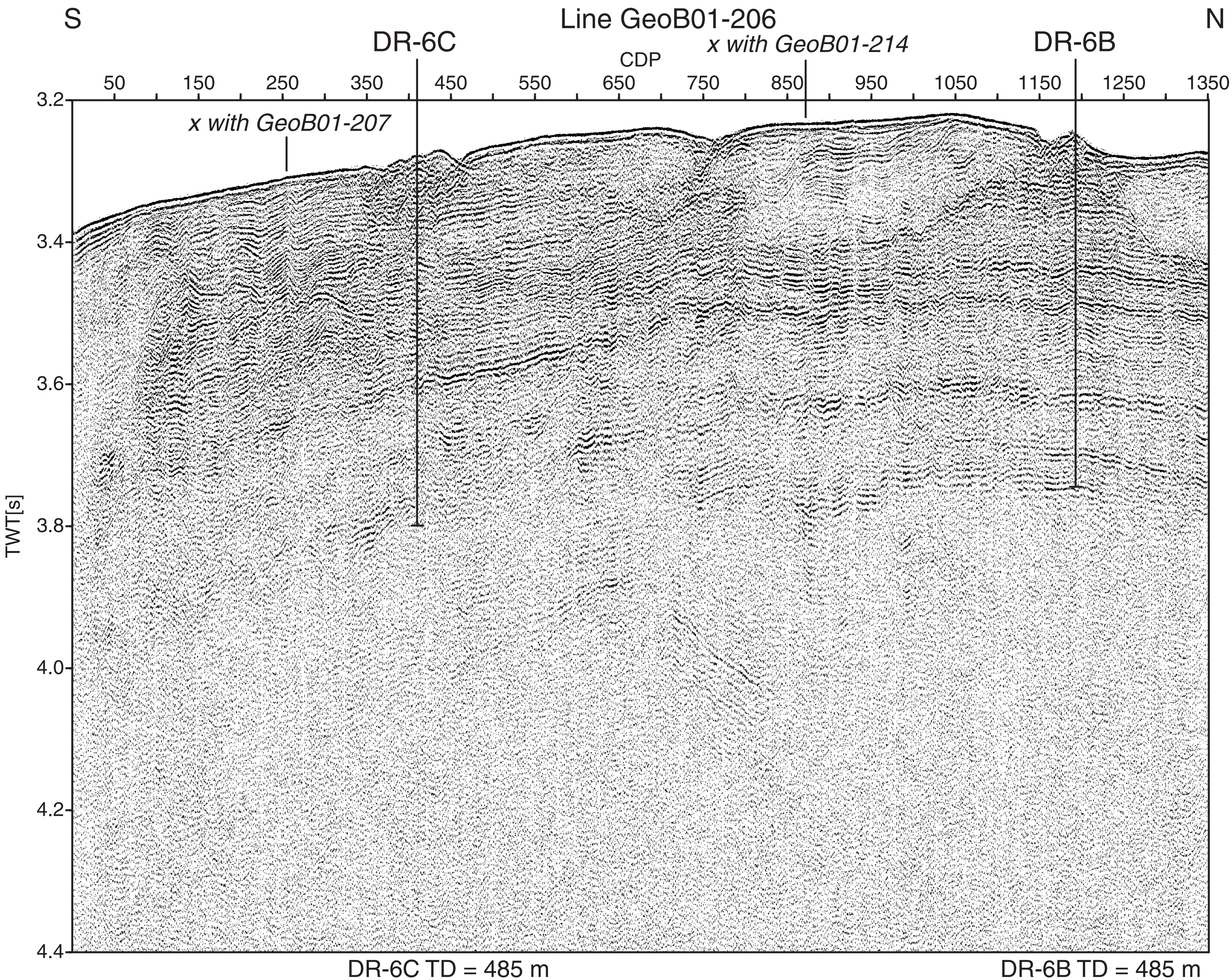
Priority: 3
Position: 9°7.3′N, 54°35.5′W
Water Depth: 2460 m
Target Drilling Depth: 485 mbsf
Approved Maximum Penetration: 485 mbsf
Seismic Coverage: Primary line GeoB01-206, crossing line GeoB01-207

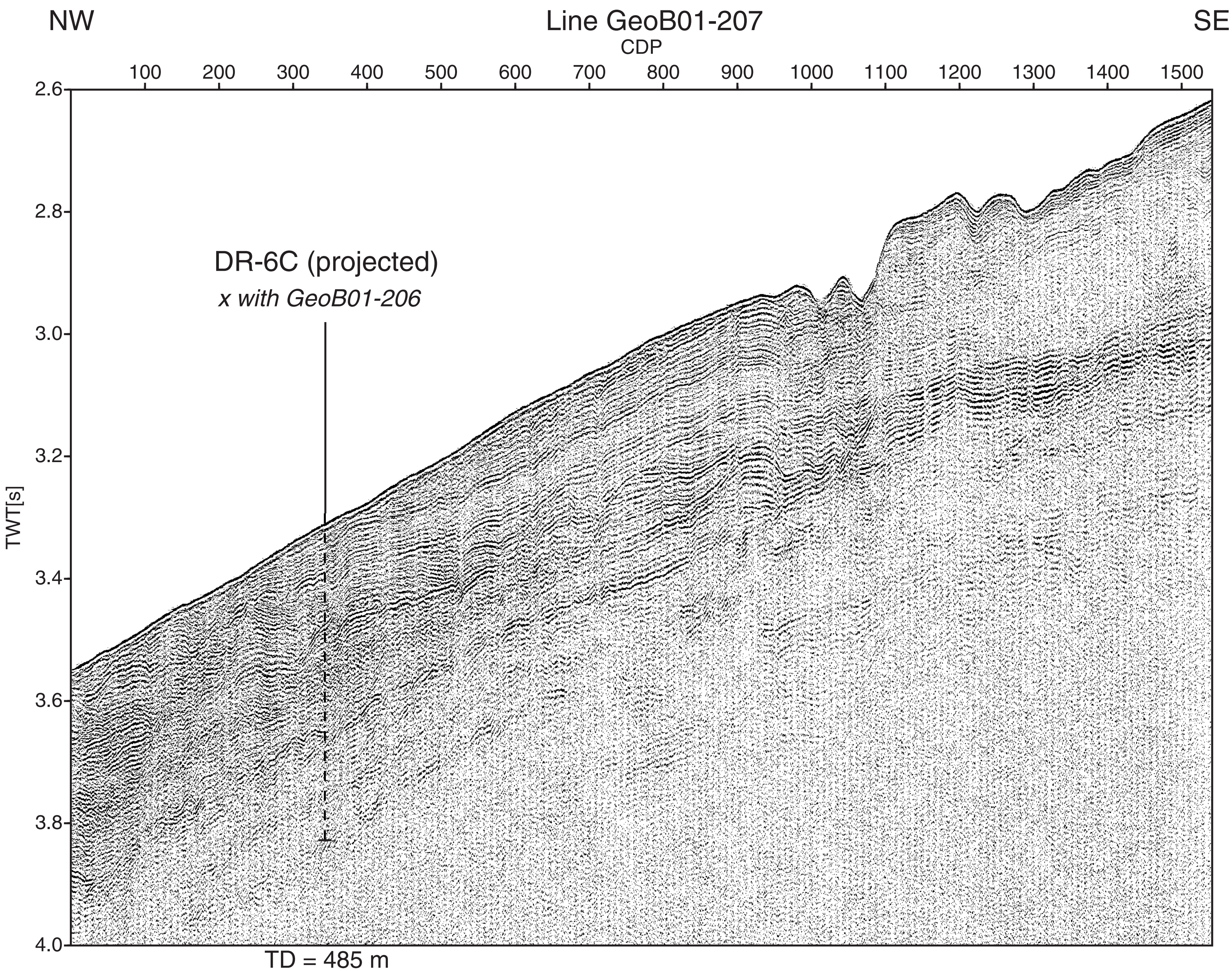
Objective: The objective of Site DR-6C is to recover shallowly buried Paleogene to Cretaceous sediments from intermediate water depths along the transect.

Drilling Program: Double APC/XCB to refusal (~485 mbsf).

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


S
Line GeoB01-206
N
DR-6C
x with GeoB01-214
DR-6B
CDP
50
150
250
350
450
550
650
750
850
950
1050
1150
1250
1350
x with GeoB01-207
TWT[s]
3.2
3.4
3.6
3.8
4.0
4.2
4.4
DR-6C TD = 485 m
DR-6B TD = 485 m


NW
Line GeoB01-207
SE
CDP
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
TWT[s]
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
DR-6C (projected)
x with GeoB01-206
TD = 485 m

Site: DR-7B

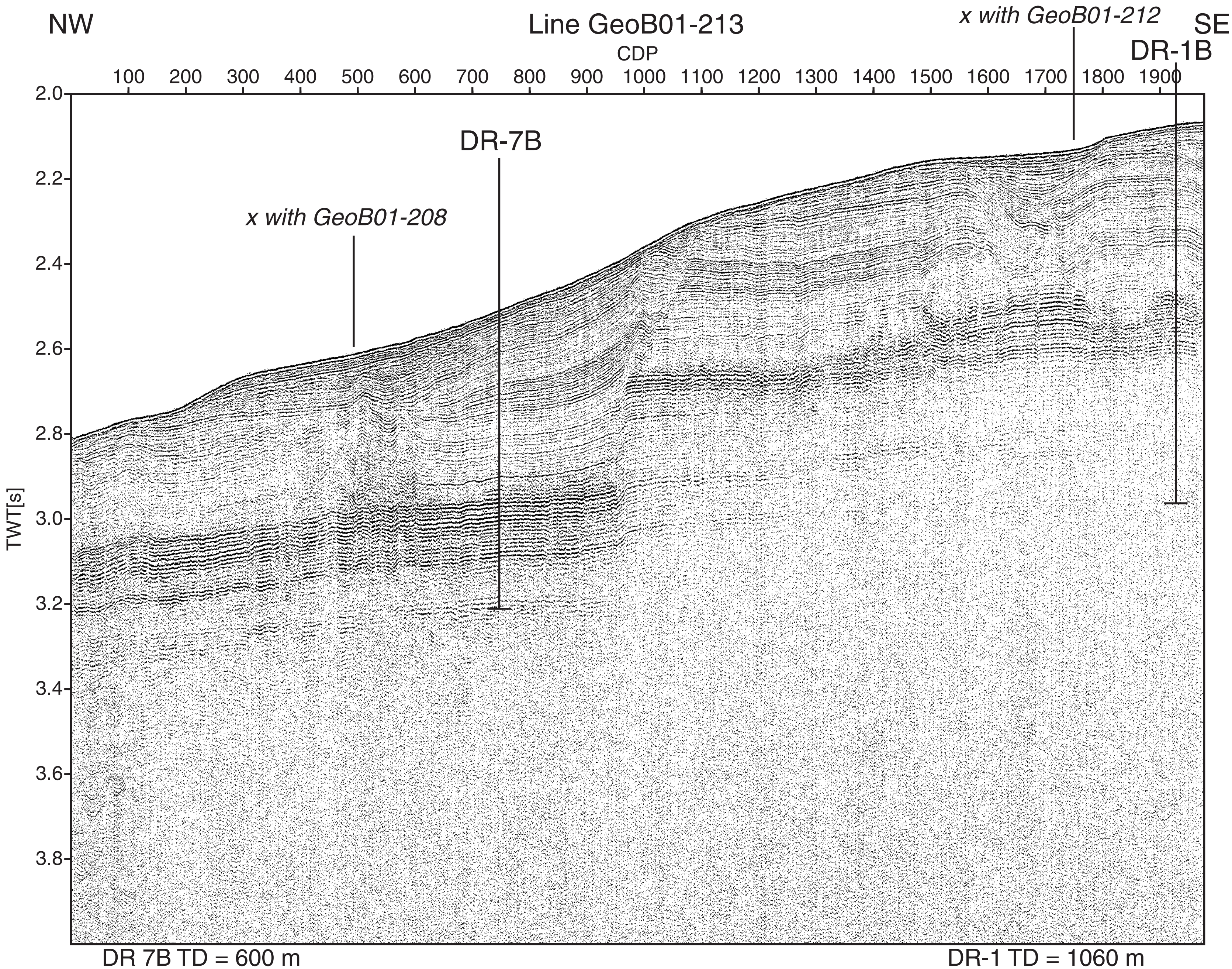
Priority: 3
Position: 9°3′N, 54°19′W
Water Depth: 1980 m
Target Drilling Depth: 600 mbsf
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: Primary line GeoB01-213, crossing line GeoB01-208

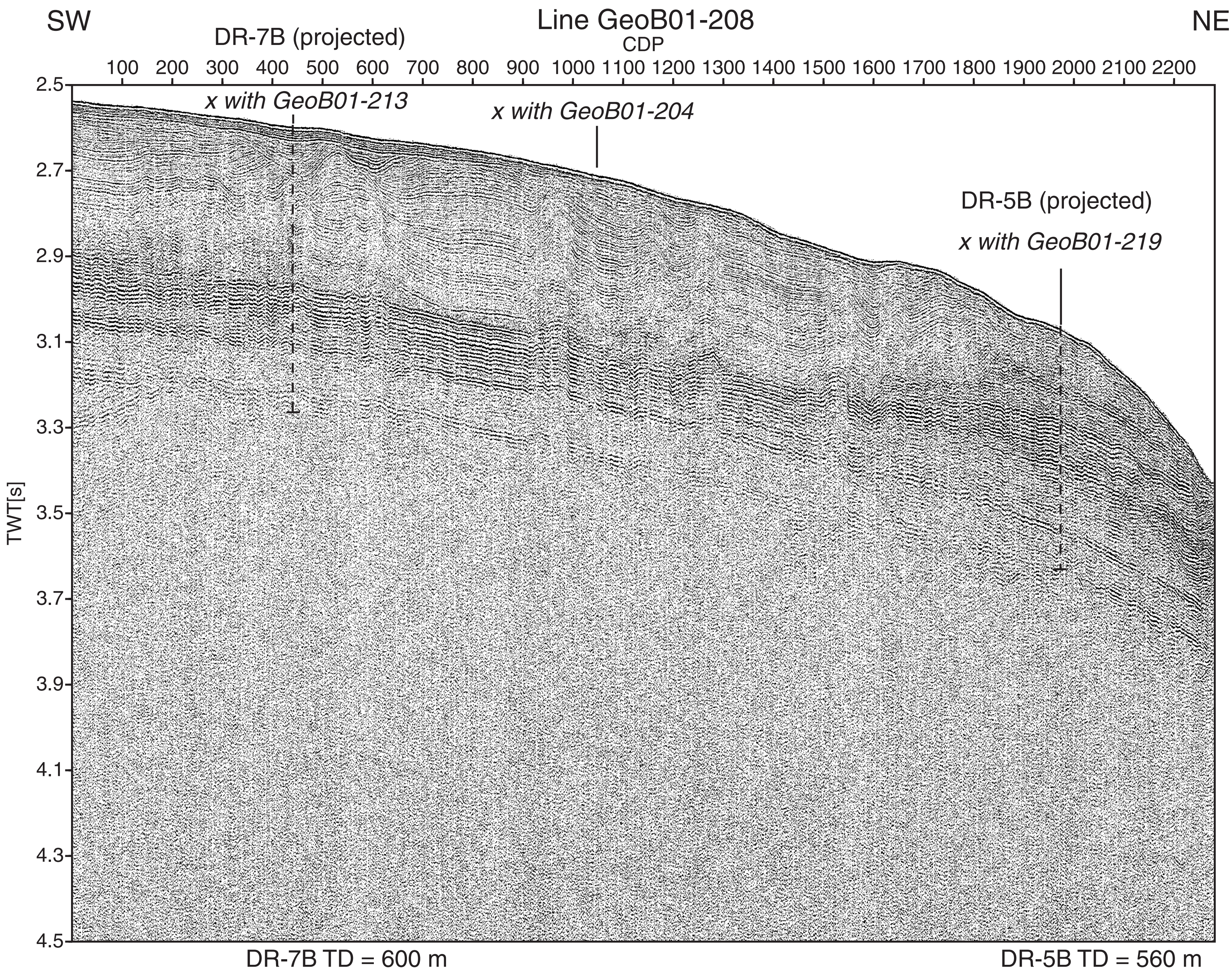
Objective: The objective of Site DR-7B is to recover Neogene through Cretaceous sediments from the shallower end of the depth transect (i.e., alternate to Site DR-2).

Drilling Program: Double APC/XCB to refusal, RCB from XCB refusal depth to 600 mbsf.

Logging Program: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


NW
Line GeoB01-213
CDP
SE
x with GeoB01-212
DR-1B
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
TWT[s]
DR-7B
x with GeoB01-208
DR 7B TD = 600 m
DR-1 TD = 1060 m


SW
Line GeoB01-208
NE
DR-7B (projected)
CDP
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200
x with GeoB01-213
x with GeoB01-204
DR-5B (projected)
x with GeoB01-219
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
TWT[s]
DR-7B TD = 600 m
DR-5B TD = 560 m

Site: DR-8B

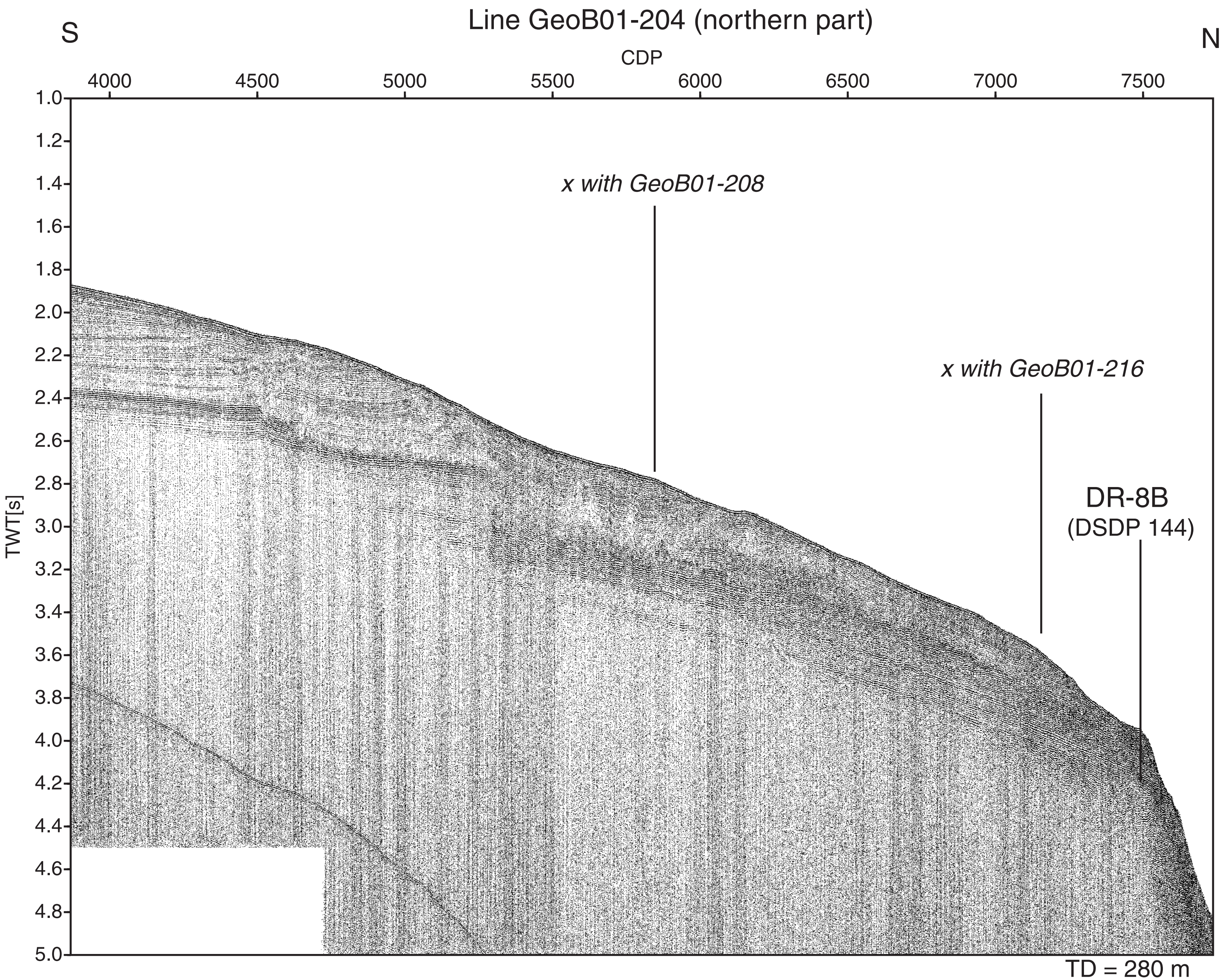
Priority: 1
Position: 9°27.23′N, 54°20.52′W
Water Depth: 2950 m
Target Drilling Depth: 280 mbsf
Approved Maximum Penetration: 280 mbsf
Seismic Coverage: Primary line GeoB01-204, crossing line GeoB01-205

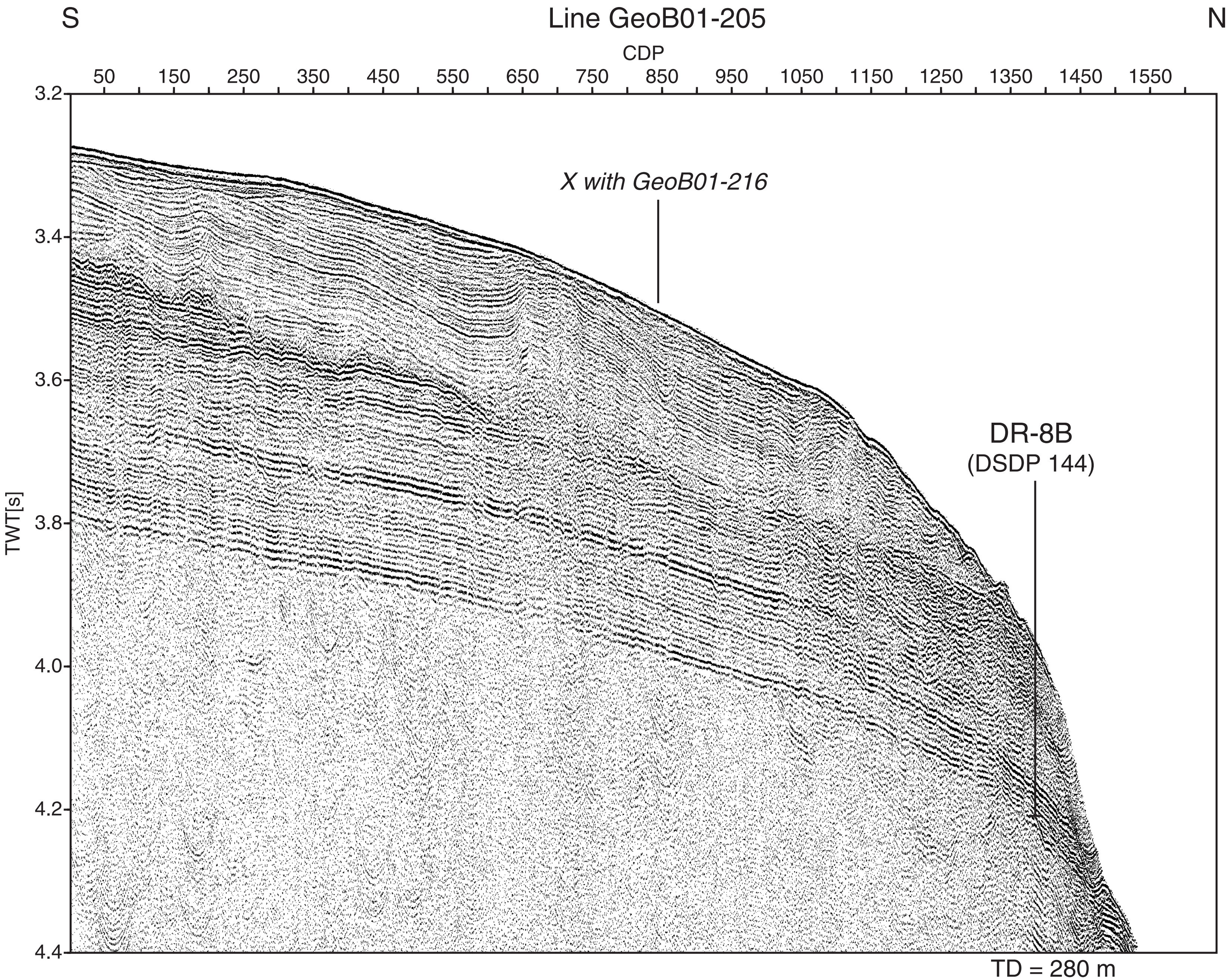
Objective: Site DR-8B is designed to recore DSDP Site 144 and recover Paleogene and Cretaceous sediments. It is the second deepest site in the transect.

Drilling Program: Triple APC/XCB to 280 mbsf.

Logging Program: Triple combo, FMS-sonic, and check shot.

Nature of Rock Anticipated: Foraminifer-nannofossil ooze, chalk, carbonaceous claystone, and black shales.


Line GeoB01-204 (northern part)
S
N
CDP
4000
4500
5000
5500
6000
6500
7000
7500
TWT[s]
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
x with GeoB01-208
x with GeoB01-216
DR-8B
(DSDP 144)
TD = 280 m


S
Line GeoB01-205
N
CDP
50
150
250
350
450
550
650
750
850
950
1050
1150
1250
1350
1450
1550
3.2
3.4
3.6
3.8
4.0
4.2
4.4
TWT[s]
X with GeoB01-216
DR-8B
(DSDP 144)
TD = 280 m

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* Incomplete and subject to change.