Integrated Ocean Drilling Program
Expedition 347 Scientific Prospectus

Baltic Sea Basin Paleoenvironment

Paleoenvironmental evolution of the Baltic Sea Basin through the last glacial cycle

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This IODP *Scientific Prospectus* is based on precruise IODP Science Advisory Structure (SAS) panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists, the Staff Scientist, 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 ECORD Science Operator Science Manager in consultation with IODP-MI.

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Abstract

During Integrated Ocean Drilling Program Expedition 347, sediments from different settings in the Baltic Sea Basin (BSB) spanning the last glacial–interglacial cycles will be cored to address four main research themes:

1. Climate and sea level dynamics of marine oxygen isotope Stage (MIS) 5, including onsets and terminations,
2. The complexities of the last glacial (MIS 4–MIS 2),
3. Glacial and Holocene climate forcing (MIS 2–MIS 1), and
4. Deep biosphere responses to glacial–interglacial cycles.

Addressing these themes will be accomplished by drilling in six subbasins: one in the gateway of the BSB (Anholt Loch), focusing on sediments from MIS 6–MIS 5 and MIS 2–MIS 1; a subbasin in the southwesternmost part of the BSB (Little Belt) that possibly retains a unique MIS 5 record; two subbasins in the south (Bornholm Basin and Hanö Bay) to target long complete records from MIS 4–MIS 2; and one deep (450 m) subbasin in the central Baltic Sea (Landsort Deep) that contains a thick and continuous record of the last ~14,000 y. Finally, the subbasin in the very north (Ångermanälven River estuary) contains a unique varved (annually deposited) sediment record of the last >10,000 y. These six areas contain a combined suite of sediment sequences encompassing the last ~140,000 y, with paleoenvironmental information on a semicontinental scale, as the Baltic Sea drains an area four times as large as the basin itself.

The location of the BSB in the heartland of the recurrently waning and waxing Scandinavian Ice Sheet (SIS) has resulted in a complex development history including repeated glaciations of different magnitude, sensitive responses to sea level and gateway threshold changes, large shifts in sedimentation patterns, and high sedimentation rates. Its position also makes it a unique link between Eurasian and northwest European terrestrial records. Therefore the sediments of this largest European intracontinental basin form a rare archive of climate evolution over the last glacial cycle. The high sedimentation rates provide an excellent opportunity to reconstruct climatic variability of global importance at a unique resolution from a marine-brackish setting in a location where comparable sequences from the surrounding onshore regions cannot be obtained.

Furthermore, the large variability (salinity, climate, sedimentation pattern, and oxygenation) that the BSB has undergone during the last glacial cycle makes it optimal

for new research on the deep biosphere, addressing questions such as its evolution, its biogeochemical processes, and how the postglacial diffusive penetration of conservative seawater ions may alter the chemical composition and microbial physiology in the subseafloor biosphere.

Schedule for Expedition 347

Integrated Ocean Drilling Program (IODP) Expedition 347 is based on IODP drilling Proposal 672. Following ranking by the IODP Science Advisory Structure, the expedition was scheduled as a Mission Specific Platform (MSP) expedition, operating under contract with the European Consortium for Ocean Research Drilling (ECORD) Science Operator (ESO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in spring/summer 2013, with a total of 60 days available for the drilling, coring, and downhole measurements described in this report and on the ESO Expedition 347 web page. The Onshore Science Party (OSP) is provisionally scheduled for autumn 2013.

The following links should be used in conjunction with this *Scientific Prospectus*:

- For the latest Expedition 347-specific platform, facilities, coring strategy, measurements plan, scheduling, and port call information, please see the ESO Expedition 347 web page at **www.eso.ecord.org/expeditions/347/347.php.**
- For general details about the facilities provided by ESO offshore, please see **www.marum.de/en/Offshore_core_curation_and_measurements.html.**
- For general details about the facilities provided by ESO at the Onshore Science Party, please see **www.marum.de/Onshore_Science_Party_OSP.html.**

The supporting site survey data for Expedition 347 are archived in the **IODP Site Survey Data Bank.** Please note that not all site survey data associated with this expedition are publicly available.

Introduction

The Baltic Sea Basin: its suitability, results, and promise

The Baltic Sea Basin (BSB) proposal addresses four overarching themes:

1. Climate and sea level dynamics of marine oxygen isotope Stage (MIS) 5, including onsets and terminations,
2. The complexities of the last glacial (MIS 4–MIS 2),
3. Glacial and Holocene climate forcing (MIS 2–MIS 1), and
4. Deep biosphere responses to glacial–interglacial cycles.

These themes will be addressed by the sedimentary records contained within the BSB.

The BSB is one of the world's largest intracontinental basins, occupying 373,000 km^2 and with a drainage area four times its size (Fig. F1). Its mean depth is ~54 m, although a few relatively deep basins exist (e.g., the Eastern Gotland Basin [248 m] and the Landsort Deep [459 m]). The BSB has served as depositional sink throughout at least the last several hundred thousand years, and its sediments comprise a unique high-resolution archive of the paleoenvironmental history of the huge drainage area, the basin itself, and neighboring sea areas. The location of the BSB in the heartland of a recurrently waning and waxing ice sheet, the Scandinavian Ice Sheet (SIS), has resulted in a complex developmental history, characteristic for many glaciated regions of the Northern Hemisphere: repeated glaciations of different magnitudes, sensitive responses to sea level and gateway threshold changes, large shifts in sedimentation patterns, and high sedimentation rates.

The BSB's position also makes it a unique link between the Eurasian and the northwest European terrestrial records and as such also serves as a link to North Atlantic marine records and Greenland ice cores. Analysis of terrestrial, marine, and ice archives combined with numerical modeling (e.g., Levine and Bigg, 2008) have shown that North Atlantic Ocean circulation plays an important role in the global climate system, affecting North America and Europe in particular, but also seems closely linked to the Asian monsoon system (Wang et al., 2001), for example. The position of the BSB roughly halfway between North Atlantic-Greenland and Asia represents a link that preserves the continental response to these oceanic forcings. These unique factors help explain why the sediments of this largest European intracontinental basin form a unique archive of climate evolution over the last glacial cycle.

The high sedimentation rates (100–500 cm/1000 y) of the BSB provide an excellent opportunity to reconstruct climatic variability of global importance at unique resolutions from a marine-brackish setting—some of the sediments can be resolved on interannual timescales—controlled by, for example, changes in Meridional Overturning Circulation (MOC), the North Atlantic Oscillation (NAO), and the Arctic Oscillation

(AO). This makes the BSB unique for sampling sediments from the last glacial cycle and the sole location to achieve these scientific targets, as comparable sequences cannot be retrieved anywhere in the surrounding onshore regions.

Decades of marine geological and geophysical research in the BSB have given us a good understanding of the thickness and distribution of the Quaternary deposits, but no (deep) drilling for scientific purposes has been performed. Our knowledge of the development of the BSB is currently based on short cores as long as 20 m, the majority of which are only half that length or shorter, and regional interpretations mainly based on terrestrial records. Marine geophysical data show, however, that much thicker and apparently undisturbed sediment sequences exist from the last glacial cycle, and until now we have merely scraped the surface of the Baltic's paleoenvironmental records.

The proposal outlined here addresses many of the main themes in the IODP science plan, particularly "Environmental changes, processes and effects," such as "External forcing of environmental change," "Environmental change induced by internal and external processes," and the initiative on "Rapid climate change." We will focus on fundamental scientific questions related to the global, hemispheric, and regional paleoenvironmental evolution of the last glacial cycle, especially the climate, glacial, and sea level history.

Scientific themes

1. Climate and sea level dynamics of MIS 5, including onsets and terminations

Last Interglacial (Eemian, Mikulino, MIS 5e; ~130–115 ka) deposits have been described from a number of marine and terrestrial sites, but are only partly documented in the North Greenland Ice Core Project (NGRIP) ice core (Andersen et al., 2004). A land-sea correlation of European pollen zones and marine isotope stages was presented for the first time by Sánshez-Goñi et al. (1999), who demonstrated a delay between the beginning of MIS 5e and that of the European terrestrial Eemian (discussed by Kukla et al., 2002). High-resolution Eemian marine shelf records (here correlated with MIS 5e) from northern Europe are, however, very scarce and usually contain only fragmented paleoenvironmental information. The same is valid for the early Weichselian stadials and interstadials (MIS 5d to 5a), which were, however, fully recovered in the NorthGRIP ice core.

Data from marine sediments in the Nordic Seas show three substantial sea-surface temperature fluctuations during MIS 5e (Fronval and Jansen, 1996). The study implies that the Last Interglacial at high northern latitudes was characterized by rapid changes in Polar Front movement, ocean circulation, and oceanic heat fluxes. This may have resulted in noticeable temperature changes in neighboring land areas, which is different from Holocene climate development, where only minor fluctuations occurred within a general cooling trend.

From presently onshore Eemian (MIS 5e) records we know that the BSB Eemian began with a lacustrine phase covering ~300 y before marine conditions were established (Kristensen and Knudsen, 2006), and higher mean sea-surface and seafloor temperatures (~6°C) and salinities (~15‰) than today characterized the first ~4 k.y. of the Eemian Baltic Sea (Kristensen and Knudsen, 2006; Funder et al., 2002). During the first 2–2.5 k.y. a pathway existed between the Baltic Basin and the Barents Sea through Karelia, but to what degree it was of importance for general ocean circulation and the climate of northern Europe is debatable (Funder et al., 2002). This circulation pattern and these high salinities may have created strong salinity stratification and the development of a permanent halocline resulting in hypoxic bottom conditions during large part of the Eemian—conditions akin to the development of the Baltic Sea during the last 8000 y and today's situation. Also, the difference between the warm and well-ventilated southwestern Eemian BSB and the cold, stagnant conditions of its easternmost parts implies that the ocean–continental climate gradient from the west to the east in northern Europe was steeper than during the Holocene (Funder et al., 2002). After ~6 k.y. into the interglacial, the Eemian Baltic Sea was characterized by a falling sea level and decreased salinity as observed in the diatom and foraminifer records (Eiríksson et al., 2006; Kristensen and Knudsen, 2006), but its further development during the subsequent MIS 5 stadials and interstadials is largely unknown.

Theme-specific scientific objectives

The following are theme-specific scientific objectives for Expedition 347:

- To increase our understanding of the climatic system and the sea level dynamics of the Last Interglacial, including the climatic oscillations at the transition between MIS 6 and MIS 5e and in the initial, climatically oscillating part of the last glacial (MIS 5d–5a).
- To contribute to an increased understanding of links between oceanic and terrestrial climate systems, including circulation patterns, during the highly variable MIS 5.

- To analyze environmental conditions during the warmest interval of MIS 5e to elucidate possible future scenarios during warmer climate and higher sea level stands.
- To improve our understanding of the response of the anthropogenically untouched Eemian (MIS 5e) Baltic Sea ecosystem to different environmental forcing factors to enhance the possibility of distinguishing anthropogenic factors from natural driving mechanisms behind presently threatened semienclosed basin environments and ecosystems.

2. The complexities of the last glacial, MIS 4–MIS 2

Since the confirmation of the high climate variability during the last glacial in the MIS 4–MIS 2 interval from the Greenland Ice Core Project (GRIP) and Greenland Ice Sheet Project 2 (GISP2) Greenland ice core records (Johnsen et al., 1992; Grootes et al., 1993), paleoclimatologists have been presented with several corresponding records, both from the marine and terrestrial North Atlantic margins (Rasmussen et al., 1997; Dickson et al., 2008; Grimm et al., 2006; Wohlfarth et al., 2008). The huge ice sheets in Eurasia—of which the SIS was the largest—and North America played major roles for this high degree of variability. The impact of sea ice and icebergs (e.g., Dokken et al., 2003), as well as glacial advances and retreats, upon the North Atlantic marine system by their interaction with the MOC were most likely key players in the variable climate pattern of the last glacial. The direct effects of this variability were best registered in proximal areas to the ice sheets. It is therefore essential to gather modern and detailed stratigraphic information from the "sediment trap areas" of these two main glaciated regions, of which the Baltic Basin is the main one for the SIS, to decipher, date, and analyze the recurrent stages of ice-covered and ice-free conditions.

The Baltic glacial history is only fragmentarily known, but we know that a first Baltic glacial event occurred during MIS 4 as recorded in sediments from northwest Finland at ~64°N (Salonen et al., 2007), whereas the first Baltic ice lobe advance into Denmark is dated to ~55–50 ka (Houmark-Nielsen, 2007). It is likely that freshwater lakes covered the deeper subbasins of the central and southern BSB until at least 60 ka, when sea level was >50 m lower than today (Lambeck and Chappell, 2001; Siddall et al., 2003). The Hanö Bay, Bornholm, and Landsort Deep Basins must have been infilled with sediments over several tens of millennia (40–60 ka?), through the first half of the last glacial. The BSB then experienced a more dynamic and variable glacial-interstadial development during the remaining parts of the glacial.

There are several indications that the southern Baltic may contain rich and more or less complete stratigraphies of MIS 3. From detailed correlations and dating of the southwestern Baltic glacial stratigraphies, Houmark-Nielsen and Kjær (2003) and Houmark-Nielsen (2007, 2008) conclude that the southwest Baltic may have experienced two major ice advances during MIS 3, at ~50 and 30 ka. The latter advance is being vividly discussed (Wohlfarth, 2009), as well as the general asynchroneity of MIS 3 ice advances at the western margin of the SIS (Mangerud, 2004) compared to ice margins in the south (Houmark-Nielsen et al., 2005).

This partly enigmatic period between ~50 and 25 ka with its partly incompatible records is followed by complex glaciation in the southern BSB (Houmark-Nielsen and Kjær, 2003) leading up to the Last Glacial Maximum (LGM). Furthermore, previous offshore studies in the southern Baltic have documented the presence of marine-brackish sediments, dated to MIS 3 or older, that were overridden by a glacier (Klingberg, 1998) at Kriegers Flak (Fig. F2), and two varved clay sequences—the upper one dates from the last deglaciation—separated by an organic-rich layer dated to >35 ka ^{14}C before present (BP) (bulk date) in Hanö Bay (Björck et al., 1990). Also, and maybe even more significant, an ongoing study of the shallow Kriegers Flak area shows a surprisingly complex stratigraphy (Fig. F2) with a variety of lithologic units, gravel-sand-silt, clays of glaciolacustrine and brackish origin, interstadial lacustrine gyttja (lake mud), and peat with ages of 39 and 41 ka BP, sandwiched between several glacial diamicts (Anjar et al., 2010).

A complicating and key factor for the BSB history is the geographic location and altitude (in relation to sea level) of the critical threshold, or “gateway,” between the open ocean and the BSB, which determines if and how much marine water can enter the BSB. Today the two main thresholds are the Öresund Strait (7 m below present sea level) and the Store Belt (~20 m below present sea level). However, the bedrock threshold of the BSB is situated 60 meters below sea level (mbsl), with the buried Alnarp-Esrum bedrock valley (SWECO VIAK, 2004) running through southwest Skåne in Sweden and northernmost Själland in Denmark, 120 km long and 6 km wide (Fig. F2). From deep coring in the 1970s of this main aquifer, fluvial and lacustrine sediment units were more or less reliably ^{14}C dated (ages summarized by Anjar et al., in press), implying that the valley was sediment filled during the latter part of MIS 3. The valley thus served as the outlet river route for the complete BSB until it was filled with sediment. Clearly, the age of this last infilling is crucial for the younger sedimentation history of the basin, including relationships between sea level and the BSB during MIS 3. The 128 cores from drilling undertaken during planning of the Kriegers Flak windmill park, of which Figure F2 shows 9, indicate that complex yet incomplete stratigraphies occur in this shallow part of the BSB. These incomplete stratigraphies imply that the nearby deep basins, Bornholm Basin and Hanö Bay, hold more complete stratigraphies; the old organic mud between two units of undisturbed varved clay in Hanö Bay shows that this basin contains long records, which is also supported by seismic data. These subbasins are controlled by bedrock topography and should potentially have better preserved pre-LGM sediment records compared to other deep subbasins carved out by the last deglaciation ice streams, where older sediments have been stripped off and piled up in arch-shaped end moraines along the Baltic coastlands.

Theme-specific scientific questions and objectives

We hypothesize that deeper bedrock-controlled basins in the southern BSB were left more or less untouched by the erosive powers of surging glaciers, supported by the Kriegers Flak and Hanö Bay records. By combining shallow offshore drilling and the land-based stratigraphy around the southern Baltic with more complete sedimentary archives in the two deep basins of the southern BSB, we will be able to address crucial scientific issues, including the following:

- To what degree did the SIS respond, in time and space, to North Atlantic climate forcing during the last glacial, and to what extent did its dynamics have an impact on the North Atlantic climate system?
- What were the feedbacks between the water body of the BSB, the SIS, and North Atlantic circulation?
- To what degree are the glacier oscillations of the SIS margin synchronous on either side of the main ice divide, centered along the Scandinavian mountain chain, and can the advances into the southern BSB be recognized as large-scale surges? Can the substantial ice advances into the southernmost BSB be verified, perhaps triggered by rapid North Atlantic warming, paving the way for Heinrich events, or were large parts of the BSB ice free (Fig. F3) during most of MIS 3?
- More specifically, how well is the highly oscillating climate pattern of MIS 3 recorded at the northeast margin of the North Atlantic as long continuous buried sediment sequences in the BSB? How did this huge drainage area react to these large-scale circulation changes? The southern BSB may hold unique archives of this time period; many large rivers drain into the basin and make the archives relevant on a semicontinental basis.

- We need better constrained modeling of the SIS with its global and regional isostatic and eustatic impacts (Lambeck et al., 1998a, 1998b). This modeling requires better knowledge of the glacial chronology and dynamics, as well as of the BSB threshold history; long archives of this development are believed to exist at some of the proposed drill sites.

3. Deglacial and Holocene (MIS 2–MIS 1) climate forcing

The deglaciation of the southern BSB between 22 and 16 ka was complex, with major deglacial phases interrupted by some intriguing still-stands and even re-advances (Houmark-Nielsen and Kjær, 2003), possibly as surges. More or less complete varved sedimentary records of this dynamic period may be found in the basins of Hanö Bay and Bornholm Basin. Low-lying areas were dammed up in front of the retreating ice front comprising the Baltic Ice Lake (BIL), and huge amounts of freshwater were released into the North Atlantic during this dynamic phase of the deglaciation between ~16 and 11.7 ka (Gyldenholm et al., 1993; Björck, 1995; Majoran and Nordberg, 1997; Jiang et al., 1998). During the final drainage of the BIL at ~11.7 ka almost 8000 km^3 of freshwater was released rapidly into the North Atlantic (Jakobsson et al., 2007), but the effects on North Atlantic thermohaline circulation may only have been minor (Andrén et al., 2002). However, it has also been suggested that it may have triggered the Preboreal Oscillation (Björck et al., 1996), as well as ice advances in northern Norway (Hald and Hagen, 1998). The oceanographic effects of the drainages should be registered in varved sediments at the Anholt Loch site. Earlier studies have suggested that the Younger Dryas cold period was caused by freshwater runoff from the Laurentide (American) Ice Sheet (Marshall and Clark, 1999), but the influence of the Baltic region has not been studied in detail.

At ~10 ka the complete BSB was deglaciated, and during the entire course of deglaciation, varved glacial clay was deposited in front of the retreating ice sheet. These deposits have been used to date the ice recession and postglacial events; varves are still being deposited in the Ångermanälven River estuary, providing a link to present time (Cato, 1985). Although we know that this long series of varved sediments should contain at least 10,000 y of historical deposition records in the estuary, it has not been possible to explore the potential of this record. We know that correlation exists between maximum daily discharge and mean varve thickness during the last 2000 y in the Ångermanälven River (Sander et al., 2002) (Fig. **F4**).

The region's geographic location makes it possible to use these unique laminated sediment archives to reconstruct atmospheric (e.g., shifts in NAO and AO variability) and oceanic (e.g., effects of changes in the strength of MOC) circulation patterns during the Holocene. These patterns might also reflect changes in Equator-to-pole teleconnections (e.g., in El Niño Southern Oscillation [ENSO]–related variability). In addition, the estuarine site reflects the precipitation records over a wide area and helps to integrate the many lake record data available.

Precipitation and evaporation are critical parameters for understanding the ecosystem functioning of the Baltic Sea, affecting salinity through dilution, vertical mixing, and river inflow. These parameters are closely related to changes in atmospheric circulation, which modify also the inflow of saline waters through the thresholds. Salinity determines stratification (together with temperature) and thus controls the extent of hypoxia and the health of the ecosystem in this enclosed sea.

The south–north transect of Baltic Sea sites will allow detailed reconstructions of Holocene hydrologic and climatic changes influencing the whole BSB. The sensitivity of the BSB system with respect to changes in sea level/salinity, productivity, hydrology/river discharge, and atmospheric circulation is a well-known fact (Zillén et al., 2008). With the planned IODP sites this sensitivity could be explored in much more detail regarding underlying mechanisms.

Laminated sediments are used as a proxy for hypoxic bottom conditions and are formed during periods with strong permanent salinity stratification, probably as a result of increased evaporation/decreased precipitation and possibly also by enhanced primary productivity. Laminated sediments in the deep basins of the Baltic Sea (e.g., Andrén et al., 2000a; Zillén et al. 2008) indicate that the open Baltic Sea ecosystem has passed certain thresholds and experienced several regime shifts during its environmental history. These high-resolution sediment records provide an excellent archive to study the long-term patterns of, for example, atmospheric circulation (such as the variability of the NAO and its trends and strength) during the Holocene.

Theme-specific scientific questions

- What are the details of climate evolution in northwestern Europe during the deglacial phase and the Holocene (MIS 2–MIS 1), and what are the forcing mechanisms as deduced from a north–south transect of Baltic subbasins with ultra-high resolution?

- What are the main mechanisms behind hypoxia driving processes in the Baltic, and to what degree have past and recent human activities played a role?
- How has Baltic in- and outflow varied over time, and how is this related to changes in large-scale atmospheric circulation and sea levels (threshold depths)?
- More specifically: is there a solar forcing signal in the melting record of a shrinking ice sheet (glacial varves at proposed Site BSB-9) or in the precipitation related fluvial system (postglacial varves at proposed Sites BSB-10 and BSB-11)? Can we reconstruct river discharge (and thereby also precipitation) with annual resolution, several millennia back in time? How did the general precipitation pattern, which is linked to the dominating AO/NAO system over the northern circum-Atlantic and circum-Arctic region, change over the Holocene (proposed Sites BSB-10 and BSB-11)? Are there periodicities in these changes, or are they linked to the large-scale insolation trend?

4. Deep biosphere responses to glacial–interglacial cycles in Baltic Sea Basin sediments

The discovery of microorganisms in deep subsurface sedimentary deposits, and even in basement rock, has profoundly changed our perspective on the limits of living organisms on our planet (Parkes et al., 1994, 2005; D'Hondt et al., 2004; Jørgensen et al., 2006). The current database of prokaryotic cells in deep sediment cores indicates that the marine deep biosphere may comprise 10% of all living biomass and more than half of all microorganisms on Earth (Whitman et al., 1998). The population densities, 10^4–10^7 cells per cubic centimeter to >1500 m sediment depth (Roussel et al., 2008), are greater than those found in ocean water.

Understanding the minimum energy requirements for growth and survival may offer a means of interpreting the distribution, composition, and activity of deeply buried communities (cf. Schink, 1997; Hoehler, 2004; Jackson and McInerney, 2002; Jørgensen and D'Hondt, 2006). With increasing depth and age of marine sediments, microbial cells become increasingly energy limited (D'Hondt et al., 2002, 2004; Schippers et al., 2005; Biddle et al., 2006). How is it possible to maintain complex functions in prokaryotic cells at an energy flux that barely allows cell growth over many years? Are the deeply buried communities relicts of a time when the sediment was originally deposited (Inagaki et al., 2005)? If this is the case, do they then reflect past oceanographic conditions and whether the sediment was deposited under marine or limnic conditions, high or low burial rates of organic material, or high or low concentrations of oxygen?

Theme-specific scientific questions

Scientific drilling in the Baltic Sea provides unique possibilities to study several basic questions concerning the deep biosphere and the Baltic Sea.

General deep biosphere questions

- How has the alternation between (1) limnic, brackish, and marine conditions, (2) oxic and suboxic/anoxic conditions, (3) low and temperate temperature, or (4) low and high organic sedimentation controlled the prokaryotic communities and the biogeochemical processes in the seabed?
- Are microorganisms that presently live in the deep sediments remnants of these limnic and marine populations, or are they selected by the modern sedimentary environment?
- Do chemical and genetic fossils (i.e., biomarkers and DNA) of the original prokaryotic organisms persist today, and are they useful as paleoceanographic indicators?
- Which biogeochemical processes predominate today in the glacial and interglacial deposits, what are their rates, and which microorganisms are carrying them out?
- How does the phylogenetic diversity of the deep biosphere in this intracontinental sea differ from that of deep open-ocean communities?

Specific Baltic Sea objectives

- To understand how the environmental and depositional history of the Baltic Sea system through transitions between the Saalian, Eemian, Weichselian, and Holocene (MIS 6–MIS 1) have affected the phylogenetic diversity of the microbial communities.
- To analyze microbiological and biogeochemical responses to major shifts: (1) between limnic, brackish, and marine phases and (2) between high and low deposition of terrestrial versus marine organic and clastic material.
- To understand how the postglacial diffusive penetration of conservative seawater ions may alter the chemical composition and microbial physiology in the subseafloor biosphere.

Proposed drill sites

Proposed site locations

For a list of proposed site locations, see Table **T1.**

Anholt Loch (proposed Sites BSB-1B and BSB-2B)

On the basis of a rather coarse grid of seismic lines, an erosional valley was mapped southeast of Anholt Island in the southern Kattekat Sea. The valley is ~25 km long and ~2 km wide and is oriented northwest to southeast. The distance from the sea bottom to the valley bottom is 200–300 m. The valley was probably formed by subglacial meltwater erosion during repeated glaciations in the early and middle Quaternary, and based on the stratigraphy in the Anholt boring, it is suggested that the valley is infilled by a sequence from MIS 6, MIS 5e, and MIS 3 (Lykke-Andersen et al., 1993). Based on later boomer profiles and shallow cores, the younger parts of the infill were referred to as being of late glacial and Holocene age (MIS 2-1; Jensen et al., 2002). The area was inundated by the SIS during the LGM, but according to our new seismic profiles, this did not lead to disturbances of the sequence in the Anholt region. Because the valley acted as a sediment trap, it may contain an unusually complete sequence of sediments from the last interglacial–glacial cycle (Theme 1) (Figs. **F5, F6**), as well as a deglacial–Holocene sequence, which will be valuable for our linkage between the BSB and the open Atlantic oceanic systems (Theme 3).

Little Belt (proposed Sites BSB-3 and BSB-4)

Seismic studies of the western BSB, east of the Island of Als, reveal an exceptionally thick accumulation of Quaternary sediments in deep valleys and basins running parallel to the coast. It is proposed that the almost complete interglacial succession found exposed at Mommark may be related to original deposition within a deep Quaternary channel along the east coast of the Island of Als, and subsequent transportation by glaciers to the west-northwest.

The kilometer-wide incised valley, which in places reaches 200 m below the seafloor, expresses an erosional unconformity, and it is suggested that the valley infill includes a thick marine MIS 5e (Eemian interglacial) succession. This interpretation is partly based on the occurrence of slices of dislocated marine MIS 5e sediments in the coastal areas around the western BSB and partly by direct evidence from wells penetrating similar valley infill, for instance close to the end of an incised valley in the Åbenrå Fjord, northwest of Als. The aim of drilling in the central part of one of the deep incised valleys east of the Island of Als is to obtain material from an in situ extremely high resolution marine MIS 5e record, providing a similar sequence to the Mommark section, but thicker and more complete (Theme 1).

To ensure an undisturbed sediment sequence from the Eemian, two sites are proposed at this location, both primary sites (Figs. **F7, F8**), as there is a risk that methane gas can occur in parts of the Quaternary sediment sequence, possibly preventing acquiring core to target depth at one of the sites.

Hanö Bay and Bornholm Basin (proposed Sites BSB-5B, BSB-6B, BSB-7B, and BSB-8)

Based on information from a short piston core and the radiocarbon age of its lowermost part, 25,930 ± 250 uncorrected radiocarbon years (T. Andrén, unpubl. data), this location was included in the R/V *Heincke* seismic cruise although it was not a part of original IODP pre-Proposal 672. The new seismic profiles indicate the possible occurrence of a thick, relatively transparent sequence of sediments, with some internal reflectors, below a relatively thin till cover of late Weichselian age (Figs. **F9, F10, F11, F12**). The lower unit is therefore of Eemian or early or mid-Weichselian age. The entire area is covered by ~10 m of Holocene mud and clay. Furthermore, during this seismic survey pockets of sediments below late Weichselian till and Holocene mud were discovered in the deeper part of the Bornholm Basin. These sediments were probably deposited in the lake that occupied the southern Baltic Basin from the Eemian interglacial up to the last Weichselian ice advance over the area. We have also included these sites in the proposal as they will give the unique opportunity to study the development of this lake both in littoral phases in the Hanö Bay area and in deep lake phases in the Bornholm Basin.

Landsort Deep (proposed Site BSB-9)

The Landsort Deep is the deepest basin in the BSB, and its geometry makes it an excellent “sediment trap,” preventing subsequent glacial erosion. Its location just south of the postulated margins of the early Weichselian glacial advances (MIS 5d and MIS 5b) makes it particularly promising for registering the early Weichselian development of the BSB, and it also displays an expanded late Weichselian and Holocene sediment sequence.

A 20 inch^3 par air gun was used together with a 50 m long single-channel streamer to collect Profiles 68170648 and 68162141, which both run along the Landsort Deep. The seismic reflection data acquired clearly show the most suitable drilling target selected for the purpose of recovering the longest undisturbed postglacial (possibly partly deglacial) sequence (Fig. **F13**).

From approximately shot point (SP) 1000 in Profile 68170648 and SP 1700 in Profile 68162141, the uppermost horizontally stratified sediment layer is thickening. Assuming a sediment sound speed of 1500 m/s, the sediment section is ~122 m thick at the thickest part near SP 1900 in Profile 68170648. This profile is intersected by Profile 68161201. This intersection provides an acoustically well constrained drilling target at a location in the Landsort Deep where the sediment section appears to reach the maximum thickness in the area and where there are no signs of erosion or other disturbances in the acoustic data.

Ångermanälven River estuary (proposed Sites BSB-10 and BSB-11)

In the Ångermanälven River estuary, varves have been deposited during the last >10,000 y and are still being deposited. Varve thicknesses in open sections along the river valley have been measured and varve diagrams cross-correlated to a local varve chronology, which is in turn correlated to the Swedish late glacial varve chronology, together constituting the so-called Swedish Time Scale (STS). No drilling in the estuary has been performed, but short piston cores have been collected, and they indicate a sediment accumulation rate of 5–10 mm/y in the early Holocene.

Two target areas were surveyed north of Härnösand in the easternmost part of Ångermanälven (Figs. **F14, F15**) using an EdgeTech chirp sonar subbottom profiler with the SB-216s tow fish. A chirp frequency modulation pulse between 3 and 9 kHz was used.

The surveyed area, located at about 62°47′N, contains a suitable area for drilling where an apparently undisturbed sediment section fills a trough and reaches a thickness of >40 ms two-way traveltime (TWT) (30 m assuming a sound speed of 1500 m/s).

Sediment thickness appears to exceed the limit of the used chirp sonar. The proposed site is located on Profile 71021235, and Profile 71021316 ends 34 m southwest of the proposed site and thus nearly provides a crossing.

Profile 71021706 crosses this site and shows no difference in the acoustic stratigraphy. The site could be moved to another location where two chirp sonar profiles cross, but the selected location, albeit not on a crossing, represents the most promising and longest undisturbed record.

The second proposed site (BSB-11) is located close to Kramfors for the purpose of connecting the clay varve series with modern varves in Ångermanälven. Cross-correlation between this site and proposed Site BSB-10 will further strengthen the varve chronology, as some varves may be missing when analyzing only one site. It will also strengthen the correlation of the varve records to the STS, something that is needed in order to achieve true calendar-year accuracy in the dating. This site has been moved ~50 m along Profile 71021706 in order to avoid some apparent undulations in the acoustic stratigraphy at the exact location of the crossing between this profile and Profile 71021604.

Site prioritization

For site prioritization by theme, see Table **T2.** Further details regarding site prioritization and proposed coring order will be made available on the ESO Expedition 347 web page (**www.eso.ecord.org/expeditions/347/347.php**).

Operational strategy

IODP Expedition 347 will be implemented as a Mission Specific Platform (MSP) expedition, where the platform and coring services are contracted from the industry market and scientific services are provided by ESO. At the time of writing, the tendering exercise for platform and coring services was in progress. Therefore, many operational details such as the drilling platform, coring rig, coring methodology, logging tools, measurements plan, and core workflow will not be available until the contract for the primary infrastructure is in place.

The latest platform, facilities, coring strategy, measurements plan, scheduling, and port call information will be updated on the ESO Expedition 347 web page (**www.eso.ecord.org/expeditions/347/347.php**).

Drilling platform

Because of the range in water depths at the proposed sites (23–451 m), the drilling platform is likely to be a dynamically positioned geotechnical vessel equipped with piston and rotary coring tools. The chosen platform will have sufficient capacity by way of food and accommodation for 24 h operation.

Coring rig and coring methodology

Details of the coring rig and coring methodology will be published on the ESO Expedition 347 web page once the vessel and coring contractors have been selected (**www.eso.ecord.org/expeditions/347/347.php**).

It is planned that, during coring of the microbiology boreholes, a perfluorocarbon tracer and/or microspheres will be continuously injected into the drill fluid for contamination testing.

Coring strategy

It is planned to core at least two boreholes at each primary site for the paleoceanographic objectives. These will be supplemented by as many as five short cores that will capture an undisturbed record of the water/sediment interface and the upper 0.75 m of the sedimentary sequence. Additionally, a microbiology-dedicated borehole will be cored at four microbiology sites in order to recover a useful volume of material for microbiological analyses. Please consult the ESO Expedition 347 web page for up-to-date coring strategy details (**www.eso.ecord.org/expeditions/347/347.php**).

Core on deck

Once the drilling operation commences and core begins to arrive on deck, after initial labeling of cores, the operations team will be responsible for delivering the cores to the curation container. The operation will proceed using a changeover of inner core barrels to ensure continuity of the coring operation in as timely a fashion as possible. The deck operators will deploy an empty core barrel immediately after the previous one has been retrieved, and then address core removal and subsequent readying of that core barrel for reuse. As the cores will be collected in plastic liners, the usual IODP curation procedures will be followed (**www.marum.de/en/Offshore_core_curation_and_measurements.html**). After curation, core materials are passed to the Science Party members for onboard description, analysis, and sampling as described in **"Science operations,"** below.

Downhole logging

During all MSP expeditions, the downhole logging program is integrated with the scientific objectives to ensure maximum scientific output. This may include the use of specialist third-party tools.

To facilitate downhole measurements and core petrophysics for MSPs, the European Petrophysics Consortium (EPC) has been developing protocols for use both offshore and in collaboration with the Center for Marine Environmental Sciences (MARUM) team during the Onshore Science Party.

Unlike the R/V *Chikyu* and riserless vessels where the pipe size is constant and allows a standard set of logging tools to be deployed, MSPs have variable pipe sizes and drill in a variety of water depths, each of which provides constraints on the anatomy of logging operations. Pipe diameter is the controlling factor, and it is envisaged that a wide range, from slimline memory-mode tools to standard oil-field tool suites, may be utilized. Water depth is also an important constraint because some MSP expeditions will operate in very shallow territorial waters where the deployment of nuclear sources may be prohibited or severely restricted.

Logging services will be contracted as part of the services for IODP Expedition 347 and will be managed by the EPC. The logging equipment and team will be constructed to allow for a seamless operation on the platform, ready to undertake any requirements as the project progresses.

Because the choice of logging tools depends on the platform and coring tool set up, details of the wireline logging program will be published on the ESO Expedition 347 web page once the vessel and coring contractors have been selected.

Science operations

A Sampling and Measurements Plan (SMP) for Expedition 347 will be prepared by ESO and the Co-Chief Scientists to meet the scientific objectives of IODP Proposal 672 following the recommendations of the Science Advisory Structure (SAS). Please see the SMP link (**www.marum.de/en/Exp347_Sampling_and_Measurement_Plan.html**).

Offshore science activities

It is the nature of MSP expeditions that there is limited laboratory space and accommodation on board, and as such there is no splitting of the cores at sea and only limited scientific analysis is carried out onboard by a subset of the Science Party. Science activities on the platform are confined to those essential for core curation, measurement of ephemeral properties, securing of proper samples for pore water chemistry and microbiology, downhole logging, and safety. Most of the scientific analysis is carried out during the Onshore Science Party in Bremen, when the cores are initially split.

The following is a summary of the offshore scientific activities (please refer to the SMP link at **www.marum.de/en/Exp347_Sampling_and_Measurement_Plan.html** and the online tutorial at **www.marum.de/en/Offshore_core_curation_and_measurements.html**):

- Basic curation and labeling of core.
- All cores will be run on the multisensor core logger (MSCL) (gamma density, *P*-wave velocity, electrical resistivity, and magnetic susceptibility). All shallow cores acquired to capture the water/sediment interface and the upper few meters of the lithology will not be run through the MSCL.
- Core catcher (CC) description and sampling for initial sedimentological and micropaleontological analysis, including taking a CC image.
- Taking and proper storage of samples for gas analyses, pore water, and microbiology interstitial water analysis and any other ephemeral properties agreed in the Sampling and Measurements Plan.
- Core storage.
- Associated data management of all activities (see below).

In order to carry out the science requirements on the platform with a subset of the Science Party, a staffing plan will be devised. The plan will require flexibility of approach from all participants, with priority to safety, core recovery, curation, and procedures for the measurement of ephemeral properties, including sampling for microbiology.

Report preparation will take place on board as required; the reports to be compiled include

- Daily and weekly operations and science reports to Integrated Ocean Drilling Program Management International, Inc. (IODP-MI), Science Party members, and relevant parties. Scientific reports are provided by the Co-Chief Scientists. Summarized daily reports will be publicly available on the ESO website for any interested parties.

- Site summary reports to IODP-MI.
- Technical Operations Report (submission to IODP-MI due 60 days postcruise).
- Completion of the offshore sections of the Expedition Reports section of the volume (primarily the "Methods" chapter).
- Operational Review report (submission to IODP-MI due 2 months postcruise).
- Press releases in line with IODP-MI outreach policy.
- Information for posting on the ESO expedition website.

Onshore science activities

The Onshore Science Party will be conducted under the supervision of Dr. Ursula Röhl, the manager of the IODP Bremen Core Repository (BCR). The scientific work will follow the Sampling and Measurements Plan to be developed in due course in conjunction with the Co-Chief Scientists.

Details of the facilities that will be available for the Onshore Science Party at the BCR located in the MARUM building on the campus of the University of Bremen (Germany) can be found in the Expedition 347 Sampling and Measurements Plan (**www.marum.de/en/Exp347_Sampling_and_Measurement_Plan.html**). Additional facilities can be made available through continuing close cooperation with additional laboratories at the MARUM Center for Marine Environmental Sciences and the Department of Geosciences at Bremen University, as well as the Max Planck Institute for Marine Microbiology (MPI), all of which are situated nearby on campus.

The following list briefly summarizes Onshore Science Party scientific activities (please see the SMP link at **www.marum.de/en/Exp347_Sampling_and_Measurement_Plan.html** and the online tutorial at **www.marum.de/Onshore_Science_Party_OSP.html**):

- Core splitting: an archive half will be set aside as per IODP policy.
- Core description: ESO will provide a data entry system that is IODP standard. For data entry, ESO will employ the ExpeditionDIS (Drilling Information System) that is entirely compatible with others being used in IODP (see **"Data management,"** below).
- Digital linescan imaging.

- Color reflectance (spectrophometry).
- Core sampling for expedition samples (to produce data for the Expedition Reports section of the Proceedings volume).
- Smear slide preparation.
- Micropaleontology: access to microscope laboratory.
- Inorganic geochemistry: whole-rock and pore fluid chemistry.
- Bulk mineralogy: X-ray diffraction (XRD) analysis.
- Petrophysical measurements (*P*-wave and moisture and density analyses).
- Paleomagnetic measurements.
- Core sampling for personal postexpedition research: a detailed sampling plan will be devised at the completion of the offshore phase and after the scientists have submitted their revised sample requests (see **"Research planning: sampling and data sharing strategy,"** below).

A staffing plan will be developed with the Co-Chief Scientists in order to ensure that all required analyses and subsampling can be carried out efficiently. The measurement plan will take account of IODP specifications for quality assurance/quality control (QA/QC) procedures.

In view of the existing geographical distribution of all Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP)/IODP cores, it is understood that the BCR will be the long-term location for the Expedition 347 cores.

Report preparation will take place during the Onshore Science Party as required by IODP-MI. The reports to be compiled include the following:

- Twice-weekly progress reports to IODP-MI and relevant parties. Scientific reports are provided by the Co-Chief Scientists.
- *Preliminary Report* (submission to USIO Publication Services 1 week after Onshore Science Party).
- Completion of the Expedition Reports section of the Proceedings volume (submission to USIO Publication Services as soon as practically possible after the Onshore Science Party).

Staffing

Scientific staffing is decided on the basis of task requirements and nominations from the IODP Program Member Offices (**www.iodp.org/program-member-offices**). ESO staffing is based on the need to carry out the drilling and scientific operations efficiently and safely (Table **T3**).

Data management

A data management plan for the expedition will be developed once the data requirements and operational logistics are finalized. The outline plan is as follows:

- The primary data capture and management system will be the ExpeditionDIS. This is a relational database. It will capture drilling, curation, and geoscience metadata and data during the offshore and onshore phases of the expedition.
- The ExpeditionDIS includes tools for data input, visualization, report generation, and data export.
- The database can be accessed directly by other interpretation or decision-making applications if required.
- A file server will be used for the storage of data not captured in the database (for example, documents and image files) and the inputs/outputs of any data processing, interpretation, and visualization applications used during the expedition.
- The EPC will manage the capture of downhole log data, MSCL data, and physical properties data. Logging metadata and MSCL data will be stored in the ExpeditionDIS. Downhole logging data will be stored separately by the EPC for processing and compositing.
- On completion of the offshore phase of the expedition, the ExpeditionDIS database and the file system will be transferred to the BCR to continue data capture during the Onshore Science Party.
- Between the end of the offshore phase and the start of the Onshore Science Party, expedition scientists will have access to the data via a password-protected website.
- On completion of the Onshore Science Party, expedition scientists will continue to have access to all data through a password-protected website throughout the moratorium period.
- During the moratorium, all metadata and data, apart from downhole log data, will be transferred to the World Data Center for Marine Environmental Sciences (WDC-MARE)/PANGAEA for long-term data archiving.

- The downhole log data will be transferred to the Lamont-Doherty Earth Observatory for long-term archiving.
- Cores and samples will be archived at the BCR.
- After the moratorium, all expedition data will be made accessible to the public.

Research planning: sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations policy (**www.iodp.org/program-policies/**). This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of the Co-Chief Scientists, Expedition Project Manager, and IODP Curator on shore and curatorial representative on board ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Every member of the science party is obligated to carry out scientific research for the expedition and publish it. Before the expedition, all shipboard scientists are required to submit research plans and associated sample/data requests (**smcs.iodp.org/**) before the deadline specified in their invitation letters. Based on sample requests (shore-based and shipboard) 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. All postcruise research projects should provide scientific reasons for desired sample size, numbers, and frequency. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to the sampling plan and access to samples and data during the expedition and the 1 y postexpedition moratorium period require the approval of the SAC.

Shipboard sampling will be restricted to acquiring ephemeral data types and to low-resolution sampling for shipboard data acquisition (e.g., biostratigraphic sampling, pore waters, and shipboard geochemistry) so that we can rapidly produce age-model data critical to the overall objectives of the expedition and plan for higher resolution sampling postcruise.

The minimum permanent archive half will be determined based on the extent of duplication of stratigraphic intervals at a particular site. It is necessary that as complete a stratigraphic interval as possible be preserved as permanent archive halves. This will be determined by the expedition's stratigraphic correlator(s), and the permanent archive halves will be officially designated by the IODP Curator. 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 expedition objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

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

The SAC strongly encourages, and may require, collaboration and/or sharing among the shipboard and shore-based scientists so that the best use is made of the recovered core. Coordination of postcruise analytical programs is anticipated to ensure that the full range of geochemical, isotopic, magnetic, and physical property studies are undertaken on a representative sample suite. The majority of sampling will take place at the Onshore Science Party in Bremen, and the SAC encourages scientists to start developing collaborations before and during the expedition.

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Table T1. Proposed site locations, Expedition 347.

Site	Position	Priority	Water depth (m)	Penetration (m)		
				Sediment	Basement	Total
BSB-1B	56°36.695′N, 11°42.361′E	P (M)	34	214	6	220
BSB-2B	56°34.667′N, 11°47.320′E	A	34	149	6	155
BSB-3	55°01.00′N, 10°07.00′E	P (M)	35	150	6	156
BSB-4	55°08.00′N, 09°48.00′E	A	12	180	6	186
BSB-5B	55°43.290′N, 15°13.590′E	P	61	36	6	42
BSB-6B	55°41.520′N, 15°32.250′E	A	67	52	6	58
BSB-7B	55°28.034′N, 15°28.680′E	A	85	74	6	80
BSB-8	55°17.258′N, 15°28.917′E	P (M)	93	93	6	99
BSB-9	58°37.60′N, 18°15.30′E	P (M)	451	152	6	159
BSB-10	62°46.70′N, 18°02.95′E	P	86	40+	0	40
BSB-11	62°57.35′N, 17°47.70′E	P	68	40+	0	40

P = primary site, A = alternate site, M = site requiring a dedicated microbiology hole. Total penetration for seven primary sites is 2143 m (assuming two paleoceanographic holes at each primary site and one microbiology hole at four sites). At the time of writing, no sites had received approval from the Environmental Protection and Safety Panel (EPSP). Primary sites and their prioritization are therefore subject to change. The latest site strategy will be published on the ESO Expedition 347 web page (**www.eso.ecord.org/expeditions/347/347.php**).

Table T2. Prioritization of sites with regard to individual themes, Expedition 347.

Theme	Primary site	Alternate site	Additional data from primary site	Additional data from alternate site
1: Climate and sea level dynamics of MIS 5	BSB-3	BSB-4	BSB-1B	BSB-2B
2: The complexities of the Last Glacial (MIS 4–MIS 2)	BSB-5B and BSB-8B	BSB-6B and BSB-7B	BSB-1B, BSB-3, and BSB-9	BSB-2B
3: Deglacial and Holocene climate forcing	BSB-1B and BSB-9-11	BSB-2B	BSB-8	BSB-6B and BSB-7B
4: Deep biosphere responses to glacial–interglacial cycles	BSB-3, BSB-9, and BSB-11			

At the time of writing, no sites had received approval from the Environmental Protection and Safety Panel (EPSP). Primary sites and their prioritization are therefore subject to change. The latest site strategy will be published on the ESO Expedition 347 web page (**www.eso.ecord.org/expeditions/347/347.php**).

Table T3. Summary of the science party and operator personnel (ESO staff), Expedition 347.

	Science party	
ESO (15)	Offshore science team (17)	Expedition scientists
Operations Manager Drilling Coordinator 1 Drilling Coordinator 2 Expedition Project Manager (EPM) Petrophysics Staff Scientist Assistant EPM ESO Petrophysicist 1 ESO Geochemist 1 ESO Geochemist 2 Curator 1 Curator 2 Logging Engineer 1 Logging Engineer 2 Database Manager Electronics Engineer	Co-Chief Scientist 1 (Sedimentologist 1) Co-Chief Scientist 2 (Microbiologist 1) Petrophysicist 2 Geochemist 3 Geochemist 4 Geochemist 5 Geochemist 6 Sedimentologist 2 Micropaleontologist 1 Micropaleontologist 2 Microbiologist 2 Microbiologist 3 Microbiologist 4 Microbiologist 5 Microbiologist 6 Stratigraphic Correlator 1 Stratigraphic Correlator 2	Offshore science team, plus additional invited scientists. The exact make-up of expertise of the science party will be chosen by ESO and the Co-Chief Scientists. The science party is expected to comprise 27–30 scientists.

Figure F1. Location of proposed Expedition 347 sites. MBio = microbiology.

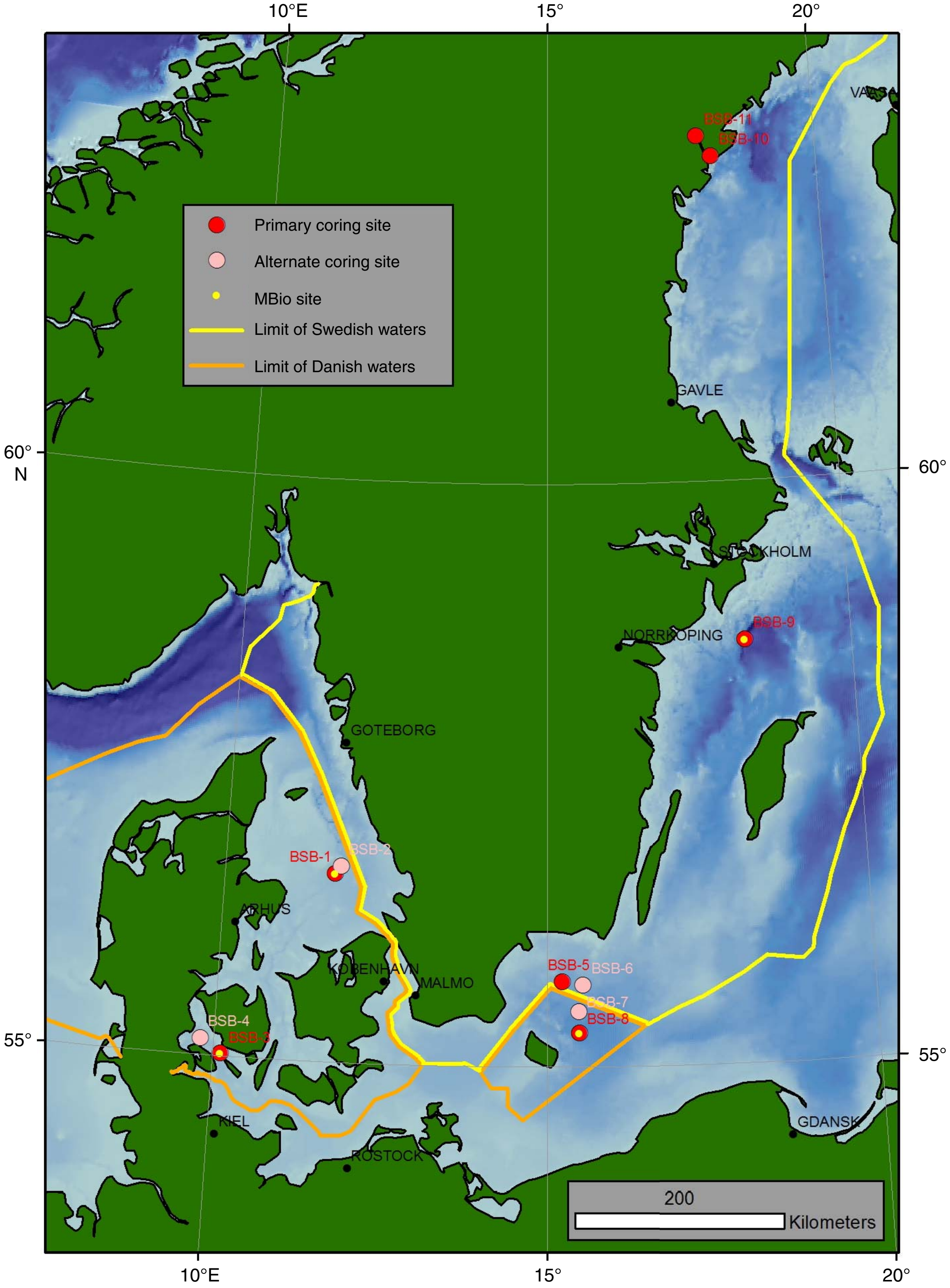


Figure F2. Southwestern Scandinavia, the possible pathway from southern Baltic Basin through the Esrum-Alnarp bedrock valley, and the location and lithostratigraphic logs of the cores retrieved from Kriegers Flak. Position of the radiocarbon dates are indicated (Anjar et al., 2010).

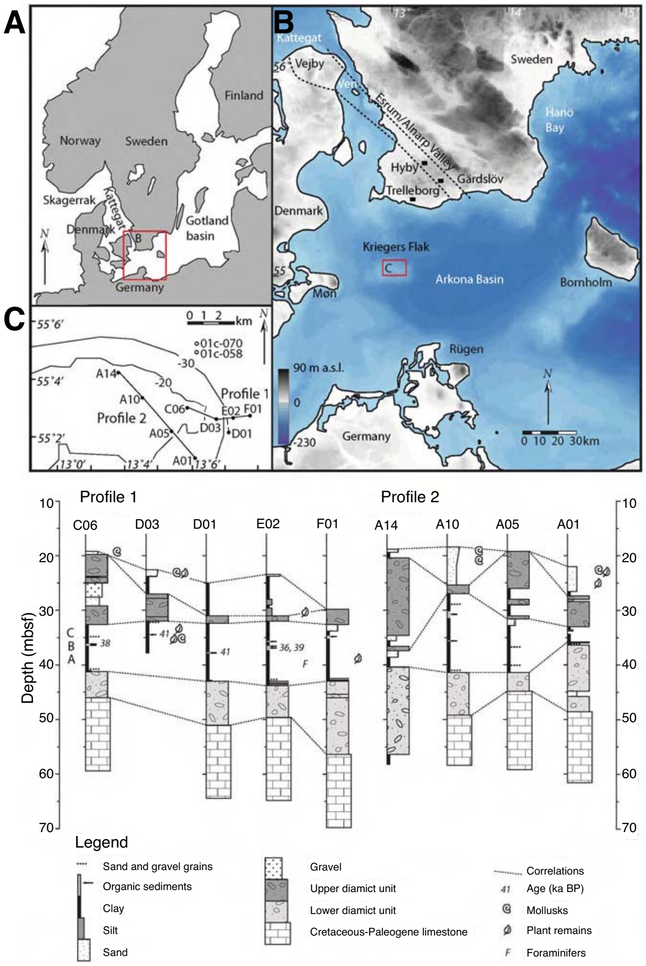


Figure F3. Paleogeography of the Baltic Sea region at 30 ka BP according to geophysical modeling of the Scandinavian Ice Sheet and isostatic adjustments based on global rheology and sea levels and regional geologic data (Lambeck, in prep.).

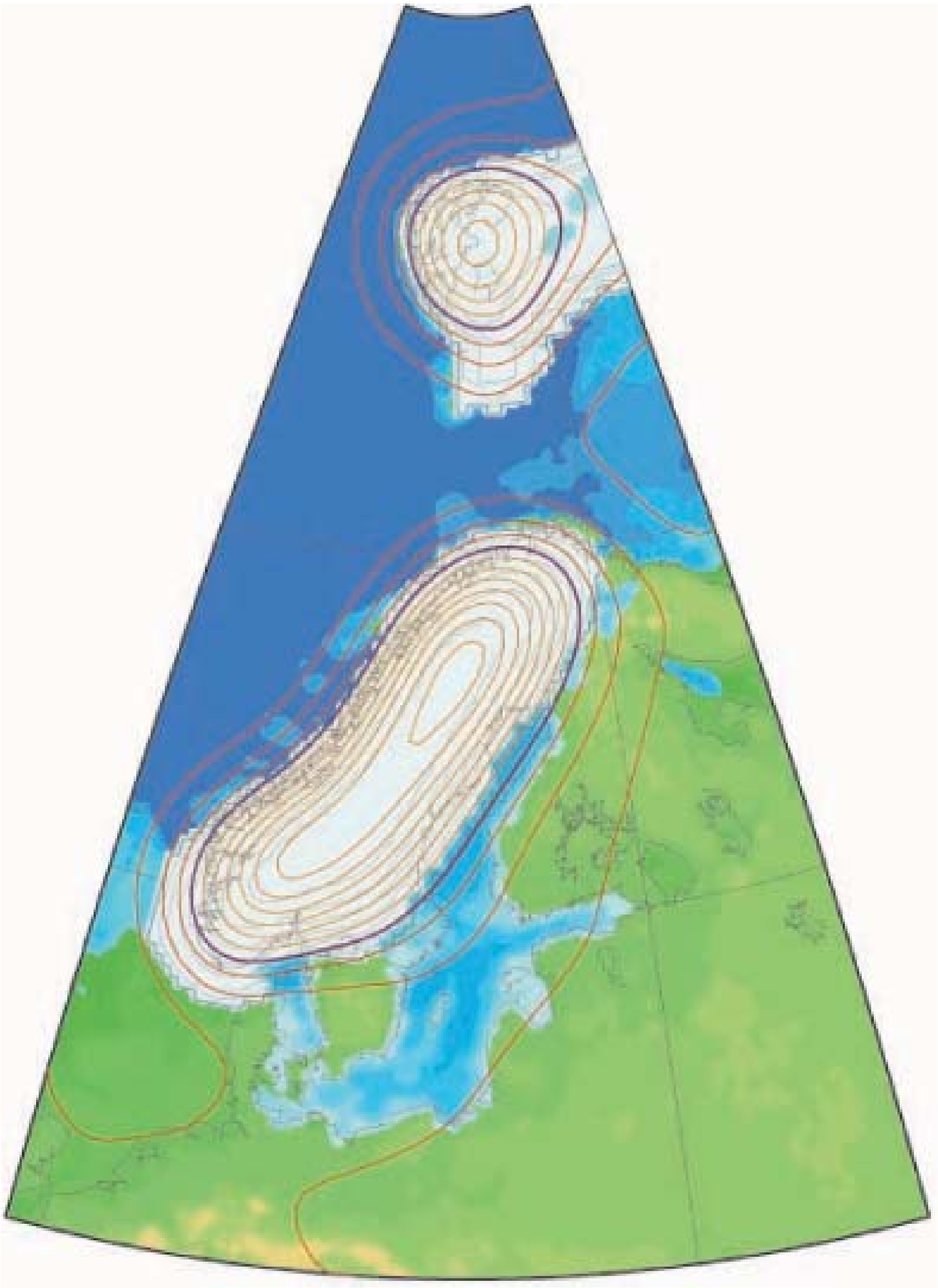


Figure F4. Scatter plot of varve thickness (cm) versus Q_{max} (m^3/s) for the 1909–1971 period. Q_{max} for the regulated period is shown by open circles and for the unregulated period by crosses. The three equations, linear, power, and logarithmic, are fitted by a least sum of squares to the data set (see fig. 5 in Sander et al., 2002).

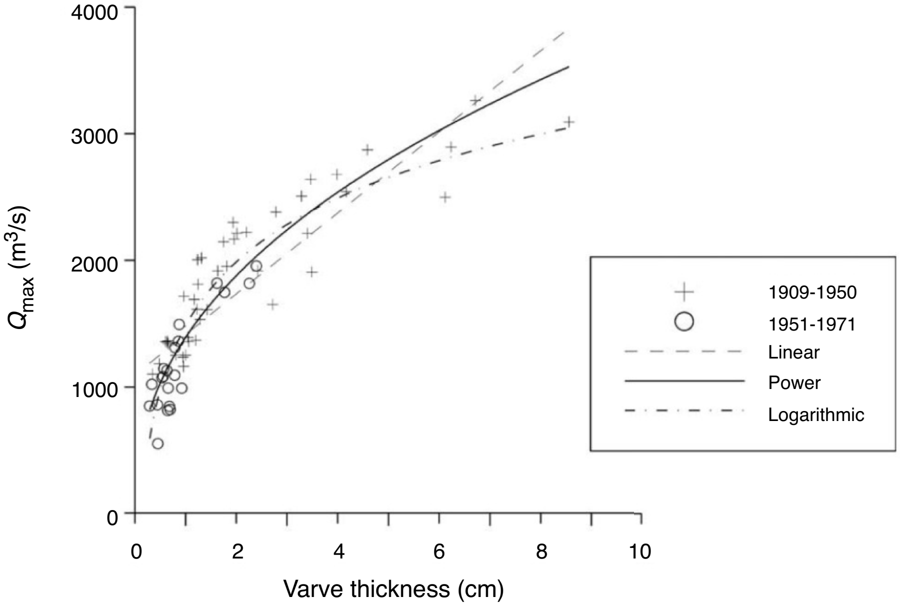
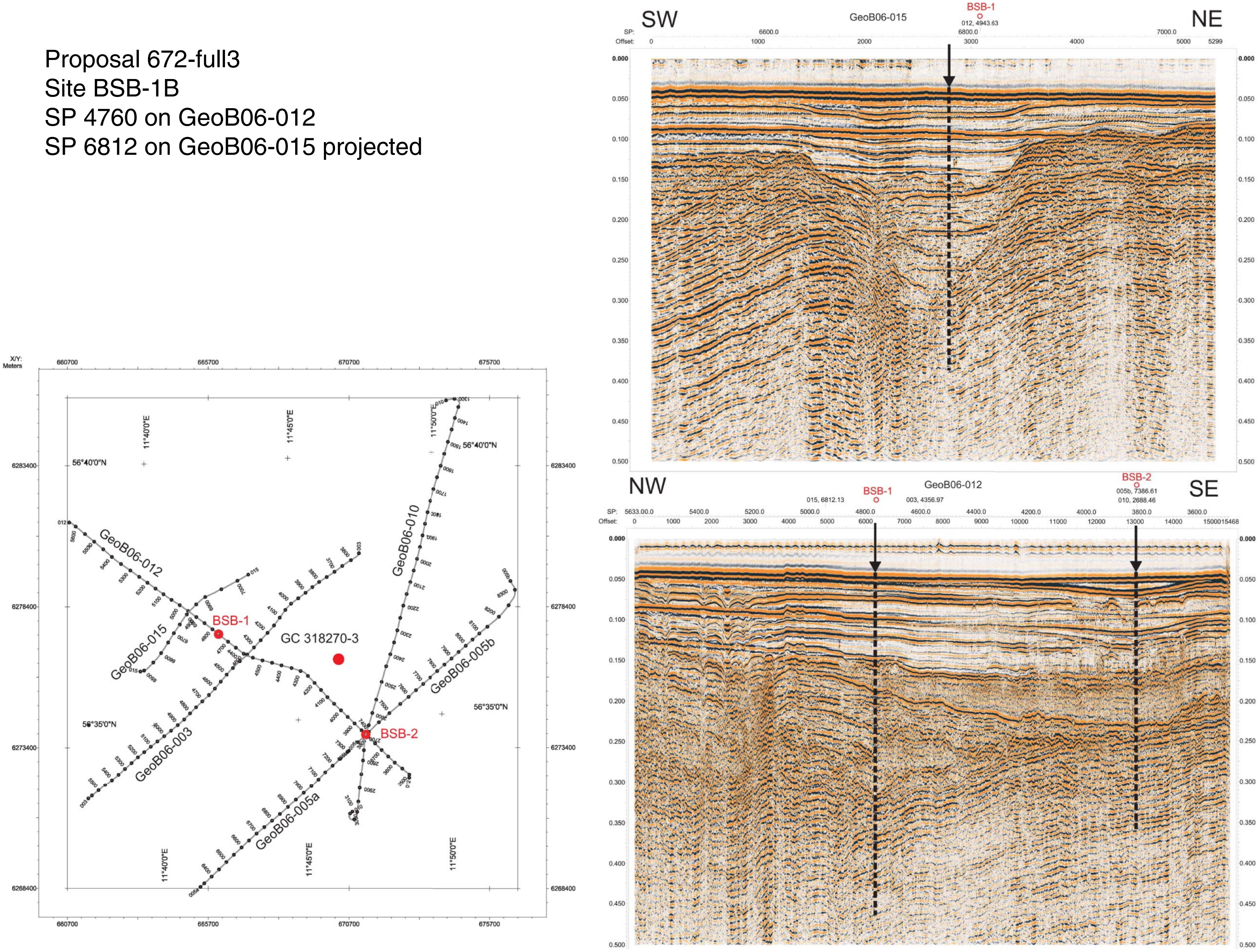
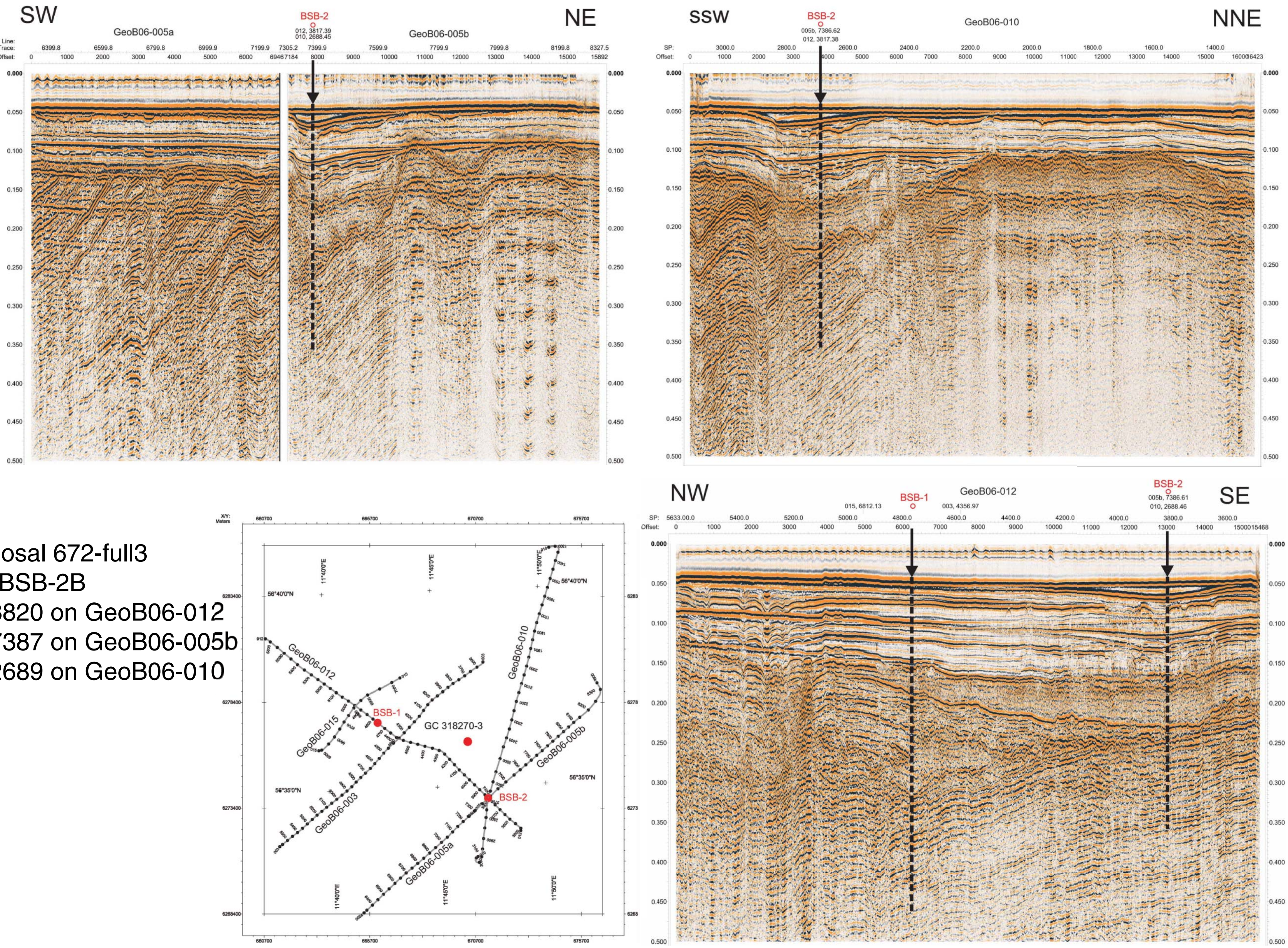


Figure F5. Seismic lines across Site BSB-1.



Proposal 672-full3
Site BSB-1B
SP 4760 on GeoB06-012
SP 6812 on GeoB06-015 projected

Figure F6. Seismic lines across Site BSB-2B.



Proposal 672-full3
Site BSB-2B
SP 3820 on GeoB06-012
SP 7387 on GeoB06-005b
SP 2689 on GeoB06-010

Figure F7. Seismic lines across Site BSB-3.

Site summary form 6

Proposal 672-full

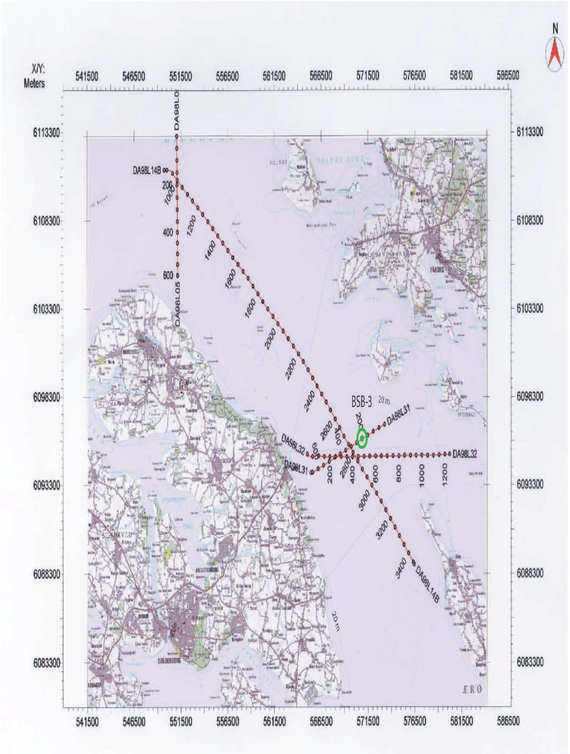
Site BSB-3

SSDB locations:

Location map: Base_Map_Als_Site3.pdf

Seismic section figures:

Line DA98-31.pdf
Line DA98-31_interpr.pdf
Line DA98-32.pdf
Line DA98-32_interp.pdf



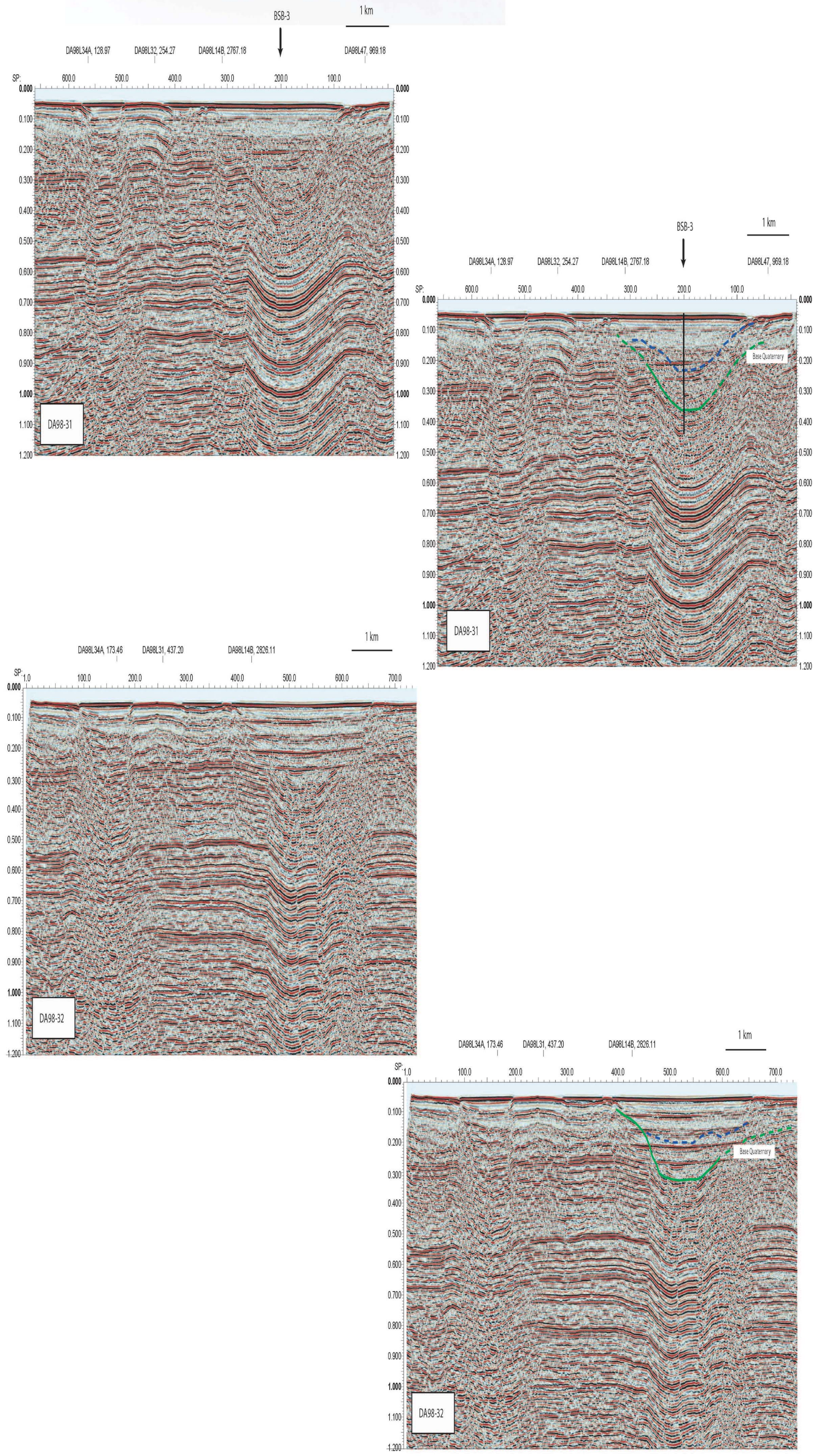
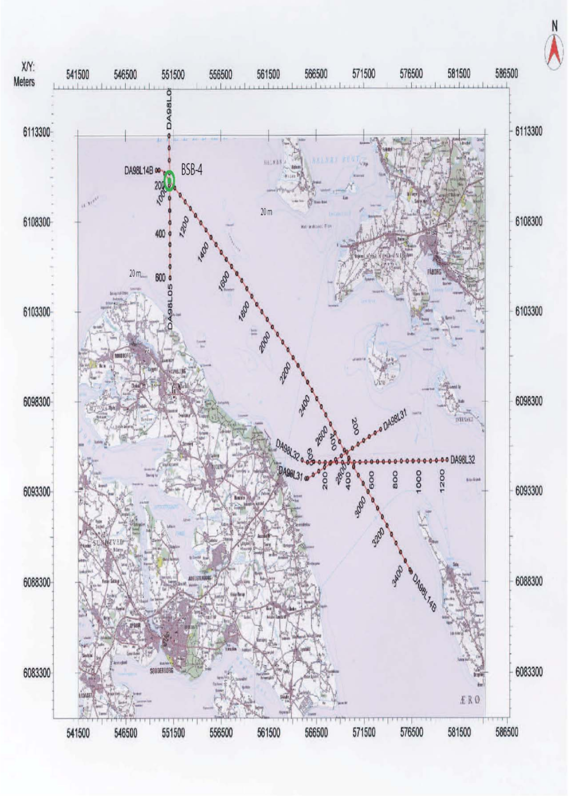


Figure F8. Seismic lines across Site BSB-4.

Proposal 672-full
Site BSB-4

Site summary form 6



Annotation: Shot Point Numbers (SP)

SSDB locations:
Location map: Bas_Map_Als_Site4.pdf

Seismic section figures:

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Line DA98-05_interpr.pdf
Line DA98-14B.pdf
Line DA98-14B_interp.pdf

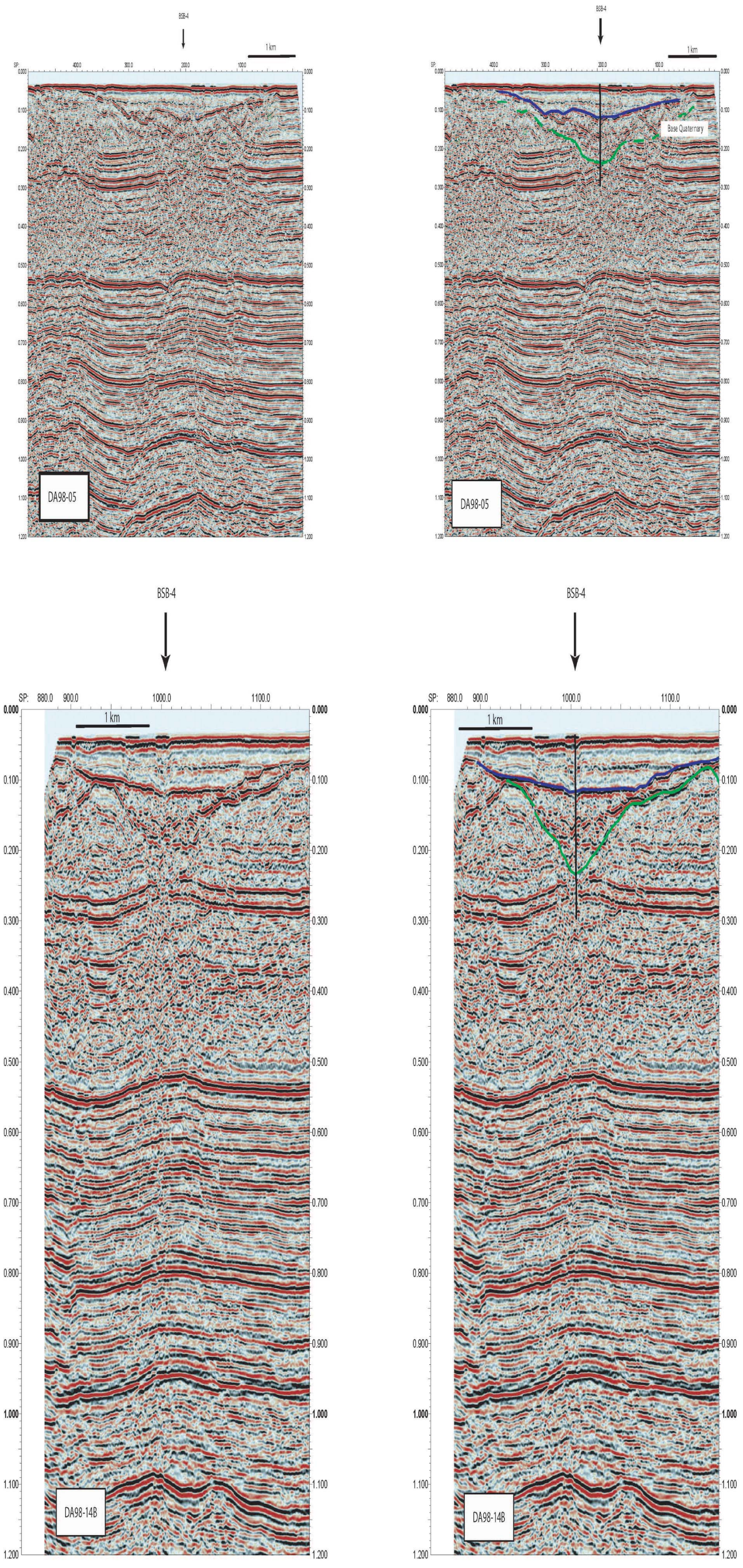


Figure F9. Seismic lines across Site BSB-5B.

Proposal 672-full3
Site BSB-5B
SP 18700 on GeoB06-057

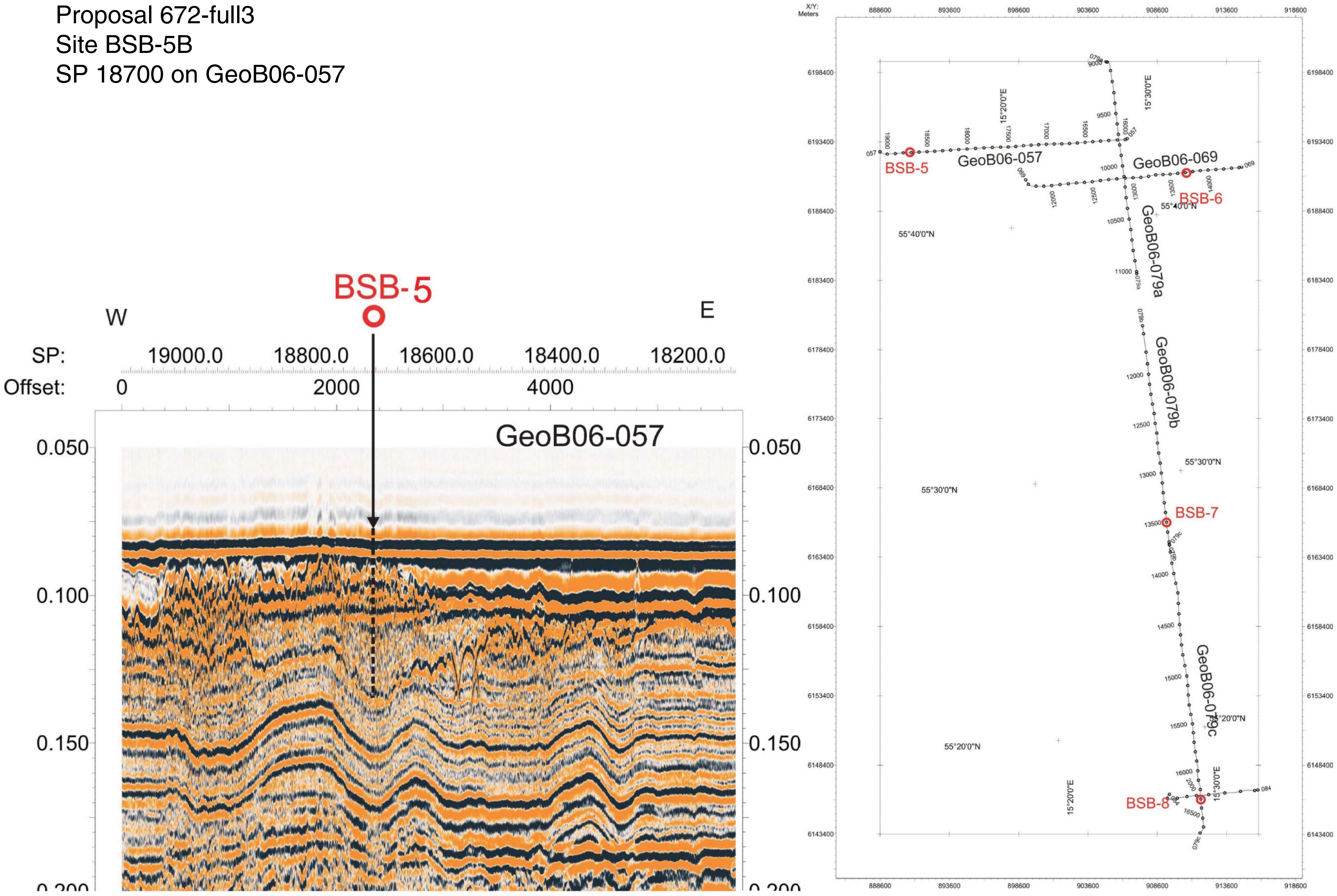


Figure F10. Seismic lines across Site BSB-6B.

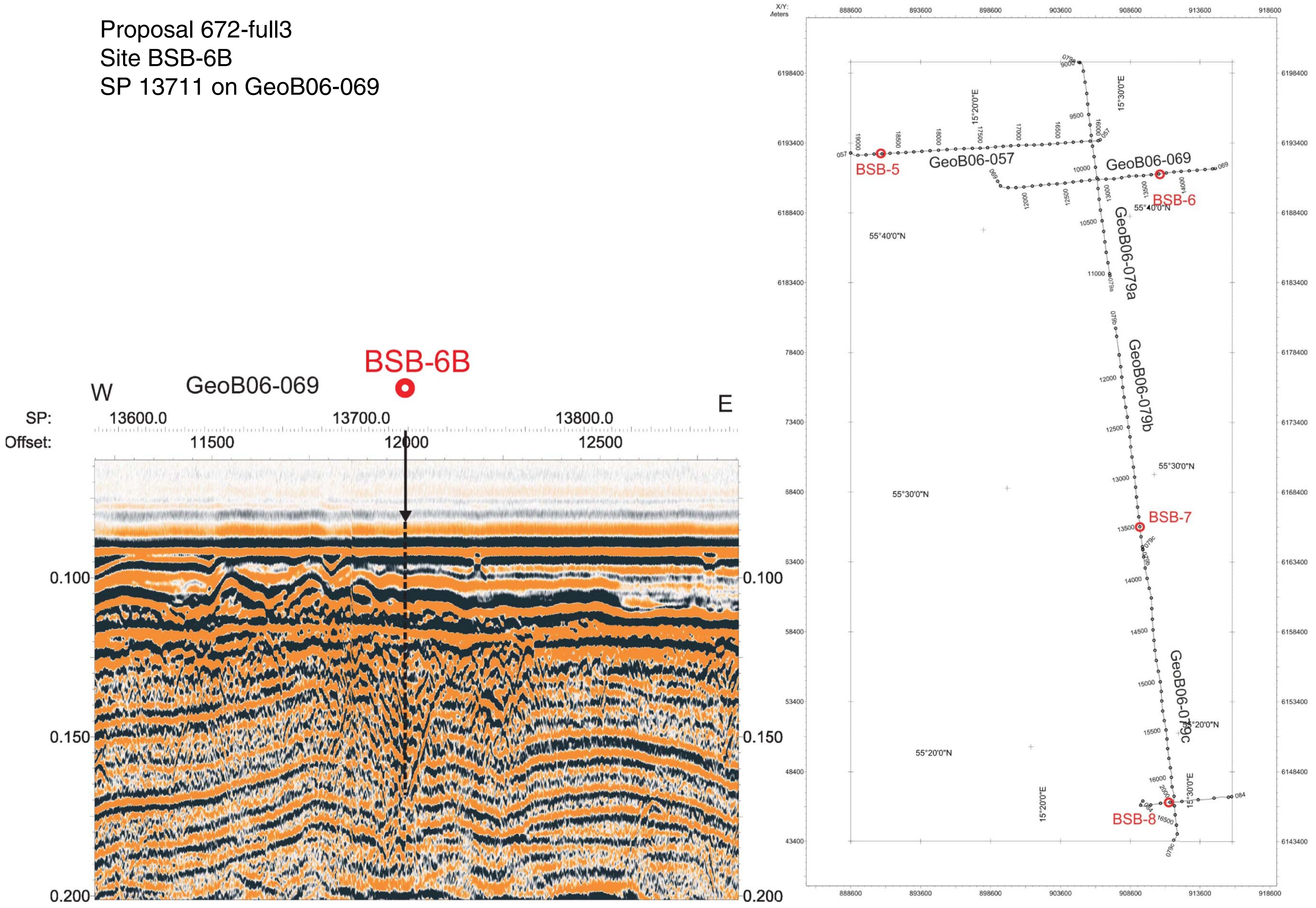


Figure F11. Seismic lines across Site BSB-7B.

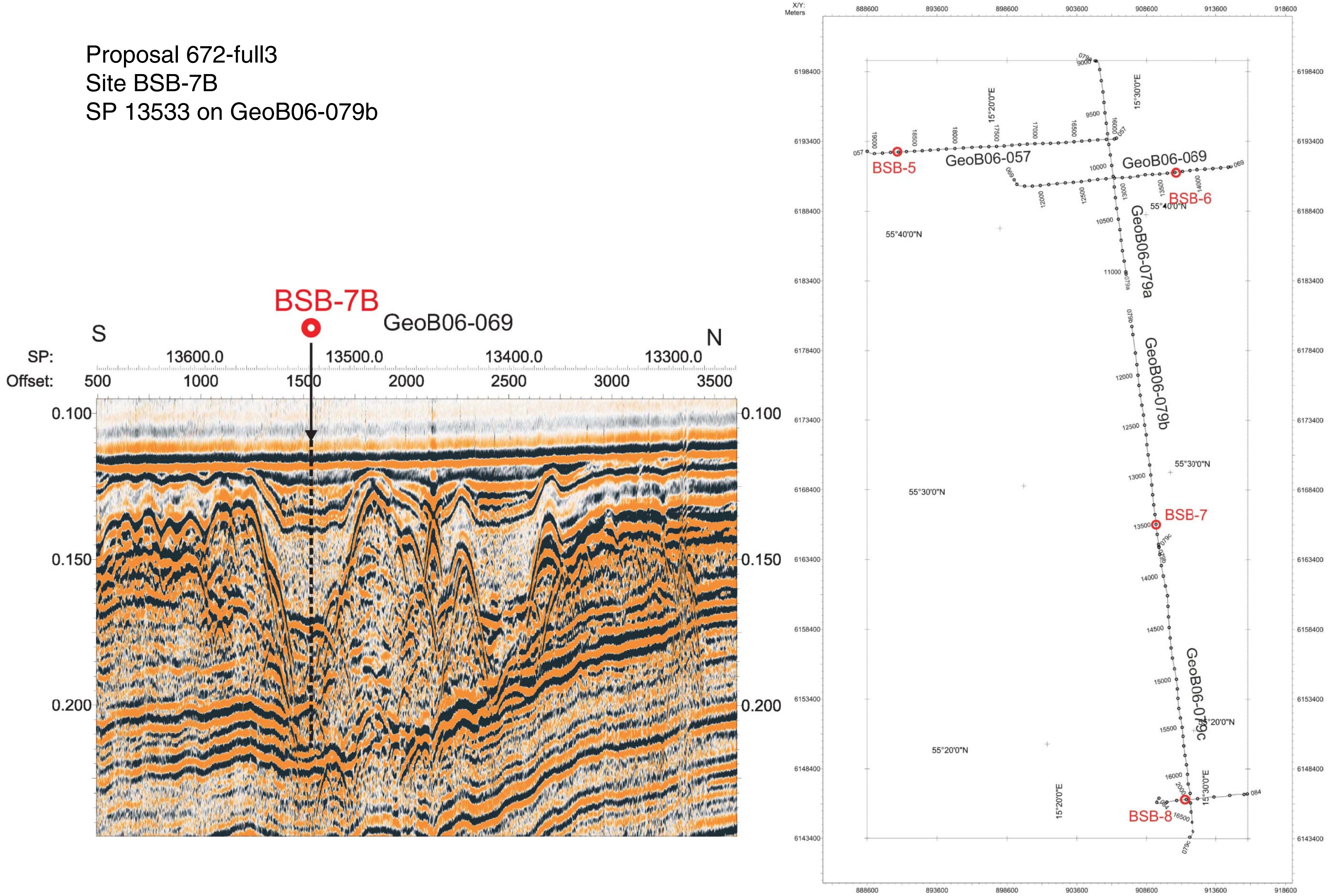
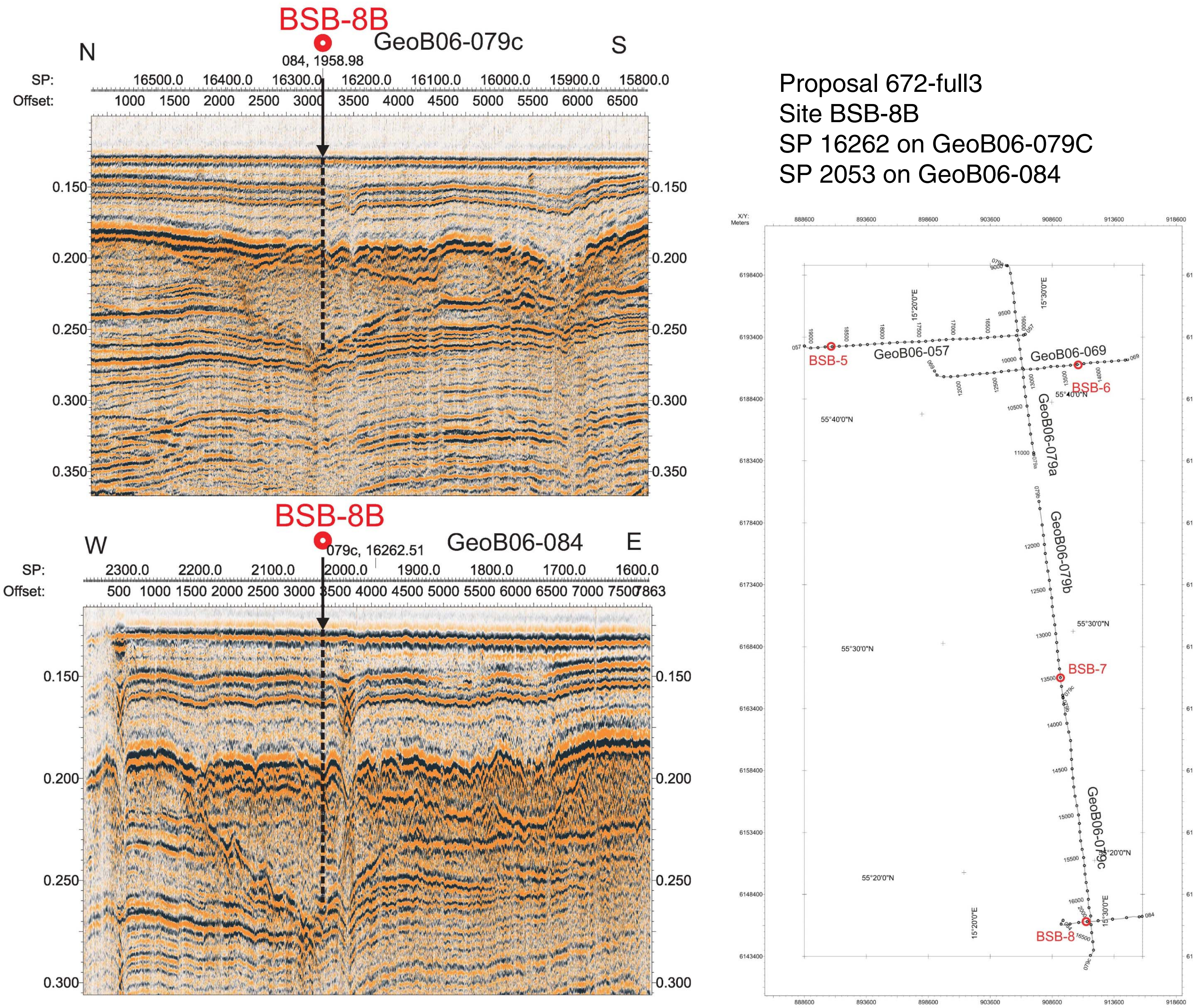


Figure F12. Seismic lines across Site BSB-8B.



Proposal 672-full3
Site BSB-8B
SP 16262 on GeoB06-079C
SP 2053 on GeoB06-084

Figure F13. Seismic lines across Site BSB-9. SSDB = Site Survey Data Bank.

Proposal 672-full
Site BSB-9

Site summary form 6

SSDB location of these graphics and supporting data

Location map:
BSB-9-map.jpg

Seismic figures:
68170648.pdf
68161201.pdf

SEGY data:
68170648.segy
68161201.segy

NAV data:
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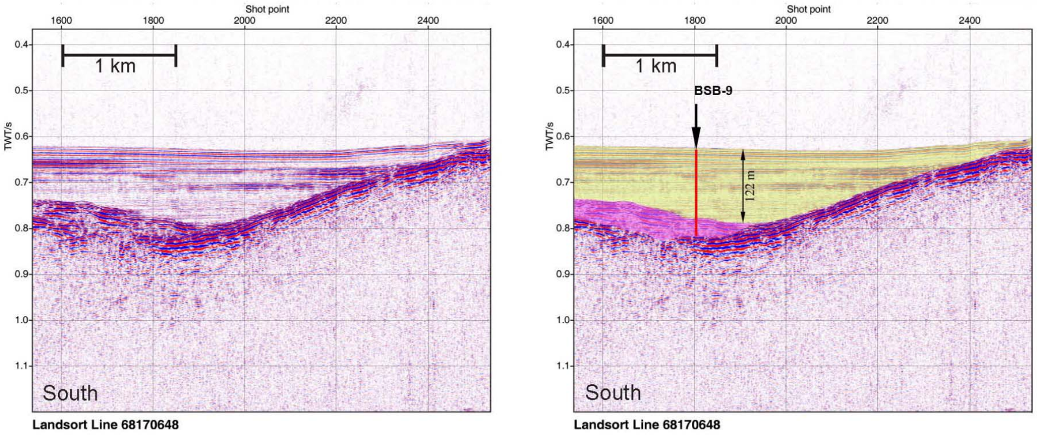
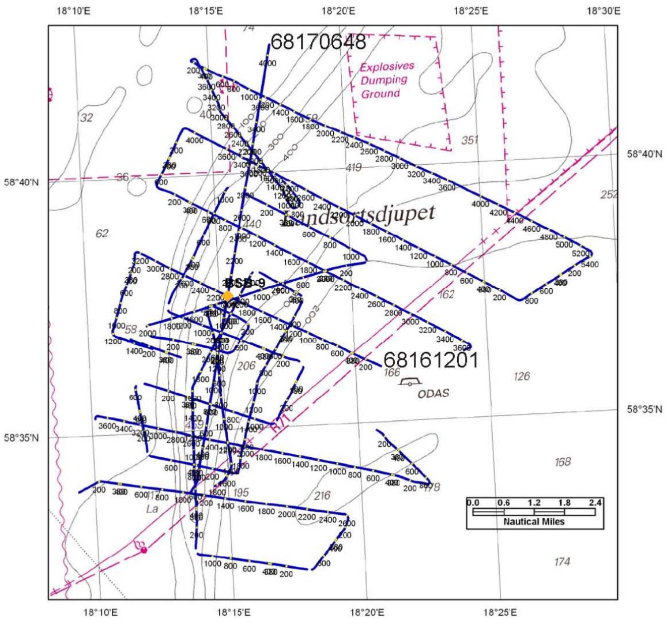
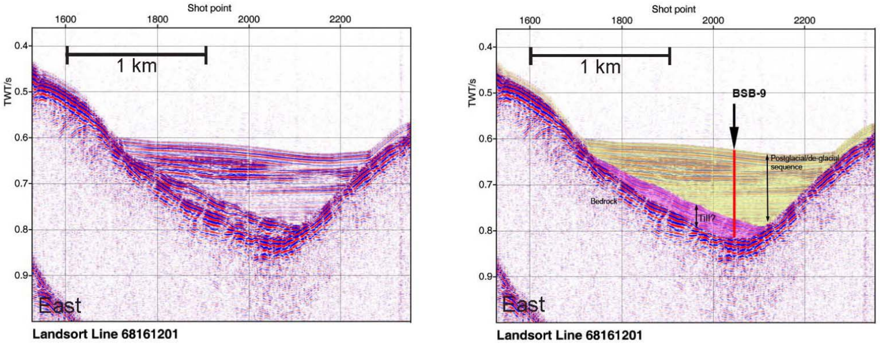
68161201_SP.nav







Note that shorter portions of profiles 68161201 and 68170648 are shown above in order to be able to show the details of the stratigraphy at this scale. The entire profile is submitted to the SSDB. A larger version of the trackline map with seismic shot points shown to the left has been uploaded to the SSDB.

Figure F14. Seismic lines across Site BSB-10. SSDB = Site Survey Data Bank.

Proposal 672-full3
Site BSB-10

Site summary form 6

SSDB location of these graphics and supporting data

Location map:	BSB-10-map.jpg
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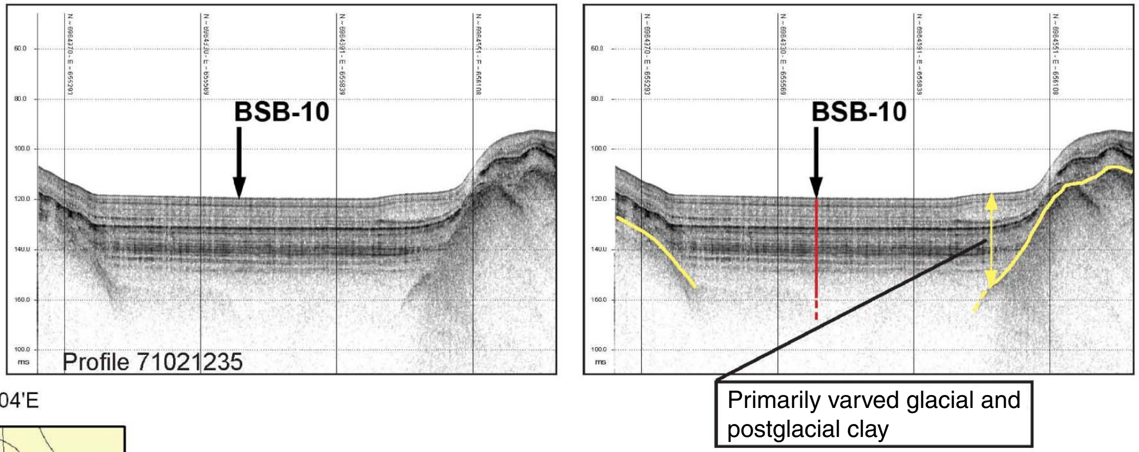
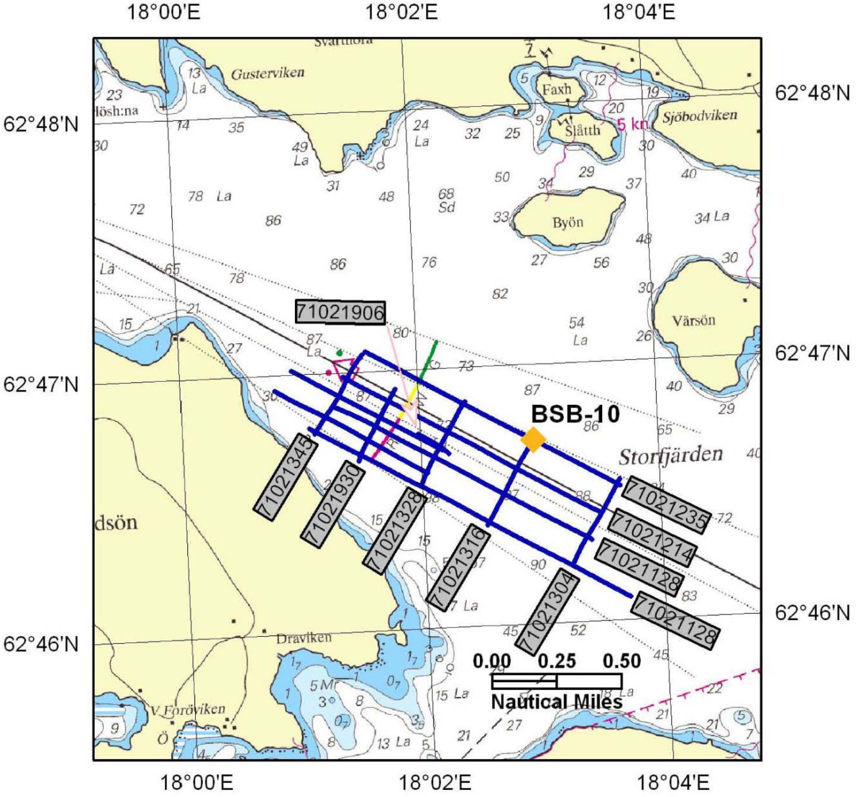
SEGY data:	71021235.segy 71021316.segy
NAV data:	71021235.nav 71021316.nav





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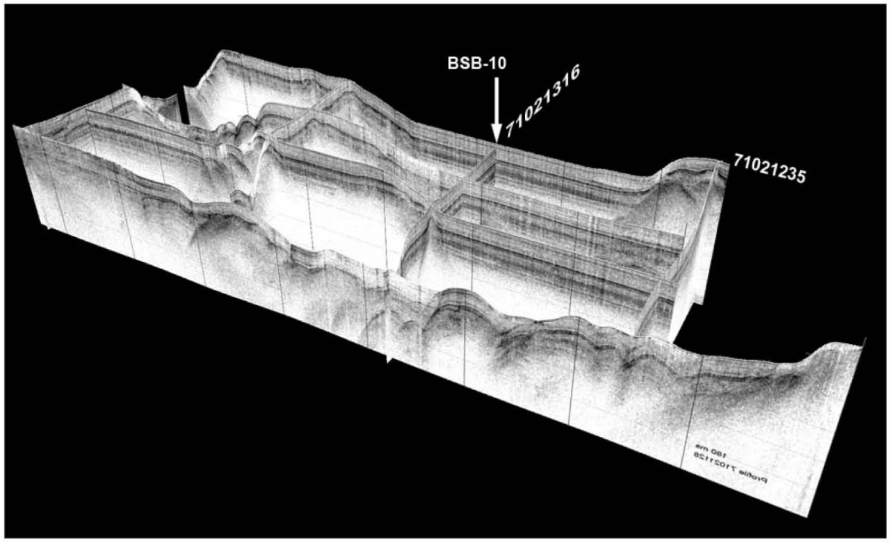
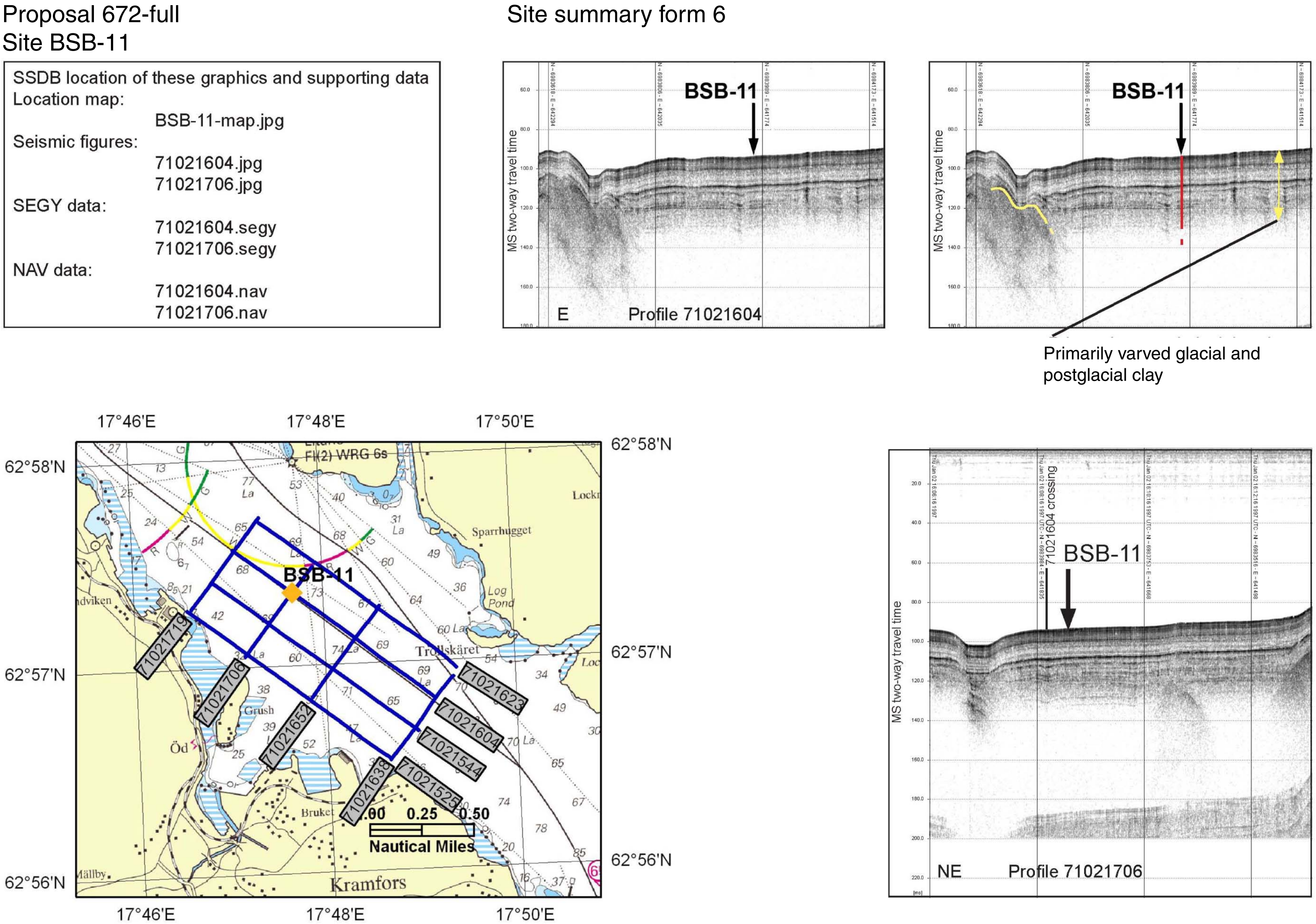


Figure F15. Seismic lines across Site BSB-11. SSDB = Site Survey Data Bank.



Proposal 672-full
Site BSB-11

SSDB location of these graphics and supporting data
Location map:
BSB-11-map.jpg
Seismic figures:
71021604.jpg
71021706.jpg
SEGY data:
71021604.segy
71021706.segy
NAV data:
71021604.nav
71021706.nav

Site summaries

Site BSB-1B

Priority:	Primary
Position:	56°36.695′N, 11°42.361′E
Water depth (m):	34.2
Target drilling depth (mbsf):	214
Approved maximum penetration (mbsf):	220
Seismic coverage:	Primary line(s): GeoB06-012, SP 4760 Crossing line(s): GeoB06-015 (projected; distance 450 m), SP 6812, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), gravity Core 318270-3 (FS *Merian* Cruise MSM-01).
Objectives (see text for details):	1. To recover the most complete sediment sequence covering the Saalian (MIS 6), Eemian (MIS 5e), and early Weichselian (MIS 2–4 and MIS 5a–5d). 2. Thick Holocene sediments can also be expected.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed. One additional core for the deep biosphere theme.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, contourites (?), glacial varved clays, clayey tills, and Eemian mud.

Seismic interpretation:

0–77 m	1450 m/s	Clay	Marine late Holocene
77–114 m	1600 m/s	Varved clay	Late Glacial
114–214 m	1600 m/s	Till, clay, partly deformed	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-2B

Priority:	Alternate
Position:	56°34.667′N, 11°47.320′E
Water depth (m):	34.2
Target drilling depth (mbsf):	149
Approved maximum penetration (mbsf):	155
Seismic coverage:	Primary line(s): GeoB06-012, SP 3820 Crossing line(s): GeoB06-005b, SP 7387; GeoB06-010, SP 2689, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), gravity Core 318270-3 (FS *Merian* Cruise MSM-01).
Objectives (see text for details):	1. To recover the most complete sediment sequence covering the Saalian (MIS 6), Eemian (MIS 5e), and early Weichselian (MIS 2–4 and MIS 5a–5d). 2. Thick Holocene sediments can also be expected.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, contourites (?), glacial varved clays, clayey tills, and Eemian mud.

Seismic interpretation:

0–12 m	1450 m/s	Clay	Marine late Holocene
12–84 m	1450 m/s	Varved clay	Late Glacial
84–137 m	1600 m/s	Till,	Glacial, interstadial/interglacial
137–149	1600 m/s	Clay	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-3

Priority:	Primary
Position:	55°01′N, 10°07′E
Water depth (m):	35
Target drilling depth (mbsf):	150
Approved maximum penetration (mbsf):	156
Seismic coverage:	Primary line(s): DA98-31 Crossing line(s): DA98-32; DA98-33
Imagery:	No photography or video available.
Sampling:	No marine drilling, Kegnaes-1 ~20 km south of site (deep well; hydrocarbon search). No hydrocarbon shows.
Objective (see text for details):	To drill and sample the most complete stratigraphic Baltic Sea Basin sediment section to reconstruct the climate and glacial history of northern Europe during the Last Glacial cycle.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed. One additional core for the deep biosphere theme.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Unconsolidated clays and sand; Eemian mud.

Seismic interpretation:

0–150 m	1800 m/s	Clay/sand	Marine/Glacial

Site summaries (continued)

Site BSB-4

Priority:	Alternate
Position:	55°08′N, 09°48′E
Water depth (m):	23
Target drilling depth (mbsf):	180
Approved maximum penetration (mbsf):	186
Seismic coverage:	Primary line(s): DA98-05 Crossing line(s): DA98-14B
Imagery:	No photography or video available.
Sampling:	No marine drilling, Kegnaes-1 ~20 km south of site (deep well; hydrocarbon search). No hydrocarbon shows.
Objective (see text for details):	To drill and sample the most complete stratigraphic Baltic Sea Basin sediment section to reconstruct the climate and glacial history of northern Europe during the Last Glacial cycle.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Unconsolidated clays and sand; Eemian mud.

Seismic interpretation:

0–180 m	1800 m/s	Clay/sand	Marine/Glacial

Site summaries (continued)

Site BSB-5B

Priority:	Primary
Position:	55°43.290′N, 15°13.590′E
Water depth (m):	61
Target drilling depth (mbsf):	36
Approved maximum penetration (mbsf):	42
Seismic coverage:	Primary line(s): GeoB06-057, SP 18700, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), Core 318270-3 (vibro core), Core 318280-5 (vibro core) (FS *Merian* Cruise MSM-01).
Objectives (see text for details):	To drill and recover early and mid-Weichselian littoral lake sediments.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, glacial varved clays, glacial tills, and Eemian mud.

Seismic interpretation:

0–7 m	1500 m/s	Clay	Marine late Holocene
7–14 m	1500 m/s	Till	Glacial
14–36 m	1600 m/s	Clay, partly deformed	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-6B

Priority:	Primary
Position:	55°41.520′N, 15°32.250′E
Water depth (m):	67
Target drilling depth (mbsf):	52
Approved maximum penetration (mbsf):	58
Seismic coverage:	Primary line(s): GeoB06-069, SP 13711, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), Core 318270-3 (vibro core), Core 318280-5 (vibro core) (FS *Merian* Cruise MSM-01).
Objectives (see text for details):	To drill and recover early and mid-Weichselian littoral lake sediments.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, glacial varved clays, glacial tills, and Eemian mud.

Seismic interpretation:

0–13 m	1500 m/s	Clay	Marine late Holocene
13–52 m	1600 m/s	Till, clay, partly deformed	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-7B

Priority:	Primary
Position:	55°28.034′N, 15°28.680′E
Water depth (m):	85
Target drilling depth (mbsf):	74
Approved maximum penetration (mbsf):	80
Seismic coverage:	Primary line(s): GeoB06-079b, SP 13533, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), Core 318270-3 (vibro-core), Core 318280-5 (vibro-core) (FS Merian Cruise MSM-01).
Objectives (see text for details):	To drill and recover early and mid-Weichselian lake sediments in deepwater phase.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, glacial varved clays, glacial tills, and Eemian mud.

Seismic interpretation:

0–13 m	1450 m/s	Clay	Marine late Holocene
13–41 m	1500 m/s	Varved clay	Late Glacial
41–74 m	1600 m/s	Till, clay, partly deformed	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-8B

Priority:	Will not be attempted because of ammunition dump safety concerns. Alternative Site BSB-7B will be utilized.
Position:	55°17.258′N, 15°28.917′E
Water depth (m):	93
Target drilling depth (mbsf):	93
Approved maximum penetration (mbsf):	93
Seismic coverage:	Primary line(s): GeoB06-079, SP 40660, SES-96 parametric sediment echosounder
Imagery:	No photography or video available.
Sampling:	No marine drilling, but land drilling (Lykke-Andersen et al., 1993), Core 318270-3 (vibro core), Core 318280-5 (vibro core) (FS *Merian* Cruise MSM-01).
Objectives (see text for details):	To drill and recover early and mid-Weichselian lake sediments in deepwater phase.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed. One additional core for the deep biosphere theme.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Holocene mud, glacial varved clays, glacial tills, and Eemian mud.

Seismic interpretation:

0–47 m	1450 m/s	Clay, varved clay	Marine late Holocene, late Glacial
47–93 m	1600 m/s	Till, clay, partly deformed	Glacial, interstadial/interglacial

Site summaries (continued)

Site BSB-9

Priority:	Primary
Position:	58°37.60′N, 18°15.30′E
Water depth (m):	451
Target drilling depth (mbsf):	152
Approved maximum penetration (mbsf):	158
Seismic coverage:	Primary line(s): 68161201: SP 2046 Crossing line(s): 68170648: SP 1804, chirp sonar profile
Imagery:	No photography or video available.
Sampling:	Several short (maximum 15 m) sediment cores available from the area (published).
Objectives (see text for details):	Seismic reflection data acquired over the Landsort Deep clearly show the most suitable drilling target selected for the purpose of recovering the longest undisturbed postglacial (possible partly deglacial) sediment sequence. Air gun Profiles 68170648 and 68162141 both run along Landsort Deep. From approximately shot point (SP) 1000 in 68170648 and SP 1700 in air gun Profile 68162141, the uppermost horizontally stratified sediment layer is thickening. Assuming a sediment sound speed of 1500 m/s, the horizontally stratified sediment section is ~122 m thick at the thickest part near SP 1900 in Profile 68170648. This profile is intersected by Profile 68161201, and the intersection provides an acoustically well constrained drilling target at a location in the Landsort Deep where the sediment section appears to reach the maximum thickness in the area and where there are no signs of erosion or other disturbances.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed. One additional core for the deep biosphere theme.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Till(?) overlaid by a horizontally stratified deglacial(?) and postglacial clay sequence.

Site summaries (continued)

Site BSB-10

Priority:	Primary.
Position:	62°46.70′N, 18°02.95′E
Water depth (m):	86
Target drilling depth (mbsf):	+30
Approved maximum penetration (mbsf):	+40
Seismic coverage:	Primary line(s): 71021235 Crossing line(s): 71021316, chirp sonar profile.
Imagery:	No photography or video available.
Sampling:	Several short (maximum 15 m) sediment cores available from the area (published).
Objectives (see text for details):	Two target areas were surveyed north of Härnösand in the easternmost part of Ångermanälven using an EdgeTech chirp sonar subbottom profiler with the SB-216s tow fish. A chirp frequency modulation pulse between 3 and 9 kHz was used. The surveyed area located at about 62°47′N contains a suitable area for drilling where an apparently undisturbed sediment section fills a trough and reaches a thickness of >40 ms TWT (30 m assuming a sound speed of 1500 m/s). The proposed primary Site BSB-10 is located on Profile 71021235, and Profile 71021316 ends 34 m southwest of the proposed site and thus nearly provides a crossing.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Varved glacial clay end silt.

Site summaries (continued)

Site BSB-11

Priority:	Primary
Position:	62°57.35′N, 17°47.70′E
Water depth (m):	68
Target drilling depth (mbsf):	+30
Approved maximum penetration (mbsf):	+40
Seismic coverage:	Primary line(s): 71021604 Crossing line(s): 71021706, chirp sonar profile.
Imagery:	No photography or video available.
Sampling:	Several short (maximum 15 m) sediment cores available from the area (published).
Objectives (see text for details):	Site BSB-11 is located close to the small city Kramfors for the purpose of connecting the clay varve series with varves being deposited at present in the Ångermanälven River.
Drilling Program:	Up to 3 × APC to refusal, XCB to target depth and up to 5 short cores to capture the upper 0.75 m of the sequence undisturbed.
Downhole logging program:	Standard logging suite: neutron-porosity, lithodensity, gamma ray, resistivity, acoustic, and formation image.
Anticipated lithology:	Varved glacial clay end silt.

Expedition scientists and scientific participants

The current list of Expedition 347 participants can be found at **www.eso.ecord.org/expeditions/347/347.php.**