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Seismic Interpretation of the Continent-Ocean Boundary along the Senja Margin and the Vestbakken Volcanic Province, SW Barents Sea

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ABSTRACT

Continental breakup between Eurasia and Greenland led to the formation of the present day continental margin in the Barents Sea. This margin evolved along a large strike-slip zone, called the De Geer Zone with oceanic spreading propagating parallel to this zone. In this study, six 2D seismic lines from the "Havretst Bjørnøya Vest" (HB) survey have been examined and interpreted in an attempt to identify seismic signatures associated with the Continent-Ocean Boundary (COB) in this passive continental margin.

The method used when interpreting the seismic lines is divided in three stages: Observations, Interpretation and Discussion. The observation phase is an objective description of the seismic reflections. In the interpretation stage, the observations are tracked, compared to the observations in other lines, and connected to geological structures. These connections are further investigated and tied to the geological evolution of the margin in the discussion phase.

All the seismic lines show a similar characteristic, with two distinctly different sections. In the upper section, consisting of post-breakup sediments, the resolution is high, and reflections relatively easy to track. The seismic reflections in the bottom section are masked, resulting in chaotic, low amplitude reflections resembling noise. Between these sections a strong, positive reflection is seen. It is divided into High Amplitude Sequence (HAS) 1 and 2, based on its depth and signature. These are interpreted as the top oceanic reflector and the continental volcanic extrusives respectively. Basalts in both sequences are the reason for the seismic masking.

The complex geology between HAS1 and HAS2 are interpreted as the Continent-Ocean Transition. In this area it is hard to see the difference between the signatures of the two crusts. Continental Marginal Ridge (CMR) is interpreted from highs found in several of the seismic lines in this transition. This is stretching along the continental margin, and its western boundary is interpreted as the COB. How this ridge was created is uncertain, but several theories are presented, from heat transferred from the juxtaposed oceanic crust, to a volcanic origin.

Interpretations are presented in six geoseismic profiles, representing each seismic line, in addition to a map of the area. This map show the interpreted location of the Eocene volcano from which the volcanic extrusives erupted, as well as the CMR and the COB. The map is

compared to Libak et al., (2012), which studies of the same region. The interpretations are found to correspond well, apart from the CMR, which is not mentioned in his study.

SAMMENDRAG

Kontinental oppbrytning mellom Eurasia og Grønland førte til dannelsen av dagens kontinentalmargin i Barentshavet. Marginen utviklet langs en sidelengsforkastning, kalt De Geer Sonen, med oseanisk spredning i parallel retning til denne sonen. I denne studien har seks 2D seismiske linjer fra datasettet "Havretst Bjørnøya Vest" (HB) blitt studert og tolket i et forsøk på å identifisere seismiske signaturer forbundet med Kontinent-Oseansk grense i denne passive kontinentale marginen.

Metoden brukt ved tolkning av de seismiske linjene er delt i tre faser: Observasjoner, tolking og diskusjon. Observasjonsfasen er en objektiv beskrivelse av de seismiske refleksjonene. I tolkningsdelen blir observasjonene kartlagt, sammenlignet med observasjoner i de andre linjene, og relatert til geologiske strukturer. Disse relasjonene er videre undersøkt og knyttet til den geologiske utviklingen av marginen i diskusjonsfasen.

Alle de seismiske linjene viste en karakteristikk, med to svært ulike seksjoner. I den øvre seksjonen, bestående av sedimenter avsatt etter kontinentaloppbrytningen, er oppløsningen høy, og refleksjonene relativt lette å kartlegge. De seismiske refleksjonene i den nedre seksjonen er maskert, noe som resulterer i kaotiske, lav-amplitude refleksjoner, som minner om støy. Mellom disse seksjonene ligger en sterk refleksjon med positiv amplitude. Denne er delt inn i Høyamplitudesekvens (HAS) 1 og 2, basert på dens dybde og signatur. Høyamplitudesekvensene er tolket som henholdsvis oseansk skorpe og vulkanske ekstrusjoner. Basalter i begge sekvensene er årsaken til den seismiske maskeringen.

Den komplekse geologien mellom HAS1 og HAS2 er tolket som overgangen mellom kontinent og oseansk skorpe. Høyder observert i flere av de seismiske linjene er tolket som en rygg, og denne strekker seg langs kontinentalmarginen. Den vestlige grensen for denne ryggen blir tolket som Kontinent-Oceansk grense. Hvordan denne ryggen ble dannet er usikkert, men flere teorier blir presentert, fra varmeoverføring fra den sidestilte oseanske skorpen til en vulkansk opprinnelse.

Tolkningen er presentert i seks geoseismiske profiler, som hver representerer en seismisk linje. I tillegg er tolkingene satt sammen til et kart over området. Kartet viser den antatte plasseringen til Eocenvulkanen hvor de vulkanske ekstrusivene stammer fra, samt kontinentalmarginryggen og Kontinent-Oceansk grense. Kartet er sammenlignet mot Libak et al., (2012),

som undersøker den samme regionen. Tolkingene samsvarer godt, sett bort ifra kontinental-marginryggen, som ikke er nevnt i hans studie.

ACKNOWLEDGMENTS

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ABBREVIATIONS

ABBREVIATION	Full text
COB	Continent-Ocean Boundary
CMR	Continental Marginal Ridge
HAS1 / HAS2	High Amplitude Sequence 1/2
HB	Havretst Bjørnøya Vest
NPD	Norwegian Petroleum Directorate
SDR	Seaward Dipping Reflector
SFZ	Senja Fault Zone
SS	Subsection
VVP	Vestbakken Volcanic Province

1 INTRODUCTION

The continental passive margin in the Barents Sea stretches from Norway to Svalbard (Figure 1). Studying continental margins are important for understanding the processes leading to continental breakup and oceanic spreading. In the Barents Sea, breakup and subsequent oceanic spreading was orthogonal to the continental margin, forming a shear margin. The result is an abrupt transition from the continental to the oceanic crust. Due to the complex nature and varying geological features of the passive margins, determining the exact boundary between the continental and oceanic crust has proved to be difficult.

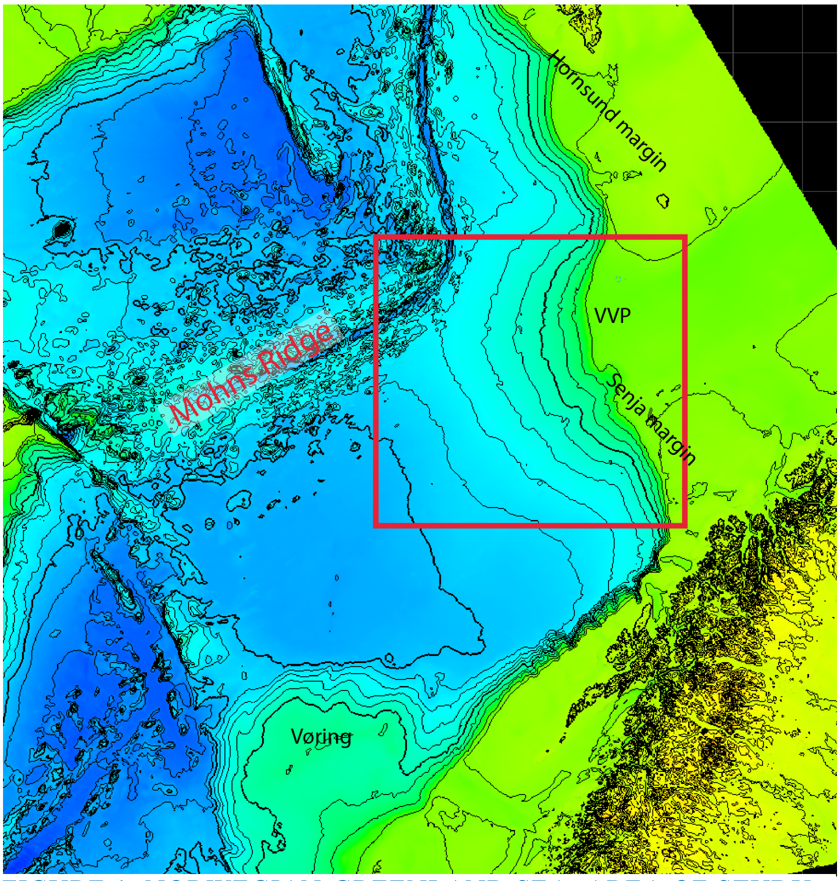

FIGURE 1: NORWEGIAN-GREENLAND SEA. AREA OF STUDY MARKED WITH THE RED RECTANGLE. BATHYMETRIC MAP FROM THE PUBLIC GEBCO DATABASE.

The area of study has been of interest for many years. Eldholm et al., (1987) described the margin as two sheared segments, the Senja and Hornsund Margin, with a rifted margin segment in between, the Vestbakken Volcanic Province. The rifted margin is characterized by the Eocene volcanic flows (Faleide et al., 1988). The latest study was done by Libak et al., (2012). His study focuses on an ocean bottom seismic line, in addition to 2D seismic lines, to investigate the crustal structure over the Barents Sea margin.

This study will examine the 2D lines, trying to locate the COB from the seismic reflection data. A large part of the interpretation process will focus on the different seismic signatures of the crusts, and if they can be separated. Then the interpretation of the COB will be compared to the COB from Libak et al., (2012).

Locating the COB is important in the establishment of countries economic zones and in the process of evaluating the petroleum potential of passive margins, which may be targets for future hydrocarbon exploration.

2 GEOLOGICAL BACKGROUND

2.1 THE DEVELOPMENT OF A PASSIVE MARGIN

The term passive margin is a synonym for different types of geological margins, ranging from divergent margins to rifted margins. A passive margin is formed by an initial rifting phase. This extensional movement leads to formation of oceanic crust and seafloor spreading. The resulting plate consists of a transition from oceanic lithosphere to continental lithosphere, (Bradley, 2008). In this section, the geological events that may result in the formation of a passive margin are studied, to get an understanding of how the continental passive margin in the Barents Sea was formed.

2.1.1 CONTINENTAL BREAKUP

The process that leads to the breakup of continents is widely studied, and its nature and causes has been discussed for a long time. When continents break apart, it usually start with a long period of small-scale rifting, but as it starts to separate, it often do so rapidly (White and McKenzie, 1989). Models of continent breakup ranges from passive rifting, where extension and thinning of the lithosphere is a result of the force distribution at plate boundaries (McKenzie, 1978), to active rifting as a result of an ascending mantle plume (Morgan, 1983).

McKenzie's model is a pure-shear model of extension, and describes how stretching of the continental lithosphere will result in thinning of the crust, and upwelling of hot asthenosphere. Faulting and subsidence is associated with this thinning. The beta factor, β, defines the amount of thinning, and is a measure of the extension (Lippard, 2011). Because of heat transport to the surface, part of the upwelled asthenosphere will be cooled down, and becomes a part of the lithosphere. This is known as thickening of the lithosphere (McKenzie, 1978). This cooling results in thermal subsidence (Lippard, 2011). McKenzie’s model is symmetrical.

An alternative model is the simple shear model of continental rifting, proposed by Wernicke in 1981. This model suggests that detachment-related zones cut through the whole thickness of the lithosphere (Lister et al., 1991). Extension is accomplished as a result of one half being pulled out from underneath the other, creating a low angle detachment fault. Upwelling in the asthenosphere occurs beneath the detachment zone. A detachment fault will result in an asymmetry to the basin (Lippard, 2011).

Morgan's model suggests that continental breakup is caused by continental drift over hot spots. As continents move over hot spots, the lithosphere heat up and leaves a trail of weakness. Tens of millions of years later, continents may break up along these lines (Morgan, 1983).

The age of the continental lithosphere will often determine its thickness, and whether the continental lithosphere is thicker than the oceanic is still controversial (McKenzie and Bickle, 1988). However, beneath Phanerozoic crust, the lithospheric thickness is about similar to that of the oceanic crust, and it also acts similar thermally .The magmatically active rifts around the world all have Phanerozoic lithosphere (White and McKenzie, 1989).

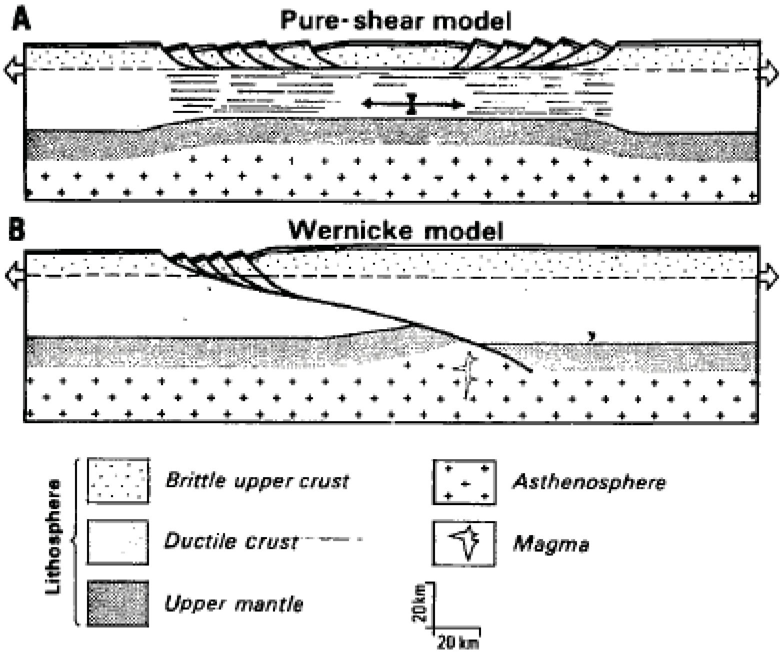

FIGURE 2: MCKENZIE'S PURE-SHEAR MODEL AND WERNICKE'S SIMPLE SHEAR MODEL. MODIFIED FROM LISTER ET AL. 1987.

As mentioned, thinning of the lithosphere wells up the asthenosphere to fill the void. This asthenosphere will partially melt as it decompresses, and the volume of melt generated depends on the amount of lithosphere thinning and the temperature of the asthenosphere (White and McKenzie, 1989). The most voluminous magmatism will occur in the main rifting phase, and the melt will quickly rise towards the surface. Parts of the melt will reach the surface, to produce voluminous flood basalts, and the remainder will intrude the continental crust in sills and dikes. The eruptive basalts will flow laterally onto the adjacent continent.

2.1.2 SEAFLOOR SPREADING

At a beta factor of >5, the continent have been stretched far enough to break completely apart, creating what is known as an oceanic spreading center. Rifts going across or near the mantle plume will be filled with large volumes of melt, and fed directly to the surface, creating a 15-30 km thick igneous ridge across the ocean floor (White and McKenzie, 1989).

The spreading rates in a spreading ridge can vary from 10-180 mm/yr, and is what controls the morphology of a spreading center (Macdonald, 1982). Mapping of the Mid Ocean Ridges have shown that their structure is discontinuous, separated by several transform faults (Macdonald, 2001). The distance between the spreading ridges are kept constant, as there is no movement between the section (Figure 3). Macdonald divided the morphology of the spreading ridges in three categories; slow, intermediate and fast. A fourth category, the ultraslow, was introduced later by Dick et al. in 2003.

The ultraslow spreading ridge is categorized by a spreading rate of less than 12 mm/yr, but rates up to 20 mm/yr show the same characteristics (Dick et al., 2003). Examples of ultraslow spreading ridges are the Arctic and Southwest Induan ridges. The common characteristics of an ultraslow spreading ridge, is intermitted volcanism, and the lack of transform faults. It consists of linked magmatic and amagmatic segments. Morphology wise, the magmatic segments form linear axial highs or troughs, and rift valley walls consisting of staircase normal faults (Dick et al., 2003). Amagmatic segments replace the transform faults, are oriented relative to the ridge's spreading direction, and are marked by an axial trough that can be up to a kilometer deep and may extend 50 kilometers or more.

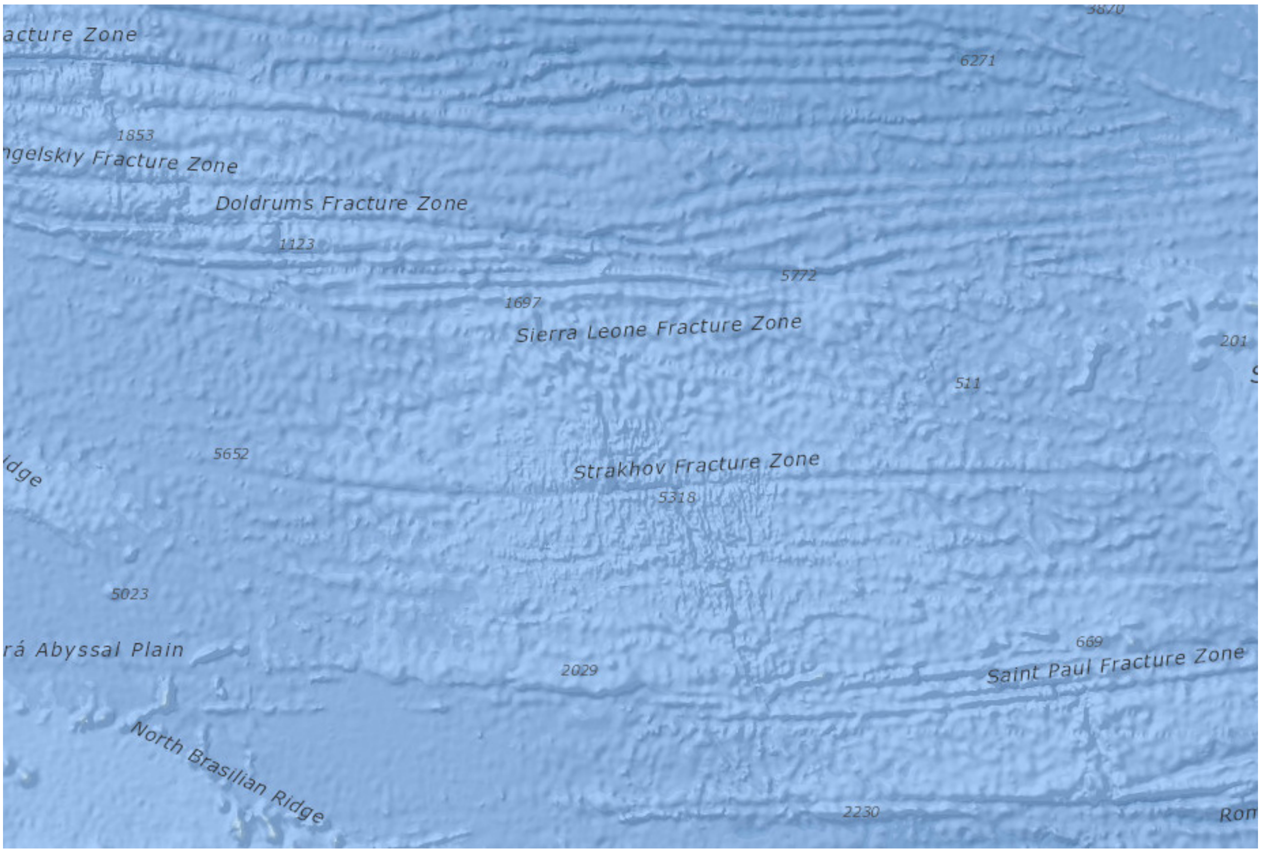

FIGURE 3: A BATHYMETRIC SECTION OF THE MID ATLANTIC RIDGE SHOWING THE TRANSFORM FAULTS, AND HOW THEY SEPARATE THE DIFFERENT SECTIONS OF THE RIDGE (NOAA, 2013).

The slow spreading ridge is characterized by a spreading rate of 10-50 mm/yr. The Neovolcanic zone is located in the middle of a 30-50 kilometers wide rift valley, and a depth ranging from 1,5 – 3 kilometers. The terrain in the rift valley is rough and faulted (Macdonald, 1982).The classic example of a slow spreading ridge is the Mid Atlantic Ridge.

Intermediate spreading ridges have spreading rates of 50-90 mm/yr, and the rift valley is shallower than the slow spreading ridges, with a depth ranging from 50-200 meters. The topography on the rift valley flanks of the spreading ridge is relatively smooth. Examples are the East Pacific Rise at 21°N, and the Galapagos spreading center (Macdonald, 1982).

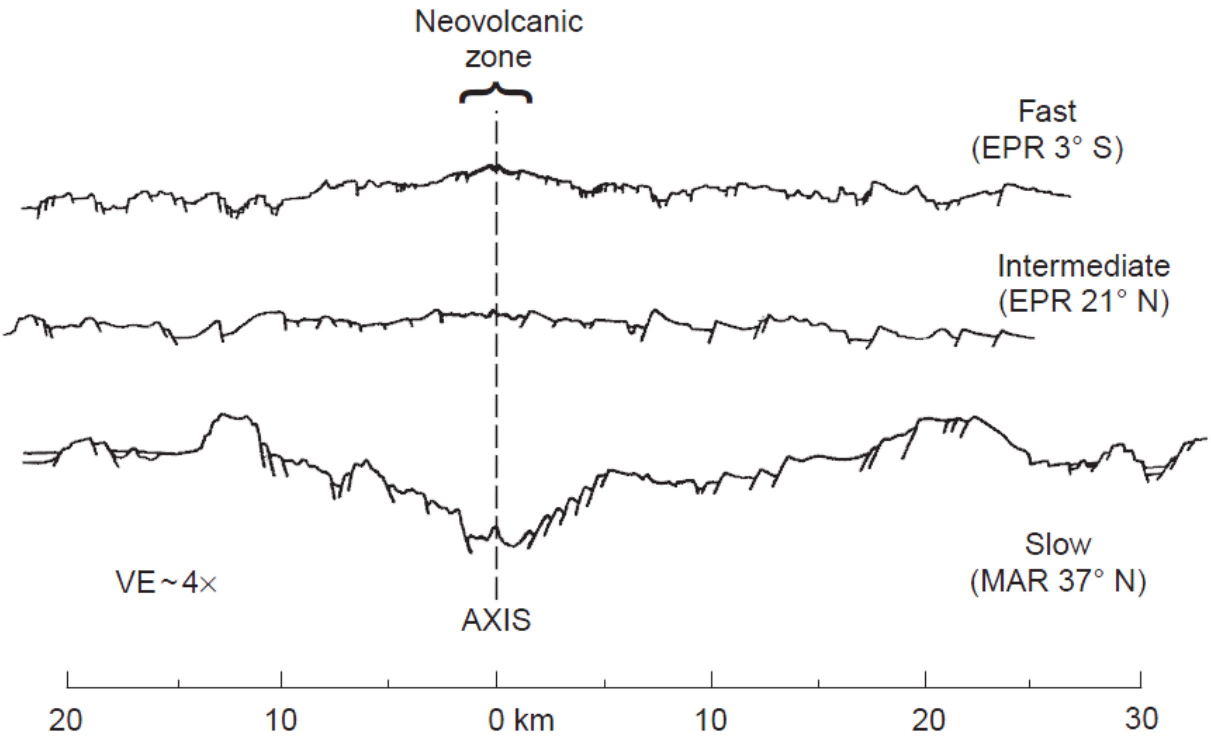

FIGURE 4: TOPOGRAPHY OF A FAST, INTERMEDIATE AND SLOW SPREADING RIDGE WITH THE NEOVOLCANIC ZONE IN THE CENTER. THE ZONE OF ACTIVE FAULTING STRETCHES FOR TENS OF KILOMETERS. MAR: MID ATLANTIC RIDGE. EPR: EAST PACIFIC RISE. FROM MACDONALD, 2001.

Ridges spreading faster than 90 mm/yr are classified as fast spreading ridges. These ridges are characterized by the lack of a rift valley, by an axial high can be observed. Its topography is smooth, with fine scale horst and graben structures (Macdonald, 1982). An example is the East Pacific Rise south of 15°N.

2.1.3 OCEANIC CRUST

The structure of the oceanic crust is divided into four main layers (Figure 5). These layers are based on studies of seismic profiles, well data and ophiolite terranes on land (Winter, 2009).

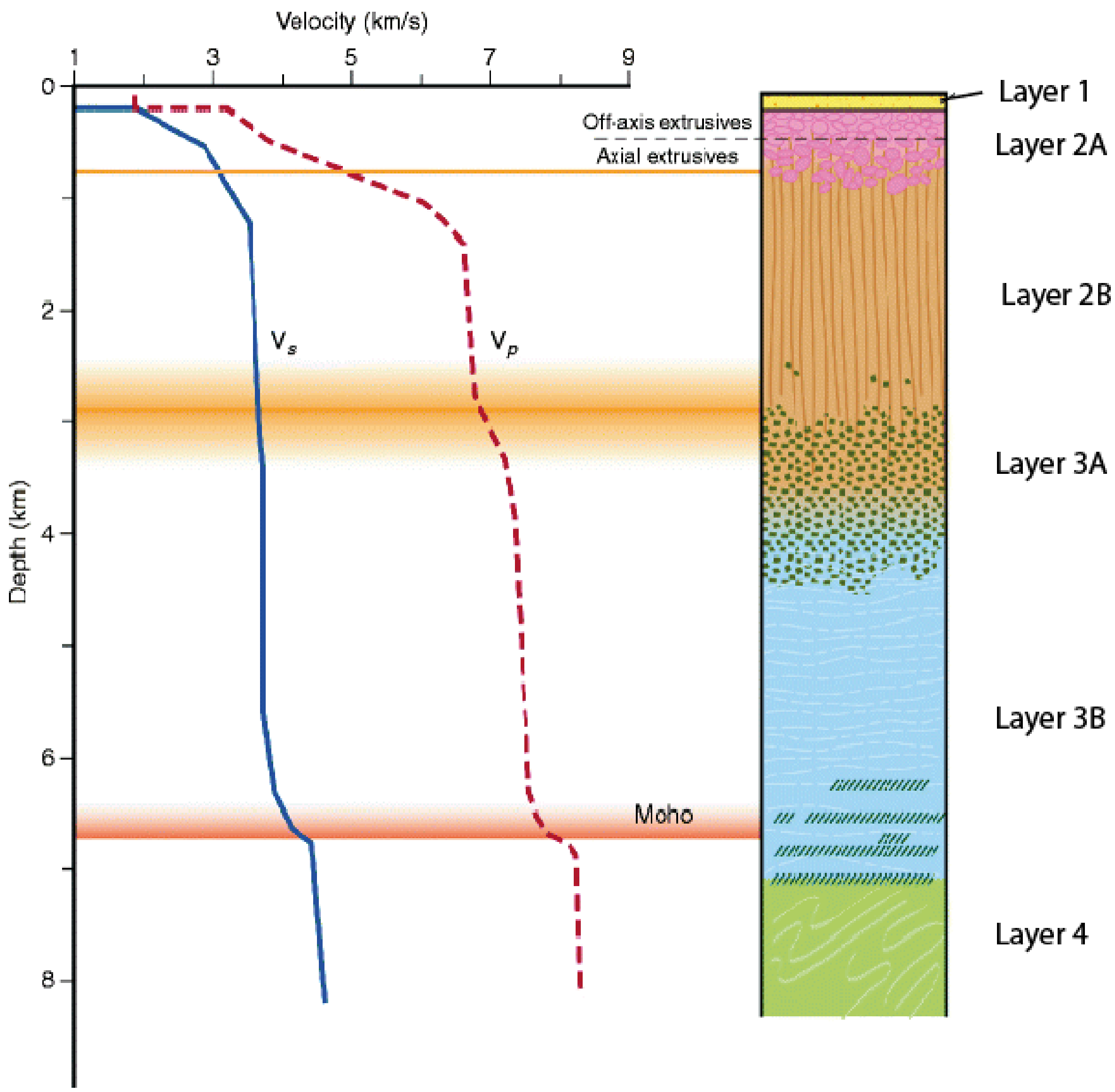

FIGURE 5: SEISMIC VELOCITIES COMPARED WITH A GEOLOGIC MODEL BASED ON OPHIOLITES. ILLUSTRATES THE DIFFERENT LAYERS IN THE OCEANIC CRUST. MODIFIED FROM MCCLAIN, 2013.

Layer 1 is a thin layer of sediments that have accumulated after the creation of new crust. This layer is therefore absent on newly generated crust (Winter, 2009). Layer 2 is basaltic, and is subdivided into sublayer 2A and 2B. Layer 2A consists of sheet-lavas and pillow basalts and is usually around 500 m thick (Winter, 2009). The transition from sediments to basalts marks a great increase in velocitiy and impedance. Layer 2B consists of sheeted dike compexes, and is 1.5 – 2 km thick. The P-wave velocity in this layers is thought to be over 6 km/s (Winter, 2009).

The end of the sheeted dikes marks the start of layer 3, which consists of gabbros. This layer is subdivided into layer 3A, which consists of isotropic gabbros, and layer 3B, consisting of layered gabbros (McClain, 2013). Layer 3 is believed to represent the crytallized magma chamber that fed basalt and dikes in layer 1 and 2 (Winter, 2009).

At the bottom of the oceanic crust, in layer 4, are ultramafic peridotites (McClain, 2013). Ultramafics suggest transition to the mantle, and the velocity jump from layer 3 to layer 4 represents the Moho (Winter, 2009). Layer 4 has P-wave velocities at 8,1 km/s, characteristic of peridotite (Winter, 2009).

2.1.4 VOLCANISM

The morphology of volcanic rocks may vary depending on several factors like feeder geometry, rate of discharge and volume, topography, cooling rate, presence of water and the properties of the magma (Planke et al., 2000). Presence of water, water depth and topography are the most important factors in the determination of the volcanic facies (Planke et al., 2000).

Studies have led to a model in five stages for the development of a rifted volcanic passive margin:

I. Initial explosive volcanism in a wet basin or aquatic setting (Planke et al., 2000). These deposits are found beneath the landward flows.
II. Subaerial large-volume effusive volcanism at seaward propagating centers, creating the Landward Flows (Berndt et al., 2001). Coastal erosion generates a volcaniclastic lava delta between the basalts in the Landward flows and volcaniclastics in the Inner flows within the rift valley (Berndt et al., 2001).
III. Subsidence forms a wedge shaped accomodation space, which is filled by subaerial flood basalts (Berndt et al., 2001, Planke et al., 2003). This unit is named the Inner Seward Dipping Reflectors (Inner SDR).

IV. Subsidence continues to the point where the eruption vents are submerged (Berndt et al., 2001). Explosive shallow marine volcanism will result in the buildup of hyaloclastite Outer Highs (Berndt et al., 2001, Planke et al., 2003).

V. As the volcanic vents are submerged deeper, the water pressure increases, and finally prohibits explosive eruptions (Berndt et al., 2001). The last volcanic facies in this model is the Outer SDR, which consists of pillow basalts and sheet flows (Berndt et al., 2001, Planke et al., 2003). Volcanism continues as normal oceanic seafloor spreading after this stage.

VOLCANIC SEISMIC FACIES

There are six main extrusive facies units studied, and recognized in volcanic passive margins, but all seismic units are not always present on a single margin (Planke et al., 2000). Identifying these units may help locate the transition from continental to oceanic crust. The six units are named Outer SDR, Outer High, Inner SDR, Landward Flows, Lava Delta and Inner Flow. A short description of the different facies units will be given, and summarized in Table 1.

Landward Flows

Landward flows are extrusive volcanic flood basalts deposited subaerially in a sheet shape (Planke and Alvestad, 1999). The source of the landward flows is hard to constaint because flood basalts may flow hundreds of kilometers (Planke et al., 2000). Its seismic signature is characterized by a strong top reflector, and a disrupted or sub parallel internal structure (Planke et al., 2000). High quality seismic data may show a negative polarity on the basal boundary (Planke et al., 2000).

Lava Delta and Inner Flows

The lithology of these facies are massive and fragmented basalts and volcaniclastics (Berndt et al., 2001). The lava delta has a bank shape, and may be truncated at the top and bottom reflector, as it lies between the Landward Flows and Inner Flows (Planke et al., 2000). The Inner flows have a high amplitude, disrupted top reflection and a negative polarity bottom reflection (Berndt et al., 2001). Overlying reflections are often subparallel, and reflections beneath are masked (Planke et al., 2000). The internal structure of the Inner Flows is usually chaotic and disrupted.

Inner SDR

The Inner SDR consists of flood basalts that have filled an accomodation space associated with subsidence (Berndt et al., 2001). It has a strong, continous reflection which is smooth or wavy, it's shape is formed like a wedge, and the internal reflections are inclined seawards. Termination of reflections internally is common (Planke et al., 2000).

Outer High

Outer Highs are formed when the volcanic vents are submerged, causing a build-up volcaniclastic and hyaloclastites in a shallow marine environment (Berndt et al., 2001). It is shaped as a mound, with a high amplitude top reflection (Planke et al., 2000). The bottom reflection is not visible, and internally the reflections are chaotic (Berndt et al., 2001).

Outer SDR

The Outer SDRs are interpreted as deep marine sheet flow constructions caused by voluminous volcanism at the sea floor (Planke et al., 2000). Outer SDRs consists of pillow and flood basalts with some interbedded sediments. The Outer SDR are located seaward of the Outer High, and is characterized by a strong and smooth top reflection, often onlapped, and it is shaped like a wedge (Planke et al., 2000). The internal reflections are inclined seawards and are low amplitude.

Facies unit	Shape	Boundaries (top/bottom)	Internal	Volcanic facies	Environment
Landward Flows	Sheet	T: Planated B:disrupted, low amplitude	Subparallel	Flood Basalts	Subaerial
Lava Delta	Bank	T: High amplitude B: Reflection truncation	Clinoform, Disrupted.	Massive & fragmented basalts, volcaniclastics	Coastal
Inner Flows	Sheet	T: High amplitude, disrupted. B: neg. polarity, obscured	Chaotic or disrupted	Volcaniclastics, Hyaloclastics and flows	Shallow marine
Inner SDR	Wedge	T: High amplitude B: Not visible	Diverging	Flood basalts	Subaerial
Outer High	Mound	T: Rough, high amplitude B: Not visible	Chaotic	Volcaniclastics & hyaloclastics	Shallow marine
Outer SDR	Wedge	T: High amplitude, onlapped B: Seldom defined	Divergent, disrupted	Flood and pillow basalts, sediments.	Deep marine

TABLE 1: CHARACTERISTICS OF VOLCANIC EXTRUSIVE FACIES UNITS. MODIFIED FROM PLANKE ET AL. 2000, PLANKE & ALVESTAD, 1999 AND BERNDT ET AL. 2001.

2.2 THE WESTERN BARENTS SEA MARGIN

2.2.1 STRUCTURAL DEVELOPMENT

Rifting initiated in late Cretaceous in the Barents Sea, and Bjørnøya and the surrounding area was located off northeast Greenland at the time (Libak et al., 2012). Translation away from Greenland initiated along the regional megashear system known as De Geer Zone (Libak et al., 2012). The De Geer Zone connected the spreading ridge in the Northern Atlantic and the spreading ridge in the Arctic (Faleide et al., 2008). Continental breakup occurred in the transition between Paleocene and Eocene, and sea floor spreading initiated. This event is dated by magnetic anomalies to about 57 Ma (Faleide et al., 1996). The continental breakup led to volcanic activity in Vestbakken Volcanic Province in Early Eocene. Oceanic spreading took place in the Mohns Ridge, meaning the neovolcanic zone terminated against the Eurasian plate. The plate movement was parallel to the De Geer Zone, which caused shear motions, and irregularities in this zone resulted in different margins segments. The Senja Margin and the Hornsund Margin became shear margins, and the Vestbakken Volcanic Province (VVP) became a rifted margin (Libak et al., 2012). Transtension caused thinning and weakening of the crust, and led to intrusions, most noticeably in the Vestbakken Volcanic Province (Czuba et al., 2010).

In earliest Oligocene time (35 Ma), the direction of the sea floor opening was altered, which led to the opening of the Northern Greenland Sea (Faleide et al., 1996). This ultraslow, asymmetric and oblique spreading ridge is known as the Knipovich Ridge (Czuba et al., 2010). Around 10 Ma ago, continental breakup occurred along the Fram Strait, finally establishing a connection between the Arctic and the Northern Atlantic Ridges (Czuba et al., 2010, Lundin and Doré, 2002). In the late Cenozoic the Barents Sea was uplifted and eroded.

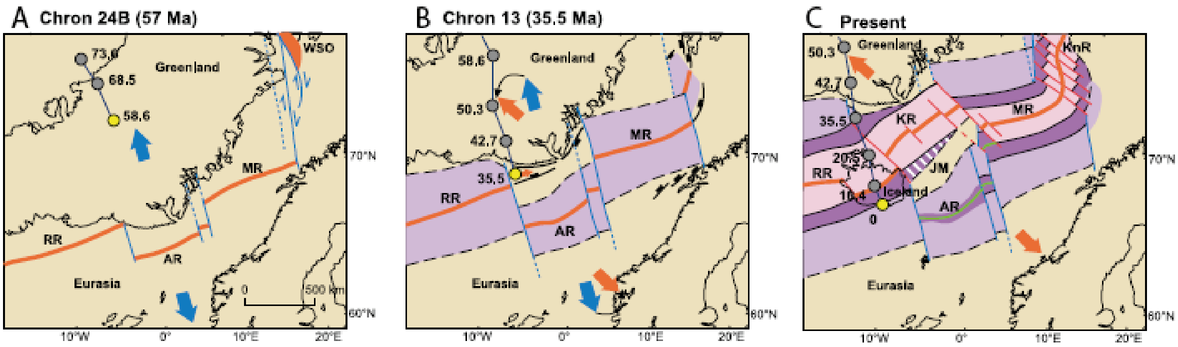

FIGURE 6: TECTONIC EVOLUTION IN THE NORWEGIAN-GREENLAND SEA. A) INITIATION OF SEAFLOOR SPREADING. BLUE ARROWS INDICATE PLATE MOVEMENT. DE GEER ZONE GIVEN BY BLUE LINES. B) PLATE REORGANIZATION AND CHANGE IN MOVEMENT (BLUE TO ORANGE ARROWS). C) PRESENT DAY PLATE ORGANIZATION. YELLOW DOTS: APPROXIMATE POSITION OF ICELAND PLUME CENTER. GREY DOTS: PREVIOUS POSITIONS. MR: MOHNS RIDGE. RR: REYKJANES RIDGE. KR: KOLBEINSEY RIDGE: AR: AEGIR RIDGE. KNR: KNIPOVICH RIDGE. JM: JAN MAYEN. WSO: WEST SPITSBERGEN OROGENY. FIGURE MODIFIED FROM LUNDIN ET AL. 2002.

2.2.2 CENOZOIC SEDIMENTATION AND STRATIGRAPHY

Sedimentation in Mesozoic and Cretaceous times took place in basins on the Barents Sea Shelf. The Cenozoic opening of the Norwegian-Greenland Sea made new depocenters on the continental margin (Vorren et al., 1988). The uplift in the late Cenozoic times was accompanied by glaciation in late Pliocene and Pleistocene, which resulted in erosion and deposition of large sedimentary wedges along the continental margin and on the adjacent oceanic crust (Faleide et al., 1996, Libak et al., 2012).

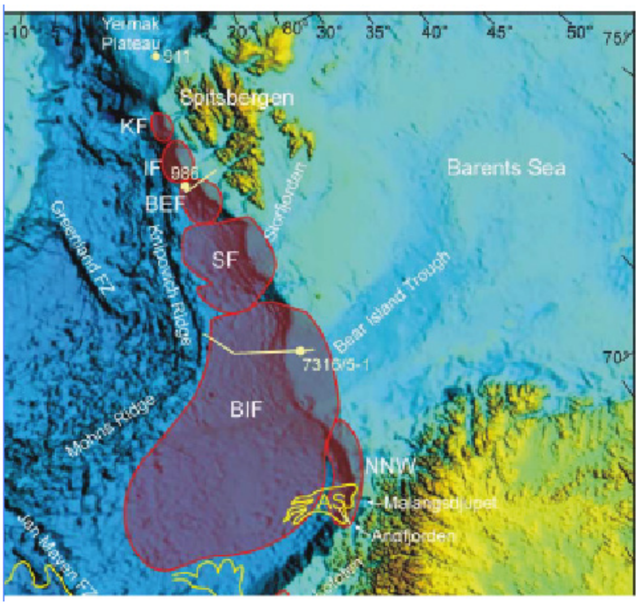

FIGURE 7: A MAP SHOWING THE EXTENT OF THE SEDIMENTARY FANS ON THE BARENTS SEA CONTINENTAL MARGIN. BIF: BJØRNØYA FAN. SF: STORFJORDEN FAN. MODIFIED FROM DAHLGREN ET AL. 2005.

Three main phases of glacial development has been identified: (1) Initial growth phase (~3.5-2.4 Ma), (2) Transitional growth expansion phase (~2.4-1.0 Ma), and (3) Final growth phase (since ~1.0 Ma) (Knies et al., 2009). In these three phases, the extent of the glaciers vary a lot, from almost absent to covering vast areas (Knies et al., 2009). Knies' model of glacier extension is shown in Figure 8.

Glaciation in the Barents Sea led to massive erosion. On Svalbard and the Svalbard Platform, the erosion was in the order of 2-3 kilometers, and 1-2 kilometers were eroded south of Bjørnøya (Dimakis et al., 1998). Sediments deposited on the continental margin, with a thickness of 2-6 kilometers, where most of the sediments were drained out to the Bjørnøya trough mouth fan and the Storfjorden trough mouth fan (Dimakis et al., 1998). The Bjørnøya fan is located between Norway and Bjørnøya, seen in the seismic lines interpreted in this report, and the Storfjorden fan is located between Bjørnøya and Svalbard (Figure 7). The volume of these trough mouth fans have been estimated to 395,000 km³ and 116,000 km³ respectively, and they have a slope of 0,2-0,8° and 0,2-1,8° (Dahlgren et al., 2005). The Storfjorden fan is up to 4 kilometers thick, which is the maximum thickness of glacial sediments in this area (Dahlgren et al., 2005).

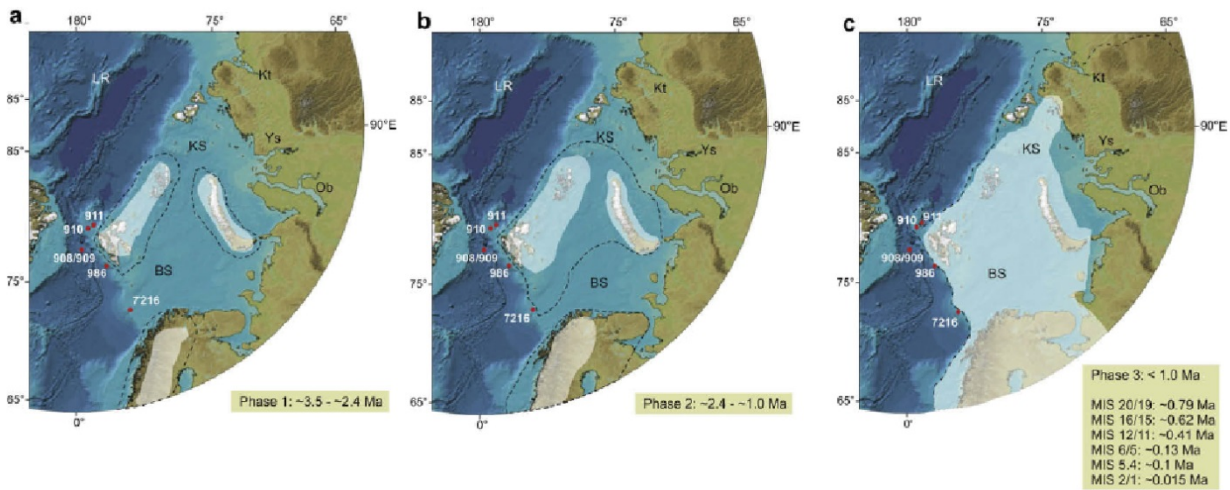

FIGURE 8: EXTENT OF THE GLACIERS DURING PLIO-PLEISTOCENE TIME PERIOD. STRIPPLED LINE: MAX EXTENSION, WHITE AREA: MINIMUM EXTENISON. FROM KNIES ET AL. 2009.

The compositions of the sediments are related to the geology of the hinterland, transport and deposition. In the Barents Sea, the hinterland consisted mostly of sedimentary rocks deposited in the eras before uplift and erosion in Cenozoic. Sampling from wells have shown that the main constituent of the wedges are glacigenic debris flows composed of diamictons, interbedded with slide debris and hemipelagic marine and glacimarine sediments (Dahlgren et al., 2005). Glacial diamictons consists of non-sorted to poorly sorted sediments, with a wide range of particle sizes (Menzies, 2013). Generally, diaminctons are composed of 10-40% sands and the rest is a balanced mix of silt and clay, but also contain coarser grains and clasts (Menzies, 2013, Dahlgren et al., 2005). The interbedded slide debris and hemipelagic sediments varies from pure clays to well-sorted sands (Dahlgren et al., 2005).

3 DATA & METHODS

3.1 SEISMIC DATA

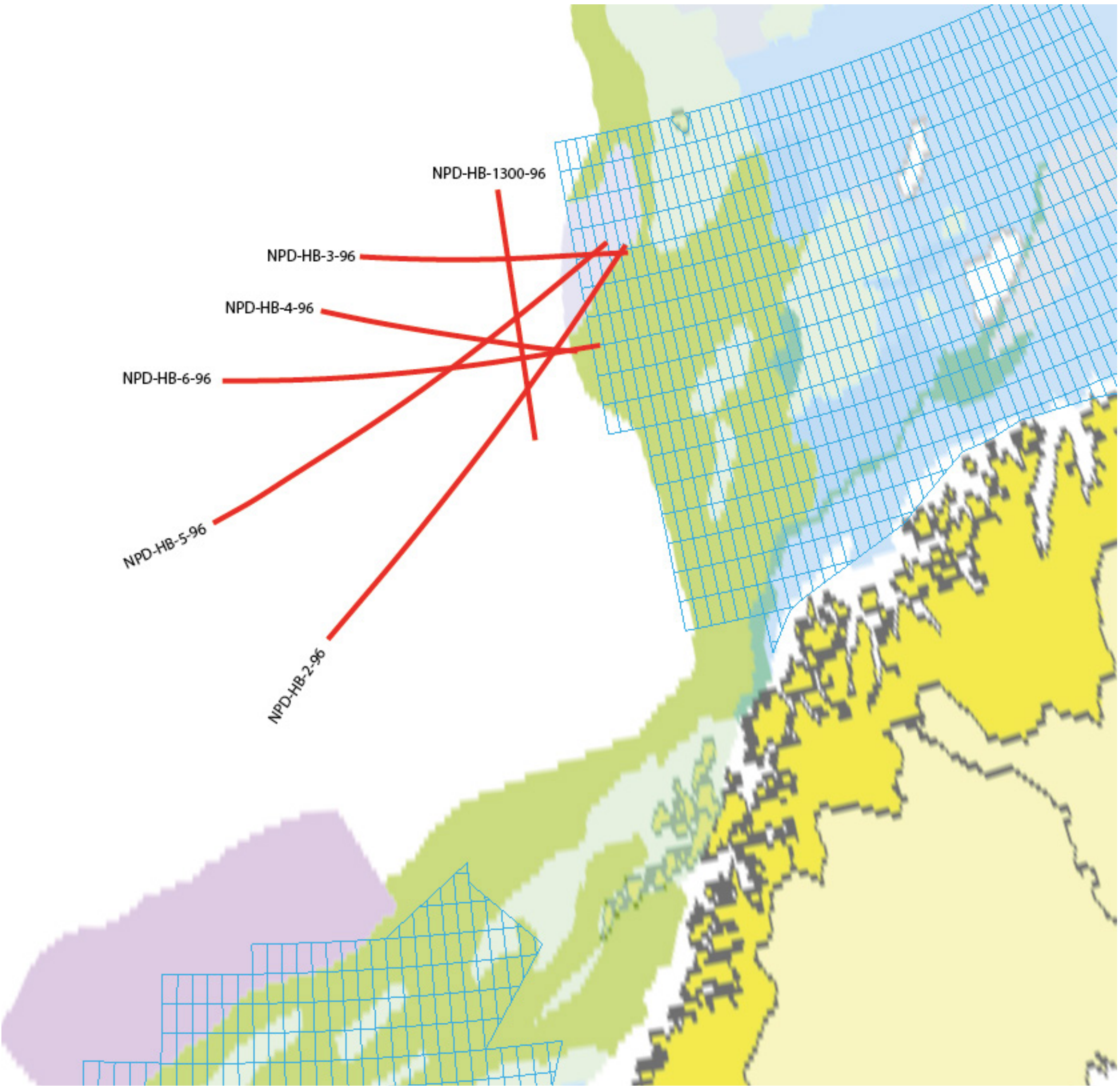

FIGURE 9: MAP SHOWING THE SEISMIC LINES STUDIED IN THIS THESIS.

The seismic data used in this study are six 2D multichannel seismic lines gathered in a survey named NPD-HB-96. The survey was gathered by the Norwegian Petroleum Directorate, and acquisition of the survey was done in 1996. HB is an abbreviation for "Havretst Bjørnøya Vest". The six lines are imaging the Barents Sea continental margin, and the oceanic crust. Some of the lines stretch all the way out to the Mohns Ridge.

Line	Coordinates (min, max)
NPD-HB-1300-96	(72º03'N , 12º32'E) , (74º11'N , 13º31E)
NPD-HB-2-96	(70º27'N , 6º39'E) , (73º39'N , 16º29'E)
NPD-HB-3-96	(73º29'N , 8º35'E) , (73º45'N , 16º35'E)
NPD-HB-4-96	(72º44'N , 7º19'E) , (73º19'N , 14º29'E)
NPD-HB-5-96	(71º30'N , 3º35'E) , (73º38'N , 16º)
NPD-HB-6-96	(72º39'N , 4º24'E) , (72º47'N , 15º13'E)

TABLE 2: COORDINATES OF THE SEISMIC LINES.

3.1.1 POLARITY

The polarity of the data is an important issue to resolve before starting to interpret the seismic reflections. Today, there are two international standards to the polarity. The American standard is that an increase in impedance results in positive amplitudes, normally displayed as a red intensity in color display. European polarity gives negative amplitudes when there is an increase in impedance, shown as a blue intensity in color display. Wavelet phase must also be decided, where the optimal for quantitative seismic interpretations is zero phase (Avseth et al., 2010).

To answer these questions, the seismic data must be analyzed. Observing the transition in the seismic signal when going from seawater to rocks at the seabottom, is a secure way to find an increase in impedance.

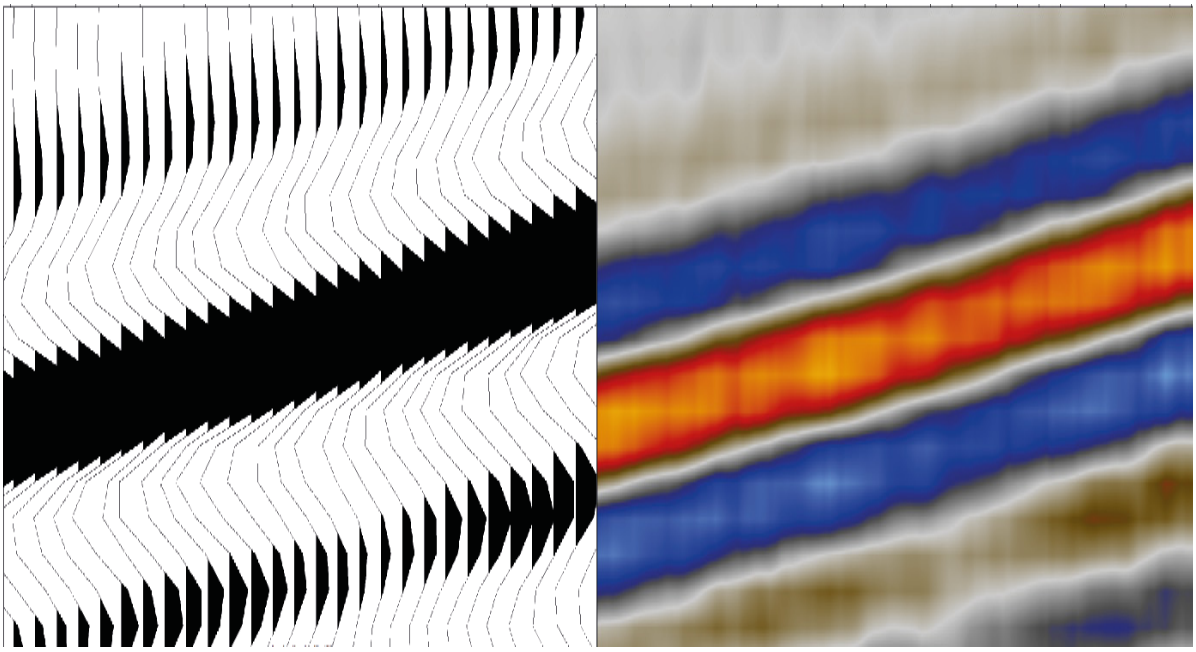

FIGURE 10: SEABOTTOM REFLECTION FROM NPD-HB-4-96. LEFT – WIGGLE TRACE. RIGHT – COLOR DISPLAY. THE POSITIVE AMPLITUDES IN THE WIGGLE TRACES CORROLATE TO THE RED INTENSITY IN THE COLOR DISPLAY, AND NEGATIVE CORROLATE TO THE BLUE INTENSITY. THE SEISMIC IS ZERO PHASE.

The seismic reflections in Figure 10Figure show that this data has American polarity, as increase in acoustic impedance results in positive amplitude. Because of the zero phase wavelet, the two negative (blue) amplitudes are interpreted as sidelobes, and the positive (red) amplitude is the main peak, which should be interpreted as the seabottom. This is of key importance to know when choosing what reflections to interpret in the sections.

3.1.2 QUALITY OF SEISMIC DATA

It is important for a seismic interpreter to have a dataset with high quality, but also to have the knowledge to distinguish between good and bad data. A geologist may interpret features that a geophysicist would identify as noise related, and similarly, a geophysicist may lack the knowledge in geology, and therefore interpret unrealistic geological features (Hesthammer et al., 2001). The importance of integrating both sciences in seismic interpretation should not be underestimated.

The details in the vertical resolution are in seismic in the range of tens of meters, because of the frequencies used in seismic are usually from 10 – 100 Hz. Higher frequencies give higher resolution. A rule of thumb is that the minimum vertical thickness of a layer to be interpreted, is given as

$$d_{min} = \frac{\lambda}{4} \quad \text{and} \quad \lambda = \frac{v}{f}$$

where λ is the wavelength of the seismic wave. Knowing that seismic velocities vary from 1500 m/s in water to 6000 m/s in some evaporites or volcanic intrusions, this can be used to calculate the minimum interpretable thickness of a layer (Avseth et al., 2010). In a layer with a velocity of 2000 m/s, and the frequency is 50 Hz, the minimum interpretable thickness would be 10 m.

3.1.3 INTERPRETATION METHOD & PRESTENTATION

The main programs used to interpret the seismic in this thesis are Schlumberger's Petrel 2013 and Adobe Illustrator CS5. Petrel is a very useful tool when handling seismic, and is used in research and in the industry. The first step is the observation phase. In this step, annotations are made in the seismic, to get the big picture of the geology behind the reflections. Correlation with well data determines which horizons should be interpreted. After the observation phase, the main seismic horizons and faults are tracked. Petrel is a very good tool to do this, because of the high resolution of the seismic, and the tools that help you track the horizons.

Seismic attributes can also help to illuminate features. After the Petrel interpretation is done, the data is exported to Adobe Illustrator CS5, which is a drawing program. This program makes high resolution drawing possible, and is good for presenting figures. The problem is that the image will be distorted and not as high definition when zooming. It is therefore nice to have the Petrel software at hand when drawing in Illustrator.

3.2 WELL DATA

Well data from the well 7316/5-1 is studied and correlated with the seismic lines. It was drilled as a wildcat exploration well by Norsk Hydro (operator), Statoil, Mobil, Conoco and Deminex Nord in production license 184. Polar Pioneer was the rig used for the drilling operation, and drilling commensed on the 21st of July 1992 and ended the 5th of October the same year. The well was drilled on the coordinates 73° 31' 11.89" N, 16° 25' 59.7" E, a point intersected by the seismic line NPD-HB-2-96, and in vicinity of the lines NPD-HB-5-96 and NPD-HB-3-96. The primary objective of the well was to appraise the potential of Tertiary prospects in lower Oligocene and upper Eocene, as well as undertake sampling and coring to provide improved stratigraphical control in the area (Semple and Bulman, 1993). The well is 4027 m deep, and penetrates the Nordland Group (Quaternary), Sotbakken Group (Tertiary) and Nygrunnen Group (Cretaceous). Conventional cores and sidewall cores were taken, shown in Table 3 and Table 4.

#	C: Cut, R: Recovered	% recovered	Lithology	Formation/group
1	C: 896.0-907.0 m R: 896.0-906.6 m	96.4	Sandstone	Nordland Gp
2	C: 1347.5-1375.0 m R: 1347.5-1374.37 m	97.7	Sandstone	Sotbakken Gp
3	C: 1451.5-1472.0 m R: 1460.6-1472.0 m	56.1	Sandstone	Sotbakken Gp

TABLE 3: CONVENTIONAL CORES TAKEN IN THE WELL 7316/5-1.

In addition to cores, the well was logged by Schlumberger using wireline tools. Table 5 shows a summary of the wireline logs run in the well and shows log type, date run and logged intervals.

Run #	Requested	Misfired	Lost	Empty	Recovered	% recovered
1A	60	10	0	3	47	78
1B	60	25	1	3	31	52
4C	60	1	14	4	41	68
4D	30	1	2	1	26	87
5E	60	0	1	28	31	52
5F	60	33	2	6	19	32
5G	30	0	9	0	21	70
Total	360	70	29	45	216	60

TABLE 4: SIDEWALL CORES FROM WELL 7316/5-1.

Log type	Date	Logged interval (mRKB)
DIL/LSS/LDL/CNL/GR/SP/AMS	27.07.92	638.3-562.5
CST/GR	28.07.92	842.0-569.0
CST/GR	28.07.92	843.0-567.0
DIL/LSS/LDL/CNL/GR/SP/AMS	14.08.92	873.5-569.5
DLL/MSFL/LDL/CNL/NGL/AMS	22.08.92	1769.0-876.5
RFT/HP/GR	22.08.92	1340.0-1377.0
DIL/LSS/GR	25.08.92	2933.0-876.5
LDL/CNL/NGS	25.08.92	2915.5-1725.0
FMS4/GR	26.08.92	2922.0-876.5
CST/GR	26.08.92	2908.0-974.0
CST/GR	26.08.92	2900.0-885.0
VSP	28.08.92	2960.0-520.0
DLL/MSFL/LSS/LDL/SNL/GR/SP	15.09.92	4029.5-2957.5
FMS4/GR	16.09.92	4029.5-2957.5
VSP	16.08.92	4020.0-1900.0
CST/GR	17.09.92	4025.0-3453.0
CST/GR	17.09.92	3448.0-2974.0
CBL/VDL	17.08.92	1500.0-830.0
CST/GR	18.09.92	3290.0-2974.0

TABLE 5: WIRELINE LOGS IN THE WELL 7316/5-1.

Well 7316/5-1 is the only deep well in the Vestbakken Volcanic Province, and one of the only wells near the continental margin. This well therefore contributes important geological information from the area, which is vital for making a correct as possible interpretation of the seismic data. Wireline log data and lithological description is used to get a better understanding and correlation with the seismic reflections interpreted, and gives higher certainty to the interpretation on all the interpreted lines, not only the line it intersects.

4 RESULTS

Following are the observations and interpretations from the six seismic lines. It is important to know that they are sorted by name, but this does not mean that they were interpreted in the same order. The seismic lines were studied simultaneously, to correlate the interpretations with the intersecting lines. To make it easy to follow the interpretations, observations are first described, and then given a geological meaning in the interpretation part. This will be the recipe for this chapter; observations, then interpretations.

The seismic lines are covering huge distances, which is hard to image in a paper format, as the details get too small. To counter this problem, only a section of the line is shown. In Figure 11 sections of the seismic lines that are presented are shown. Key areas for the interpretation will be even more enlarged, to make sure that important details are not lost. These areas will be presented as subsections.

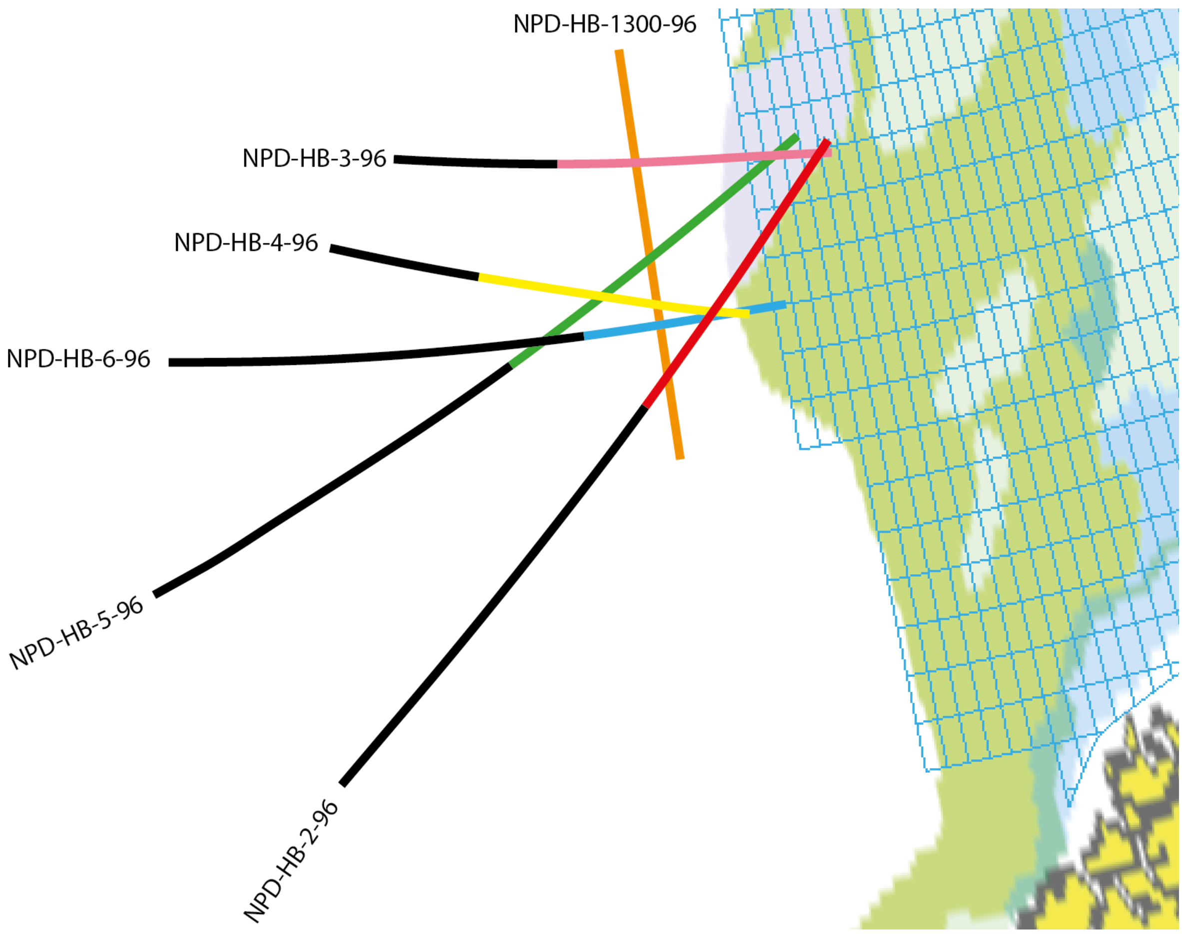

FIGURE 11: THE SEISMIC LINES THAT ARE SHOWN IN THE RESULTS CHAPTER. THE COLORED SECTIONS ARE WHAT IS PRESENTED IN FIGURES. MODIFIED FROM (NPD, 2013).

As this thesis focuses on the continental-oceanic transition, this will be the focus of the seismic interpretation. Deep, volcanic and crustal features are most interesting, and the sedimentary layers on top will not be interpreted extensively, as that is a major project itself.

4.1 NPD-HB-1300-96

The HB-1300 line is the only line with a NS direction. It is lined parallel to the continental margin, and images the Bjørnøya Fan. It is the only line that intersects all the five other lines, and is therefore a good reference for the interpretations of the different horizons. HB-1300 is the only line that is interpreted in its full length of ~238 kilometers.

4.1.1 OBSERVATIONS

The initial observation when looking at this line is the difference between the upper and bottom half. Reflections in the upper half have high resolution, and is easily followed and identified. In the bottom half, it is hard to observe anything but some reflections that emerge from the noise. What separates the two parts is a high amplitude sequence that seems to stretch across the whole line. For simplicity, this sequence will be referred to as High Amplitude Sequence 1, (HAS1).

The following observations refer to Figure 12.

1. HAS1. High amplitude sequence. Its signature changes from one positive, strong reflection, to a set of strong reflections. In this seismic line, it is mostly apparent as a single, positive reflection. A closer look is given in subsection 2 (SS2).
2. HAS1 is interrupted by several vertical displacement zones. This is most apparent in the southern end of the line. Here, it is shifted up and down a long interval. This area will be studied closer in subsection 1.
3. The bottom half is mostly noise, but some reflections are seen amongst the disturbed surroundings. These reflections have a limited extent, and are hard to interpret.
4. In the upper part, the reflections are parallel, and easy to follow. There are many strong reflections that are continuous across the whole seismic line.
5. In a limited area in the middle of the line, reflections are disturbed, and discontinuous. Strong reflections suddenly terminate against this area of more chaotic reflection signature. It is very hard to track reflections in this area.

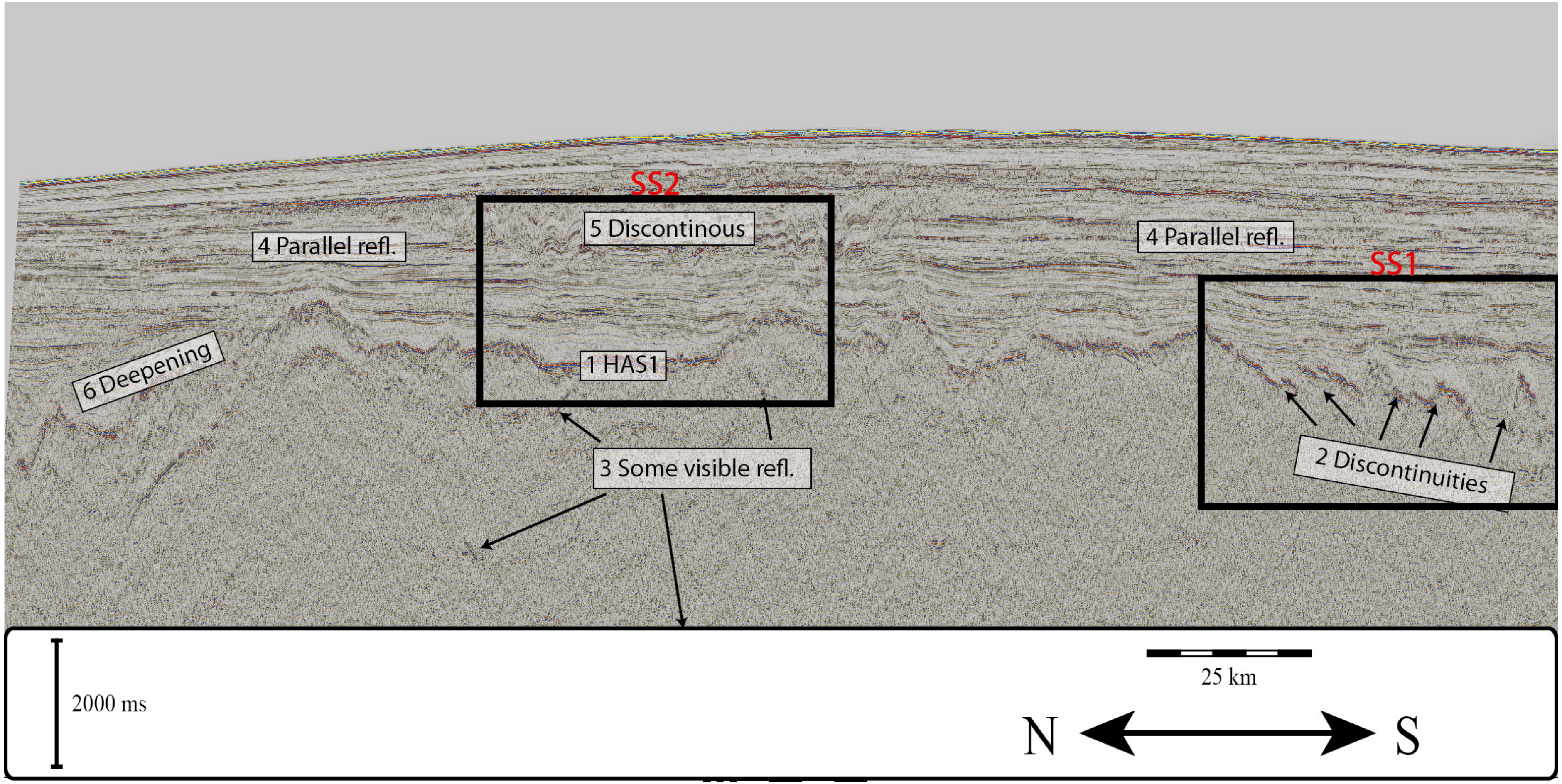

FIGURE 12: NPD-HB-1300-96 WITH INITIAL OBSERVATIONS. SUBSECTION 1 AND 2 DISPLAYED WITH BLACK BOXES IN THE FIGURE.

6. At the northern side of the seismic line, HAS1 is inclined downwards. At the top of the slope, it is at 5000 ms, and on the bottom it is at 7000 ms. As this sequence is getting deeper, the pack of reflections overlying it is getting thicker. It is also noticeable that the top reflection is deeper on both sides of the seismic line.

HB-1300-SS1

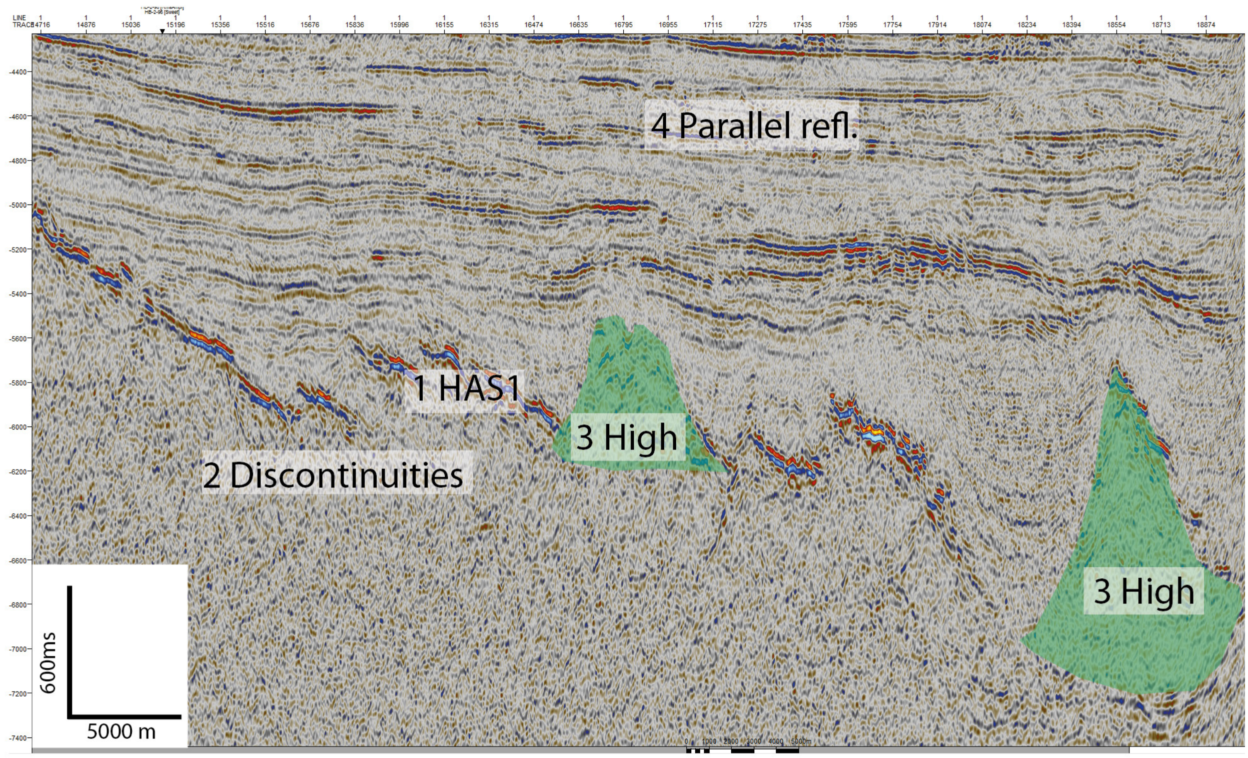

FIGURE 13: HB-1300 SUBSECTION 1

Subsection 1 focuses on the area on the southernmost side of the seismic line. This area gives a good impression of how the signature of HAS1 looks like, and how the overlying and underlying reflections are situated next to it.

1. HAS1 is seen as a strong reflection that can be tracked across the subsection. Its reflection signature is seen as two negative amplitude sidelobes, with a positive amplitude peak in the middle. This is similar to the seabottom reflection, indicating that HAS1 symbolizes an increase in impedance. The sidelobes are vague in areas.
2. HAS1 is discontinuous in this part of the seismic line, and going from right to left in the subsection, most of the displacements are downwards. On average, the lengths of the displacements are around 300ms.

3. Two distinct highs are found ,which seem to be a quite normal event in HAS1. The highs seem very steep in this display, but both the horizontal scale and vertical scale is very big. The vertical scale is very dependent on the velocities in the different lithologies, meaning the true angles of the slopes are probably less than what appears here. Some calculations will be carried out in the interpretation part to estimate the steepness.
4. In the upper part of the subsection, reflections are dominated by parallel, subhorizontal reflections. They are terminating against the highs in HAS1, and do not seem to be affected by HAS1 beneath. Amplitudes of the reflections are vary from high to very low, and the ones with high amplitudes are not problematic to track. The interval closest to HAS1 seems to contain the weakest reflections, indicating low impedance contrasts.

HB-1300-SS2

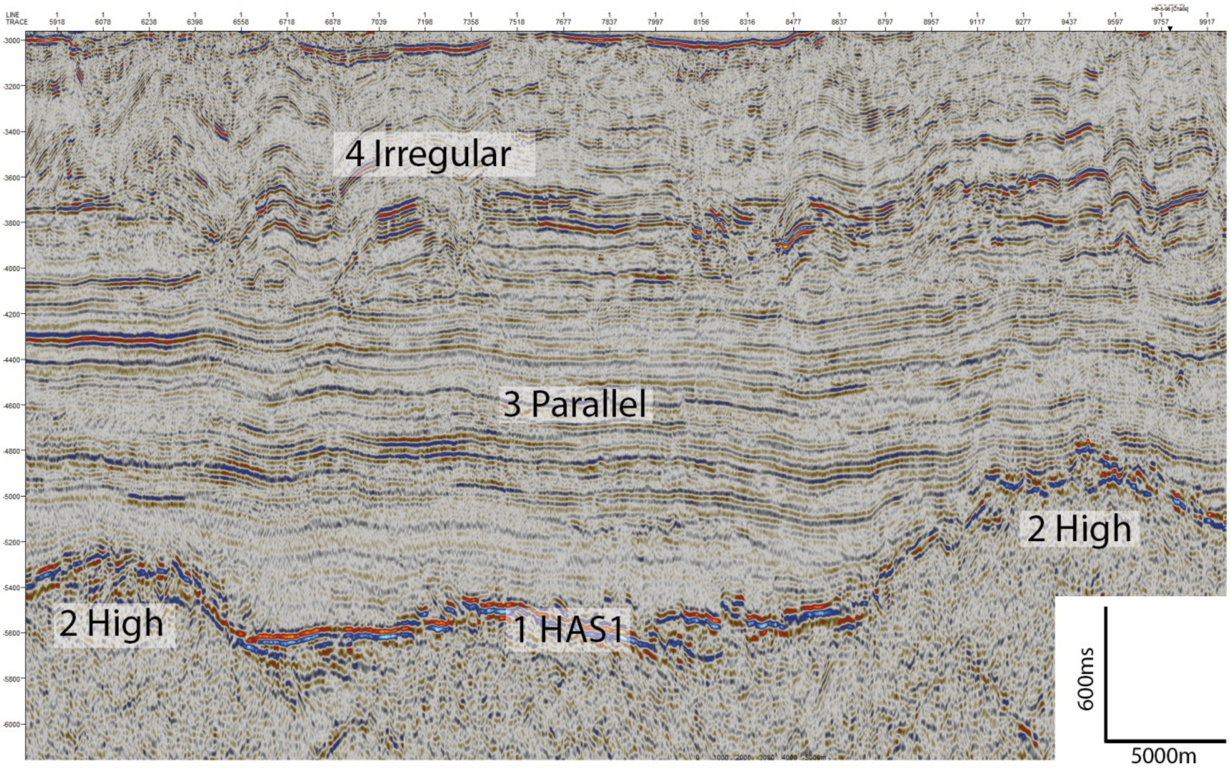

FIGURE 14: HB-1300 SUBSECTION 2.

Subsection 2 is a focused area from the middle of the HB-1300 line, and depicts a less segmented part of HAS1 than seen in HB-1300-SS1. It also focuses on the irregular and chaotic part of in the shallower reflections.

1. The top of HAS1 can be described the same here as in the previous section, but here the reflections in vicinity underneath it is stronger, which indicates some impedance contrasts. Some zones of discontinuity are found, but the displacement s are small.
2. Two high structures are observed in HAS1 on both sides of the subsection. The northern high is about 350 ms higher than the middle segment of HAS1, and the southern high is about 700 ms higher.
3. The reflections above HAS1 look horizontal and parallel. The lower ones are terminating against the HAS1 highs. They are easily tracked throughout the subsection. As in HB-1300-SS1, the lowermost reflections overlying HAS1 is of low amplitude compared to the surrounding.
4. In the top of the subsection, the reflections are irregular and disturbed. The shape of reflections vary, but most are parallel, indicating that the disturbing events are effecting all the reflections in the same fashion

4.1.2 INTERPRETATION

HAS1 is interpreted to be the boundary between sediments and the top basalt of the oceanic crust. In several of the seismic lines, HAS1 can be tracked out to the Mohns Ridge. The Mohns Ridge is an active spreading center, where oceanic crust is generated. This interpretation has little uncerntainty. The HB-1300 line has a NS direction, and is located some distance away from the continental shelf, indicating that the continental crust does not underlie this area. From the intersection of the other lines, it is seen that this line is located far from the transitional zone between oceanic and continental crust, strengthening the interpretation of HAS1 as oceanic crust.

The amplitude of HAS1 suggests a large contrast in acoustic impedance between the overlying layer and the basalt. From section 2.4, it is known that the velocity increases rapidly when the wave enters the basalt. This explains the reflection signature of HAS1.

Discontinuities in HAS1 are interpreted to be faults. The majority of faults seem to be normal, displacing the hanging wall downwards. Because of the low seismic resolution beneath HAS1, it is hard to determine the vertical range of the faults. As oceanic spreading is a result of extensional tectonism, normal faults are to be expected, which supports the interpretation of the discontinuities being faults.

The two highs seen in HB-1300-SS2 are interpreted to be basaltic highs generated at times of voluminous volcanic activity in the neovolcanic zone. Increase in magmatic output will generate highs, as the basalt cools quickly when it emerges onto the seafloor, and will not be able to flow away for great distances, making it accumulate upwards. It is hard to calculate the height in meters, but if it is assumed that the average velocity in the highs is 6000 m/s, an estimation can be done. The smallest high will then have a height of 1050 m, and the largest high will be 4200m. The approximate slope of the highs will be and 11º and 30º respectively, but this is an assumption with a large uncerntainty (Appendix 1).

HAS1 can be followed throughout the whole seismic line, and the conclusion from this is that this line only depicts oceanic crust and overlying sediments. No transition from oceanic to continental crust can be found. HB-1300 works as a good reference line, as it intersects all of the other seismic lines in this study. This gives a certainty when interpreting the oceanic crust on the other lines, as it must be present at the intersection with HB-1300.

The geology beneath the HAS1 reflector is hard to interpret, because it is masked by the overlying top basalt reflector. The general seismic image in this part is noisy and structureless. The reflections that are seen are not continuous, making it hard to know their origin. I**t is** known that the Moho are present somewhere beneath the basalt, and if the seismic image wan not masked, it might have been seen here. Because of the uncertainties of interpreting the deep structures in this line, no placement of the Moho will be given.

The overlying reflectors are interpreted to be sediments transported from the Barents Sea. Most of the sediments were eroded away in the glacier periods, explained in section 2.2. Huge amounts of sediment were deposited off the continental shelf, and this is what is seen here. All the six seismic lines are imaging the Bjørnøya Fan, which is the largest sedimentary fan off the Barents Sea continental margin. The glacial sediment layers are mostly consisting of clays, but as they are originated from glacial erosion, sand and larger clasts are found within the layers. This may be the reason for the contrasts in acoustic impedance, resulting in highly visible reflectors. On top of the oceanic crust, a thin layer of Oligocene-Miocene deposits are interpreted.

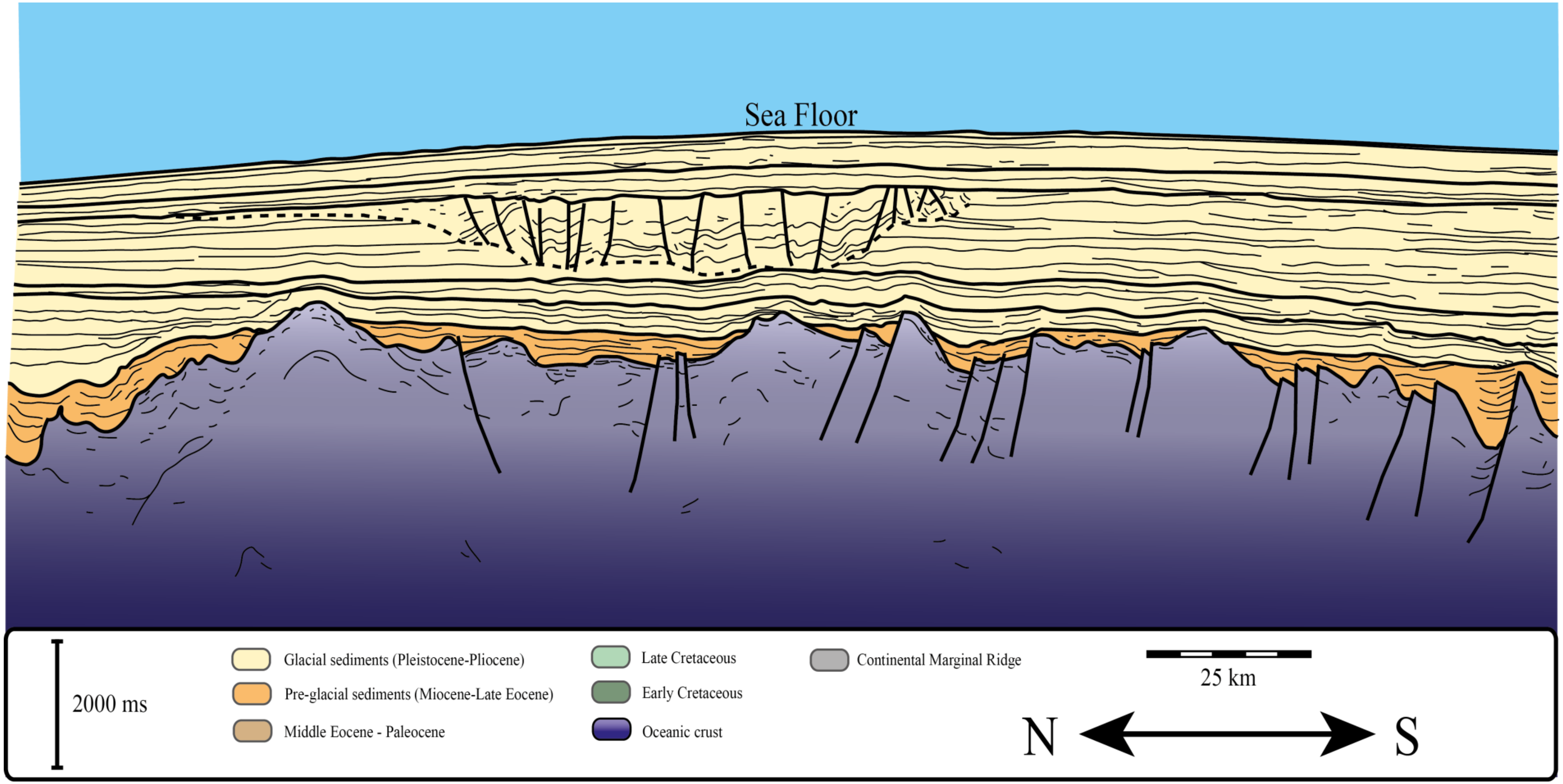

FIGURE 15: GEOSEISMIC INTERPRETATION MODEL FOR SEISMIC LINE NPD-HB-1300-96.

4.2 NPD-HB-2-96

The HB-2 line has a NE direction, stretching from the Lofoten Basin in SW to the Vestbakken Volcanic Province in NE. The line is intersected by HB-1300, HB-3, HB-4 and HB-6. Well 7316/5-1 is located on the NE end of this line, making this line very important for the under-standing of the lithology in the area of study. Note that the segment of the line that is used is only a fraction of the line in the NE end, illustrated in Figure 11.

4.2.1 OBSERVATIONS

At first look at this line, it is apparent that there are a lot of reflections that are visible. The majority of the interpretable reflections are located in the upper half of the seimsic line, as expected. The thickness of this upper part of reflections ranges from ~3800 ms in the SW part to ~2300 ms in the NE part. Overall, the trend is that the reflections in the upper part have a low angle inclination from NE to SW, seen best in the SW part of the line. Many of the reflections seem sub-parallel, and are truncated at the top reflector in NE. Further down, reflections are terminated against underlying reflections, separtaing them in different packages. In areas, reflections are very discontinous, separated by sub-vertical zones. This is evident in the middle of the seismic line, and in the NE end.

Two areas of high amplitude reflections are found on this seismic line, separating the upper subparallel reflections from the deeper weak and chaotic reflections. These areas stand out from the rest of the reflections because of their shape and structure, and their high amplitude. The southwesternmost of these two are identified as the HAS1 reflector, as it is found in the HB-1300 line. The high amplitude sequence in the NE will be reffered to as HAS2. On the NE side of the interval, the pack of strong reflectors are located higher than in the SW part. The area between these intervals of strong reflectors consists of what seem to be two highs, indicated by red arrows. In comparison to the surrounding reflectors, the slope of these highs are very steep, and the overlying reflections terminate against them. The internal resolution in the highs is low, and structures are hard to identify. Some strong reflections are found beneath the highs, but their shape and structure are irregular and segmented. To get a more detailed look, three subsections are found that are of interest for finding the transition between continental and oceanic crust. These subsections are marked in Figure 16 as SS1, SS2 and SS3.

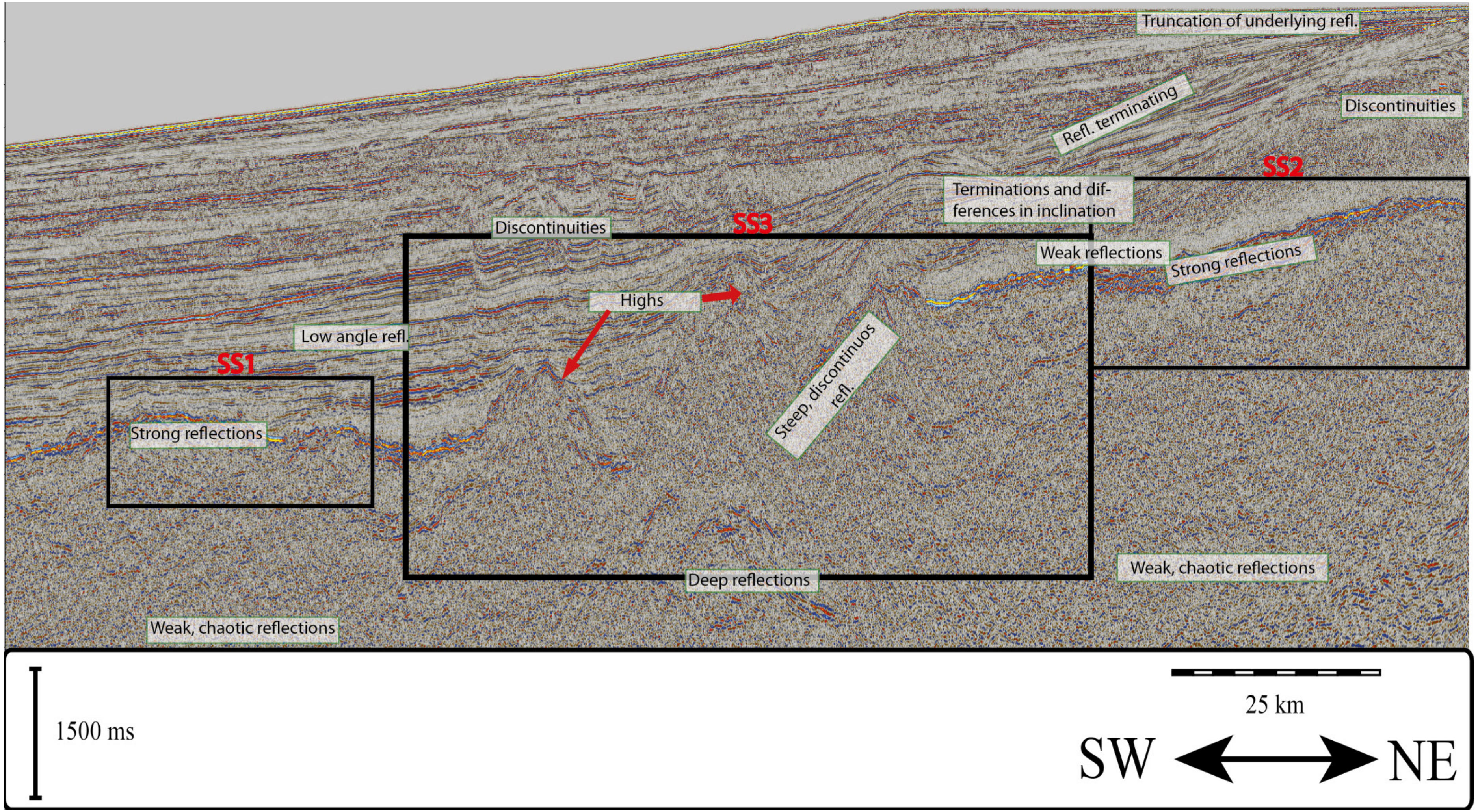

FIGURE 16: NPD-HB-2-96 WITH INITIAL OBSERVATIONS. SUBSECTION 1, 2 AND 3 DISPLAYED WITH BLACK BOXES IN THE FIGURE.

HB-2-SS1

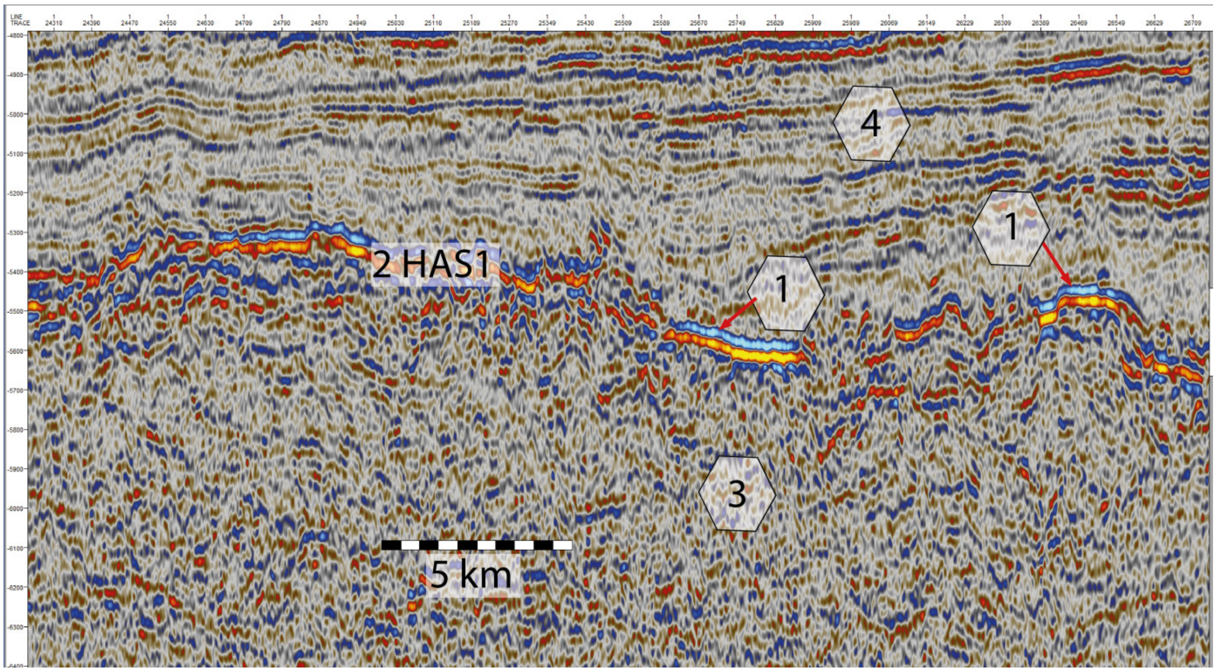

FIGURE 17: HB-2 SUBSECTION 1.

SS1 focuses on the transition from the parallel reflections in the upper part of the seismic line to the chaotic, noisy reflections in the lower part. The transition happens over a set of strong reflections which is easily observed, HAS1, and is one of the main features in the seismic data. Observations are explained in the section beneath.

1. A strong, positive amplitude reflection with approximately 2-3 km lateral extent. The two reflections depict an increase in amplitude, as the peak is positive, with negative sidelobes. Marks the top of HAS1. It can be noticed that the reflections in HAS1 are dimmed beneath these strong top reflections.
2. Top of HAS1. High amplitudes, but not as high as in (1). Reflections are irregular and only continuous in short segments. The thickness of HAS1 is approximately 225 ms. HAS1 has a depth that varies across the section.
3. Deeper reflections show a lack of consistency in amplitudes, and resemble noise. No apparent structure is seen, and amplitudes are low. The difference from the upper part of the section is apparent, as the reflections have no lateral extent. This may be caused by the structure of the formation, or by masking from the overlying HAS1.

4. Reflections in the upper part show, as mentioned, a low angle inclination towards the SE. With some exceptions, they are parallel, and quite consistent. Close to HAS1, the amplitudes seem to decrease.

HB-2-SS2

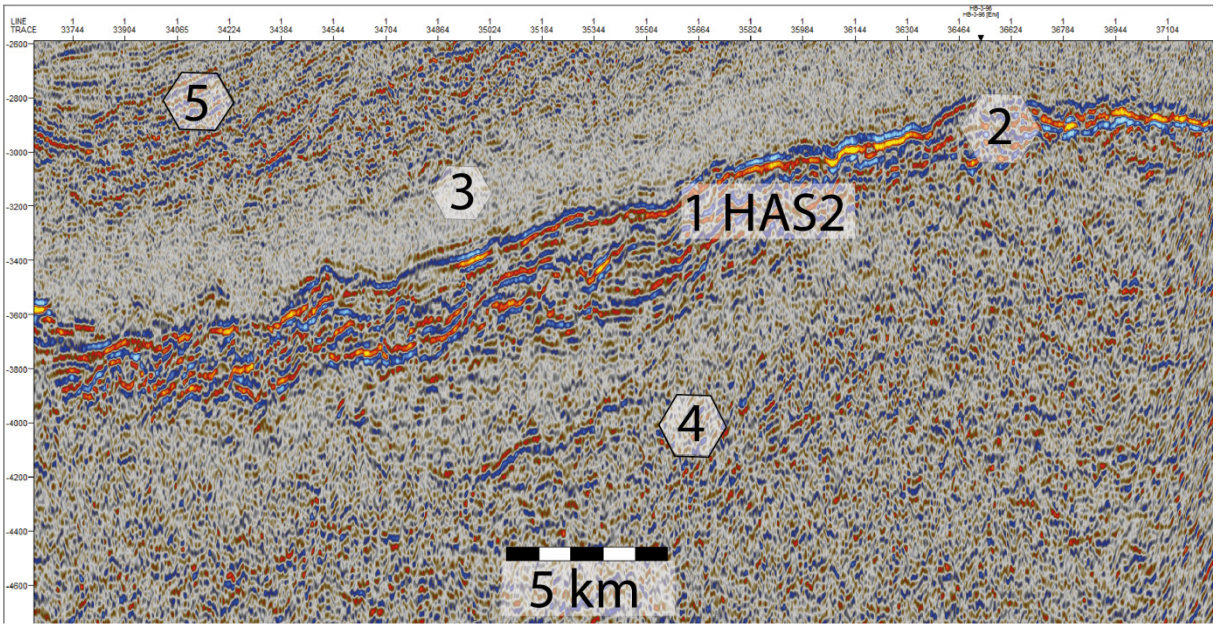

FIGURE 18: HB-2 SUBSECTION 2.

As in HB-2-SS1, there is a transition from the parallel reflections in the upper part to the shaded reflections deeper. The two parts are separated by HAS2. This sequence contains high amplitude reflections, and is on average >300 ms thick. It is possible to observe internal structures in HAS2. Some zones of discontinuity are seen. The whole sequence is inclined downwards from (2), in a SE direction, and is thickening to the left.

1. Inclination of HAS2 begins. The sequence is thinner here, about 100 ms. It is in this area that well 7316/5-1 is drilled.
2. The area over HAS2 seems to be a continuous zone of low amplitudes. Hard to see any structural features at all, besides the dip of the layers. Wavy, not linear reflectors.
3. The signature in the lower part of the subsection is, as in the lower part of HB-2-SS1, consists of discontinuous, low amplitude reflections, which are hard to interpret. There are some stronger signals that are interpretable, but their lateral extent is limited.
4. In the upper part, parallel reflections are seen. Inclination towards the SW.

HB-2-SS3

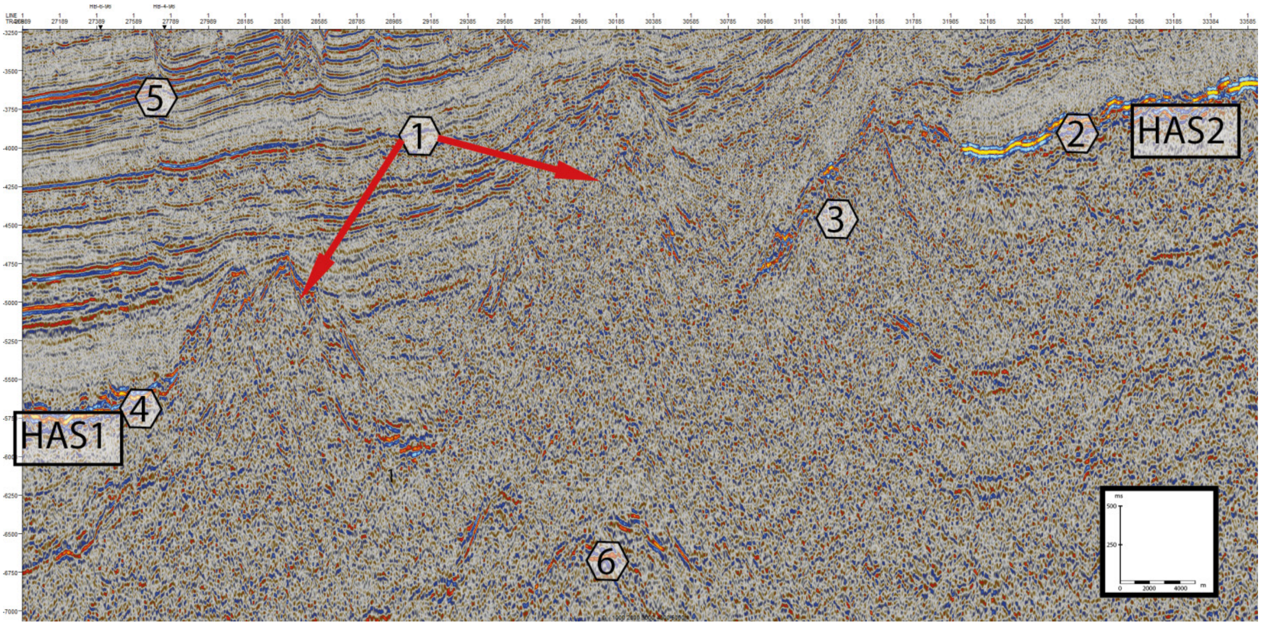

FIGURE 19: HB-2 SUBSECTION 3.

The main features in SS3 are the two distinct highs that separate HAS1 and HAS2. The top reflection of the highs is not as strong as in the common HAS1/HAS2 signature, but their relief is easily seen. The largest one is 2500 ms high, and over 20 km wide. The smaller one is 1200 ms and ~13 km wide. Internally, reflectors are chaotic, weak and hard to track.

1. HAS2 is lying to the NE of the highs. It terminates abruptly, and so does the low amplitude zone above it.
2. Steep reflections with inclination in a southeasterly direction. Low internal amplitudes. Reflections above are truncated at the northwesternmost high.
3. HAS1.
4. The upper part consists of parallel, low angle inclined reflections of varying amplitudes. The reflections are truncated at the highs, and are in some areas shifted up or down by vertical zones of discontinuity.

4.2.2 INTERPRETATION

Cenozoic sediments

As described in the observation part, the seismic line can roughly be divided into two parts; the upper part with continuous reflections, and the bottom part with masked, noisy reflections, with some high amplitude events. The upper part is interpreted to be sediments deposited in the Cenozoic. This sequence is again divided into different age sequences, based on well 7316/5-1 which has been drilled in the NE corner of this line, seen in Figure 20.

Within and between the sedimentary sequences, unconformities are found, indicating periods of uplift and erosion. One of the most noticeable is the one between the glacial and pre-glacial sediments. Several faults are interpreted in the area of where the well is drilled, but these are eroded by the erosional surface separating the units. The well does not encounter Oligocene or Miocene sediments, indicating erosion of these layers. Several other erosional surfaces are found within the Pleistocene/Pliocene interval.

Oceanic Crust

The masked bottom section is interpreted to be the deeper continental layers, and the oceanic crust. HAS1 is the top basalt reflector of the oceanic crust. It is smoother in this seismic line than in many of the others, as it does not show the typical normal faulted relief .This may be because of the direction of the line, which is about orthogonal to the spreading direction. Reflections beneath the top basalt are masked, making any interpretations very hard. From knowledge about the structure of the crust (chapter 2.1.3), the contrasts in acoustic impedance in the top of the crust is interpreted to be because of the velocity increases in oceanic layer 2.

Beneath layer 2, the reflections are too noisy to interpret any structures without large uncertainties. The Moho is not seen, but assumed to be found at 5-7 kilometers depth, which would correlate to about 1600-2300 ms in traveltime, given an average velocity of 6000 m/s in the oceanic crust. The occasional stronger amplitudes in HAS1 are interpreted to be because of local differences in impedance contrasts, and composition of the basalt.

Continental crust

HAS2 is interpreted to be volcanic extrusives generated in connection with the breakup of the continent. Information from the well, and other studies, dates this to Paleocene-Early Eocene. Seen as a 300 ms thick sequence, HAS2 is a heterogeneous unit, with differences in velocities and densities and structure. This is interpreted because of the several high amplitude contrasts, resulting in several strong reflectors within the unit. The inclination of the unit seen in SS2 is interpreted to be because of the faulting in the area. Looking at the angle of the inclination, it is much smaller than the highs in the volcanic flows in HB-3 and HB-5, indicating that this high is not imaging the volcano itself, but the adjacent topography.

Interpretation of the deeper layers of the continental crust brings high uncertainties. These layers are not easily observed, because of the masking from the overlying volcanic rocks. Some reflections can be trakced, but the main contributor to the interpretation of the Cretaceous is the well data. The well penetrates rocks of Maastrichtian age at 3751,5 m (Semple and Bulman, 1993). Igneous rocks are located in the Cretaceous interval as well, and this is interpreted to be volcanic intrusives. Deeper interpretations are based on thickness found from other studies ((Ryseth et al., 2003, Gabrielsen et al., 1990), and should be looked at as an estimation of how the upper crust may be like.

Faults are observed and followed into the deep layers. Thelargest faults are found in Late Eocene – Cretaceous layers, related to the Cretaceous-Cenozoic rift period. Some are also found in the Late Eocene – Miocene unit, and some of these are interpreted to be a reactivation of older faults.

Continent-Ocean Boundary

The COB is believed to be found in SS3. From observations, it is known that the main features in this subsection are the two highs which separate HAS1 and HAS2. The western high in SS3 is interpreted to be a high in the oceanic crust, and at its eastern base, the COB is interpreted to be located. Voluminous volcanism at in the spreading zone may explain this high.The oldest oceanic crust along the HB-2 line is aged Early Oligocene, and the change in relative plate motion might explain the increased magma production in this time period (Libak et al., 2012).

The largest high is interpreted to be a part of a marginal ridge which has formed along the continental side of the shear margin. It is interpreted to be a ridge because it is found in HB-5 and HB-6 as well. Many geological events may create such a ridge. Dale Bird discusses marginal ridges created by heat transfer from the juxtaposed oceanic crust as the continental crust moves along the plate boundary (Bird, 2001). The southwestern side of the VVP boarders the Senja Fault Zone (SFZ), and seafloor spreading was in orthogonal to this fault zone which was part of the De Geer Zone (chapter 2.2.1). This will be further investigated in chapter 5.

The ridge may also be created by volcanism. Volcanic activity is known from the break-up of the continent in Eocene, in the same period as the lava flows. Volcanism in Oligocene is also described by Jebsen, (1998) and Libak et al.,(2012), and there is a possibility that this ridge is created by volcanism at this age.

The deep reflection seen in SS3 may be a pull up, which is caused by high velocities in the ridge. When the velocities in this ridge are higher in the surrounding rocks, this will cause the traveltime of the seismic wave to be shorter, resulting in a pull up in the reflection signal. It may also be an effect of the uplift of the ridge, causing internal components to be uplifted,or a volcanic intrusion.. Because of the depth, and the chaotic reflections in the signal, it is hard to determine the exact interpretation of this reflection.

The final geoseismic line is presented in Figure 20.

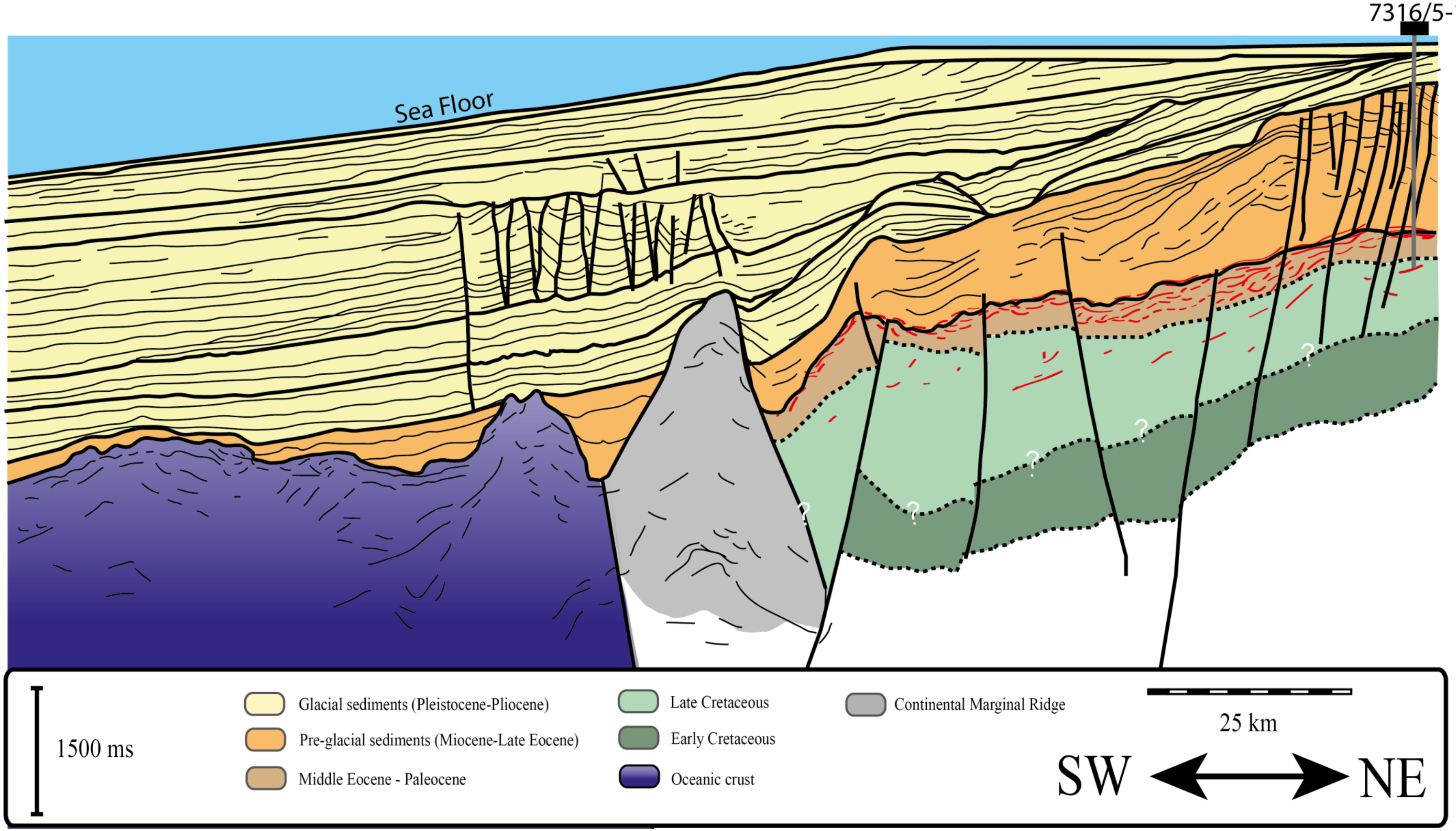

FIGURE 20: GEOSEISMIC INTERPRETION MODEL FOR SEISMIC LINE NPD-HB-2-96.

4.3 NPD-HB-3-96

The HB-3-96 line is stretching from the Mohns Ridge in the North Atlantic to the Vestbakken Volcanic Province in the Barents Sea. The line is directed west to east, and is the northern-most line in the Havretst Bjørnøya survey lines in this direction. It is intersected by HB-1300, HB-2 and HB-5. Only the eastern part of the line will be interpreted, as this is the part in which the COB will be located

4.3.1 OBSERVATIONS

As in the previous lines, this seismic line is also consisting of two distinctly different areas. The upper consists of highly visible, parallel reflections of different strength. The lower area is masked, and only a few discontinuous reflections are seen. The boundary between these areas is seen as a strong, positive amplitude reflection, stretching from west to east. This boundary is of most interest for this study.

The following list is referring to Figure 22, moving from left to right in the figure:

1. HAS1 is identified in the west, and shows the characteristic discontinuous pattern as seen in many of the other lines. The reflection is separated into segments, all of which are tilted at an angle. The vertical gaps between the segments are about 200ms.

The reflection is consisting of one positive peak amplitude with negative sidelobes. The area beneath HAS1 is masked, and it is very hard to interpret any structures because of the weak signal.

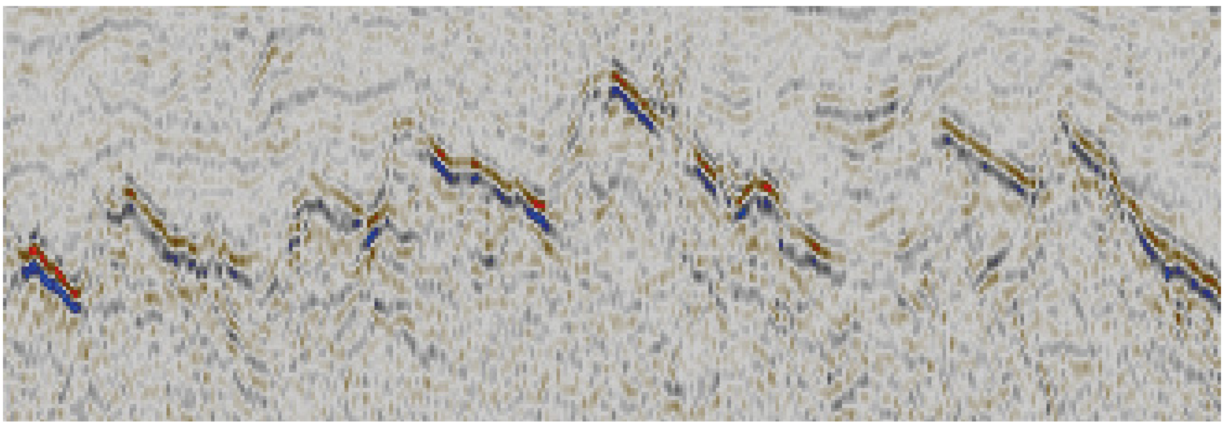

FIGURE 21: DISCONTINUITIES IN HAS1.

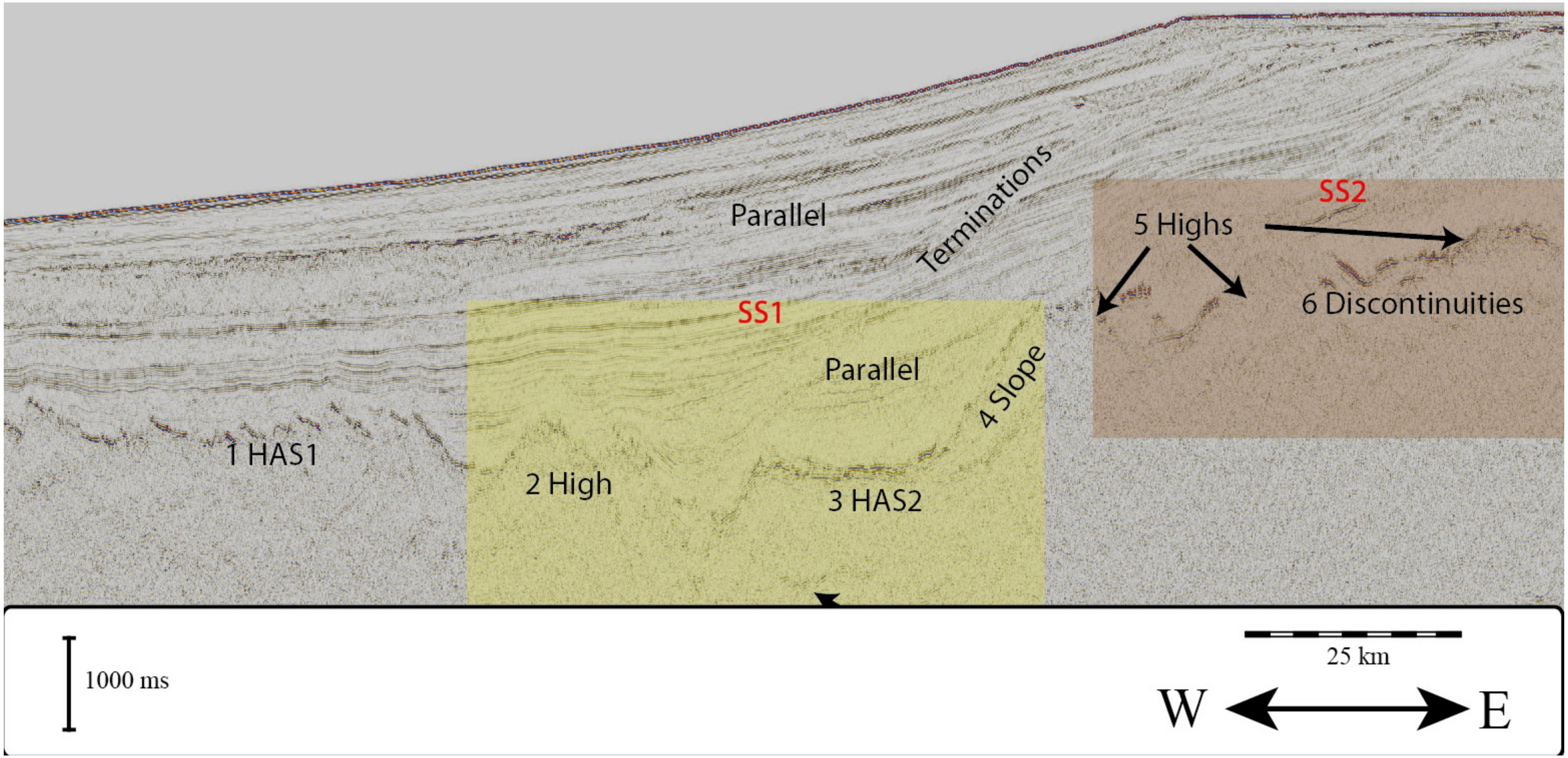

FIGURE 22: NPD-HB-3-96 WITH INITIAL OBSERVATIONS. YELLOW ZONE IS SUBSECTION 1, BROWN ZONE IS SUBSECTION 2.

2. Eastwards, the discontinuous pattern of HAS1 enters into a structural high. This structure shows a more chaotic reflection signature. A closer look of points 2,3 and 4 is given in HB-3-SS1.

3. The start of HAS2. HAS2 consists of several strong reflections, but the top reflection signature is a positive peak with negative sidelobes. The sequence begins horizontal, but gradually inclines upwards into a steep slope (4) lifting it 1500ms.

4. The HAS2 slope in point 4 lifts the reflection sequence to about 3600ms depth, and here several highs are found in its signature. The varying depth, and angle of the reflections are identified as structural highs..

5 & 6. In the area of the three highs, zones of discontinuity are found. A closer look of this is also given in HB-3-SS2. The three highs identified are shown with pointed out with arrows in Figure 22.

The reflections in the upper part are very similar to the ones seen in the other seismic lines. There are many strong, trackable reflections stretching great distances. The reflections seem to be divided into different sets, and the sets are terminating against each other. The western reflections are terminating against reflections with a steeper angle in the east, and these steeper reflections are truncated at the set lying at the top , near the sea floor. There are several areas where reflections are being truncated, or are terminating against other reflections. The internal structures in the sets are mostly parallel, but some chaotic areas are founds, with discontinuities and low impedance contrasts.

HB-3-SS1

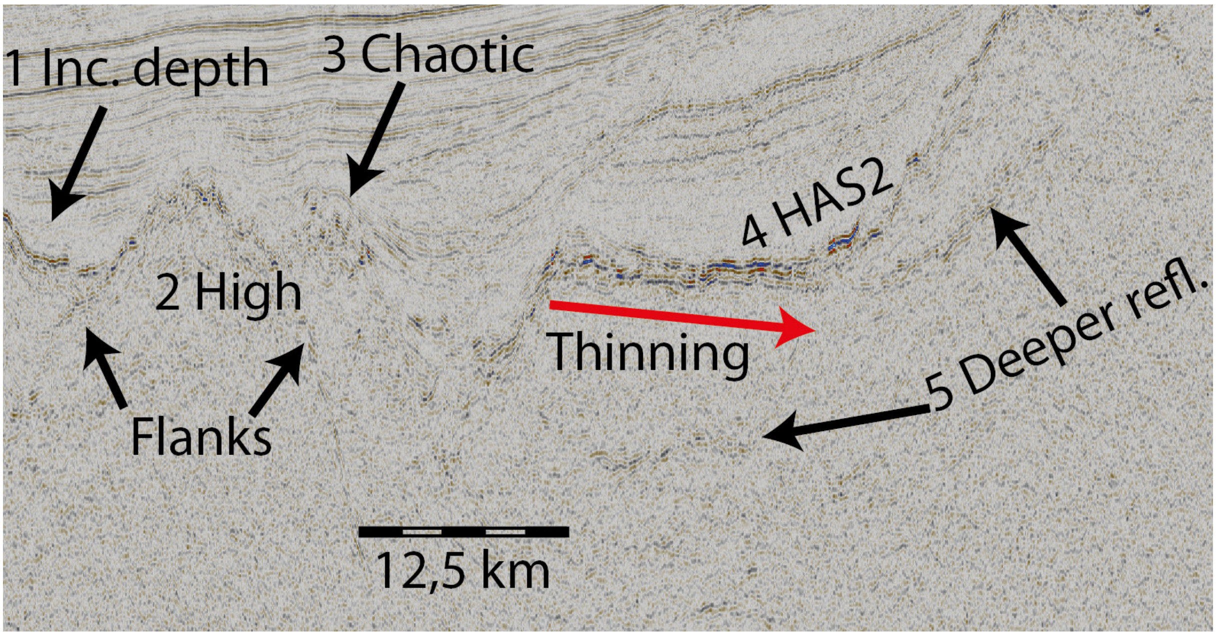

FIGURE 23: HB-3 SUBSECTION 1 WITH OBSERVATIONS.

HB-3-SS1 gives a closer look at the transition from HAS1 to HAS2, and the structure of HAS2. Observations in the following list are from left to right in Figure 23.

1 & 2- It is noticeable that HAS1 is tilted downwards going eastwards. As it is hitting the high, a reflection is emerging from underneath it. This reflection forms the structural high. The internal reflections in the high are barely visible and chaotic.

3- The signature is altered, and becomes more chaotic. A smaller high is observed, and the flank of (2) is seen between the two, as it extends into the masked reflections beneath. The reflection from (3) towards HAS2 is barely visible, and only some brighter areas distinguishes its relief from the low amplitude surroundings.

4- HAS2 begins with a sudden increase in amplitude. The sequence is almost horizontal, and is thickest in the western end, thinning eastwards. At its thickest, it is about 400ms, thinning down to about 250ms at the bottom of the slope. The slope is steep and is the start of a high. This high rises above the other highs in this subsection, and connection between the reflection of it and the horizontal part on the bottom of the slope is the reason they both are thought to the HAS2. The signature on top is rugged.

5- Beneath the HAS2 slope, another reflection sequence is found. It seems to be connected with the lower reflections in HAS2's horizontal part, which is an interesting observation. Following the slope upwards, the distance increases to this underlying reflection sequence.

HB-3-SS2

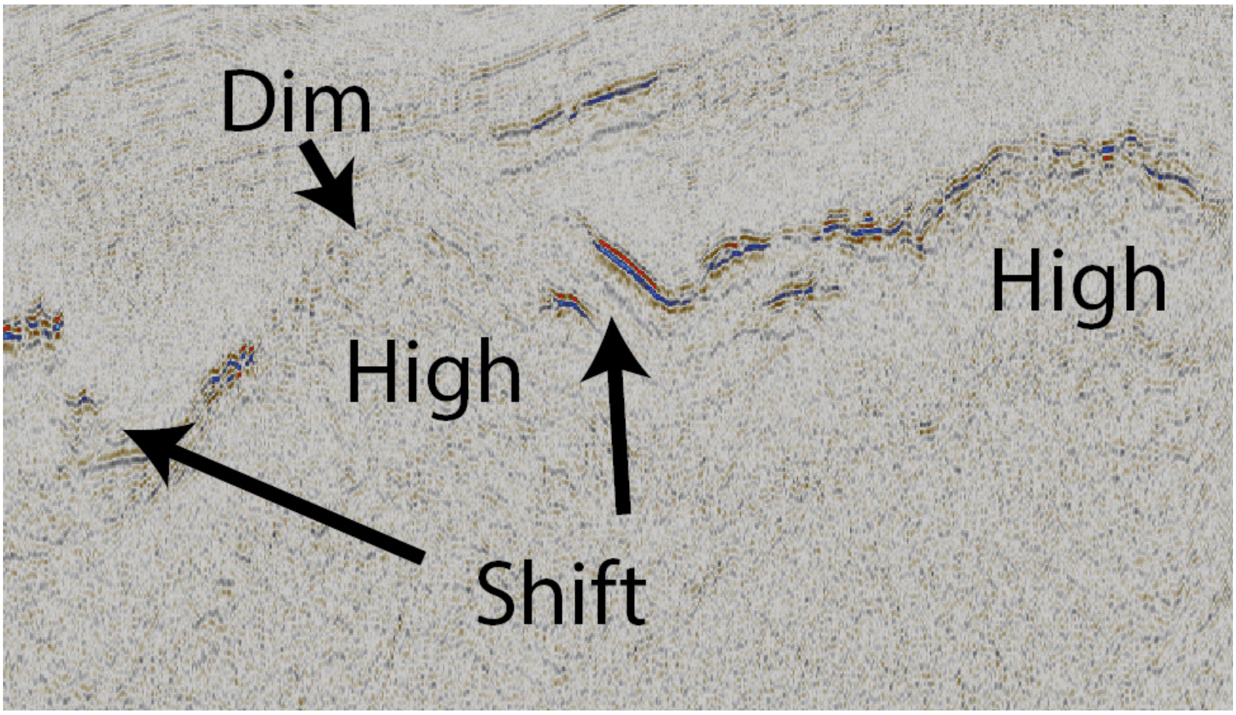

FIGURE 24: HB-3 SUBSECTION 2.

HB-3-SS2 continues where HB-3-SS1 ended. A shift in depth is observed in the left of the subsection, where HAS2 is shifted down. The rise of a new high begins. HAS2’s signature is not consisting of as many reflections here. It is in parts only seen as one strong positive reflection, and is quite similar to HAS1. The first high has a dim spot on its peak, and the contour of the high is just barely seen. At the right side of this high, the reflection strength is suddenly back to normal, and it is again shifted, this time upwards. From this point it is gradually increasing in altitude. Here, the thickness of HAS2 returns, with several reflections beneath the top reflector.

4.3.2 INTERPRETATION

Cenozoic Sediments

Because this thesis focuses on the COB, the sediments deposited long after continental breakup is not as thoroughly interpreted. The thick pack of parallel reflections above the top oceanic crust is interpreted as glacial sediments deposited after the continental breakup, with a thin layer of pre-glacial Miocene-Oligocene sediments it's the bottom. The outer sediments are filling the relief of the oceanic crust, onlapping the highs and faults, and are showing some differential compaction. This happens because of larger sediment load in the middle of basin than on the flanks, making the middle compact more because of the weight of the sediments.

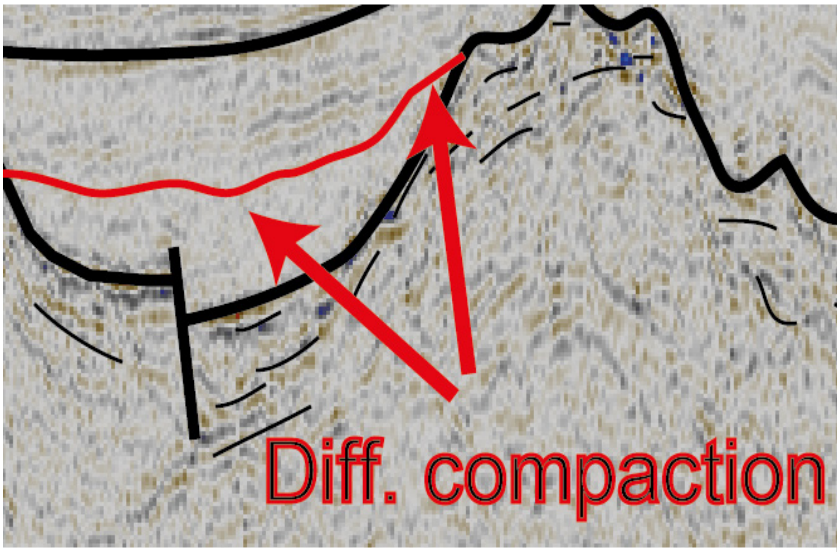

FIGURE 25: DIFFERENTIAL COMPACTION IN SEDIMENTS.

Several erosive surfaces and unconformities are found in the sediment layers. The most prominent of these are the erosive surface separating the glacial Plio-/Pleistocene sequence and the pre-glacial Miocene- Late Eocene sequence. The dating of the sediment layers are based on the well 7316/5-1 and other studies (e.g. Ryseth et al. 2005).

Continent-Ocean boundary

HAS1 is interpreted to be the top basalt reflector of the oceanic crust, as described in the previous chapters. The discontinuities in the top basalt are interpreted to be normal faults. Faulting of this kind is commonly connected with slow-spreading centers. The lithosphere is thick enough in slow spreading ridges to support normal faulting very close to the spreading center (MacDonald, 2001). About 80% of the inward dipping faults (dip towards the spreading center) are found in slow-spreading ridges, and Figure 26 is a good example of inward dipping faults (Macdonald, 2001). In the final geoseismic model, the oceanic crust will be colored purple.

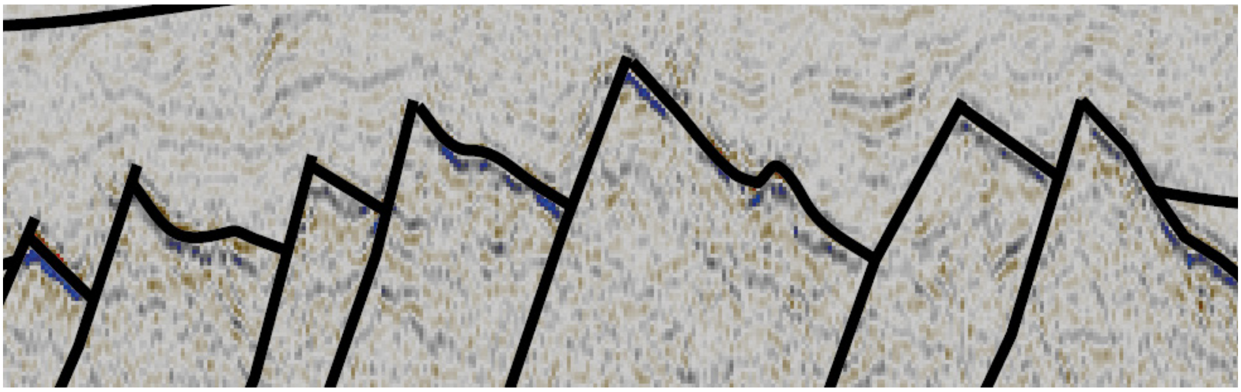

FIGURE 26: INWARD DIPPING NORMAL FAULTS IN THE OCEANIC CRUST.

HAS1 is seen here as a single positive amplitude reflection, and this is interpreted to be because of the transition from low velocity sediments to high velocity basalt. The underlying crust is masked by the basalt layer, which is problematic to image beneath.

HAS2 is interpreted to be volcanic flow basalts from the Early Eocence volcanic activity in the Vestbakken Volcanic Province (VVP). HAS2 is well known from previous studies and well data to be volcanic flows in connection with the continental breakup.

At the eastern side of this seismic line, the highs in HAS2 are interpreted to be part of buried volcanoes, which was the origin of the volcanic extrusives. Subsidence and rifting related to the extensional tectonics of continental breakup and initiation of seafloor spreading is interpreted to be the reason for the shape and large variations in the depth of HAS2, in addition to the buildup of the volcano. The stretching and subsequent thinning of the crust may have weakened the crust, resulting in faults and subsidence.

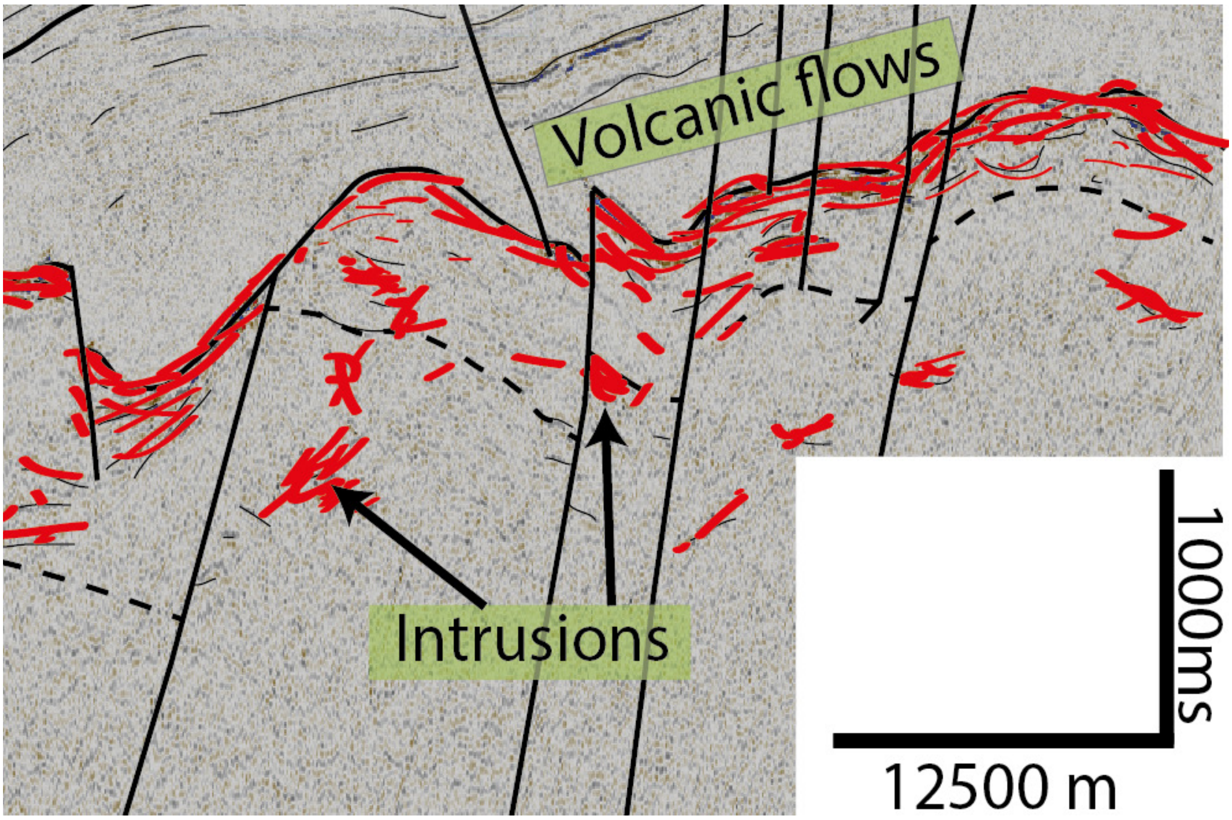

FIGURE 27: INTERPRETATION OF VOLCANIC FLOWS AND INTRUSIONS IN RED. DOTTED LINE REPRESENTS THE BOUNDARY BETWEEN CENOZOIC AND CRETACEOUS.

HAS2 is masking the underlying layers, making it hard to interpret this section. The thickness of the Paleocene unit is estimated from well data and other studies (Gabrielsen et al., 1990, Ryseth et al., 2003). The same applies for the Cenozoic and Cretaceous transition, but this is also somewhat seen in reflections.

Rifting in Late Cretaceous to Early Cenozoic is seen in the reflections in this area, but the faults are hard to follow in the deeper areas, making the interpretation less accurate. Reactivation of faults seems to have occurred, as some faults can be traced into Late Eocene-Oligocene sediments, which agrees with the interpretation done in previous studies by Faleide et al. (1993) And Jebsen (1998). The faulting in the volcanic extrusives is also an indication of reactivation of older faults, as the basalt probably settled quite rapid and continuously on a smooth surface.

HAS1 is established as the top oceanic crust, and HAS2 is interpreted as volcanic flows generated in the VVP, meaning it is basalts erupted on the continental crust. The transition between the two occurs in subsection 1. The end of HAS2 is interpreted to be the end of the continental crust, and the start of the oceanic crust. Termination of HAS2 is abrupt, and is interpreted to be because of a normal fault seen in Figure 28. As the volcanic flows in VVP are also found on the Greenland side, it is believed that the flows stretched even further out, but as the continental crust broke up, oceanic crust was generated, and separated the two plates (Hinz et al., 1993, Libak et al., 2012)

The two highs in the oceanic crust were probably made by voluminous volcanic activity in the neovolcanic zone of the spreading ridge. The final interpreation of HB-3 is seen in Figure 29.

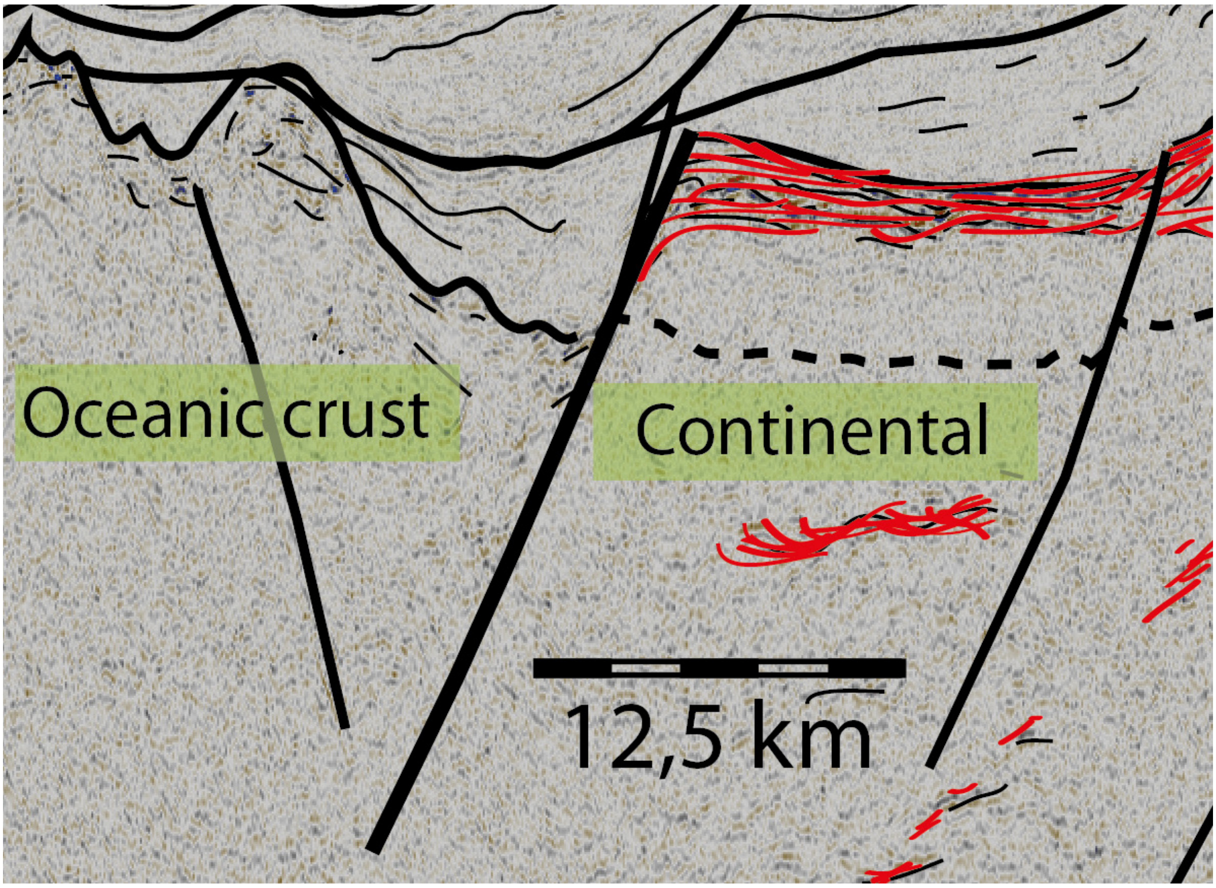

FIGURE 28: CONTINENT-OCEAN BOUNDARY IN NPD-HB-3-96.

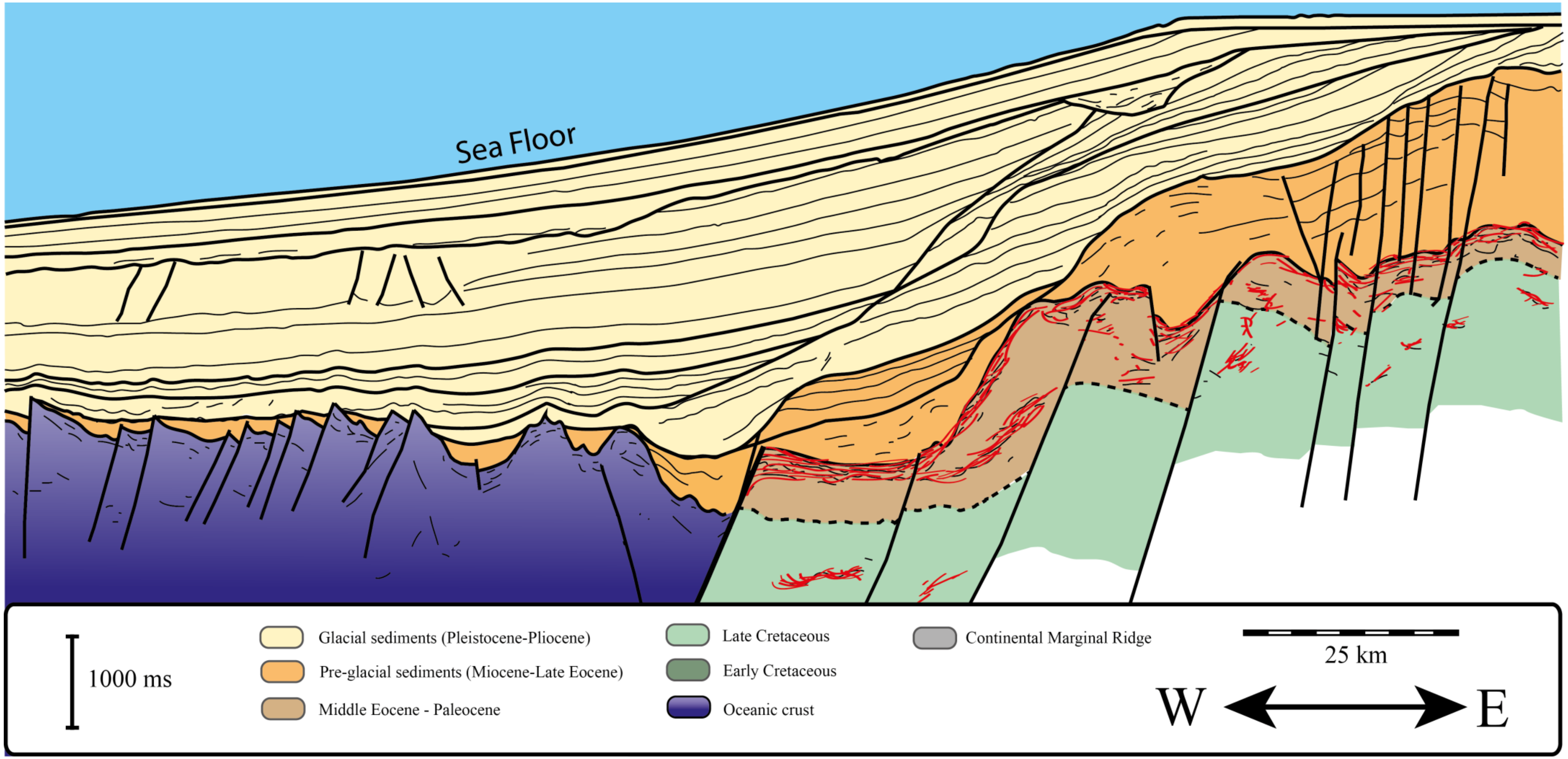

FIGURE 29: GEOSEISMIC INTERPRETION MODEL FOR SEISMIC LINE NPD-HB-3-96.

4.4 NPD-HB-4-96

The HB-4 line is a seismic image of the WE profile of the Bjørnøya fan. The line also images the Mohns Ridge in the west. HB-4 is intersected by HB-1300, HB-2, HB-5 and HB-6. As this study focuses on the continental-ocean transition, the focus of this line will be the easternmost area, as indicated in Figure 11.

4.4.1 OBSERVATIONS

The observations in this chapter are related to Figure 30.

As the previous lines, this also depicts the sediment slope off the margin of from the Barents Sea. This slope is a thick sequence of mostly parallel reflections, with some more chaotic areas. This line, as the others, can be divided into two sequences; the upper visible parallel reflections, and the bottom masked and shaded reflections. The reflections in the upper part can be followed for great distances, and the visibility throughout the line is good. Some discontinuity in the reflections is seen, but the main picture is that they are parallel and is inclined at a low angle. In the easternmost part, an event is terminating reflections, and some displacements are seen. Many places reflections seem to be truncating the underlying reflections. In the bottom part, where reflections are very noisy and low amplitude, it is not possible to follow reflections. In some areas, there are some more visible reflections, but it is very hard to interpret something from them.

What separates these two parts of the section, is a high amplitude reflection, easily followed through the entire seismic line. This marks an increase in impedance between the two parts. It is noticeable how the seismic image changes from the top to the bottom part. This high amplitude reflection has been identified in the other lines as well, known as HAS1. As this line is investigated somewhat further out from the continental shelf, it is seen how the upper sequence of parallel reflections is thinning greatly westwards, and how HAS1 is quite constant in TWT altitude. HAS 1 is, although easily trackable, discontinuous. Almost through the whole section, this sequence is shifted upwards or downwards in subvertical zones, seen in Figure 30 by the pink line. In one area HAS1 is seen as a distinct high (marked in green).

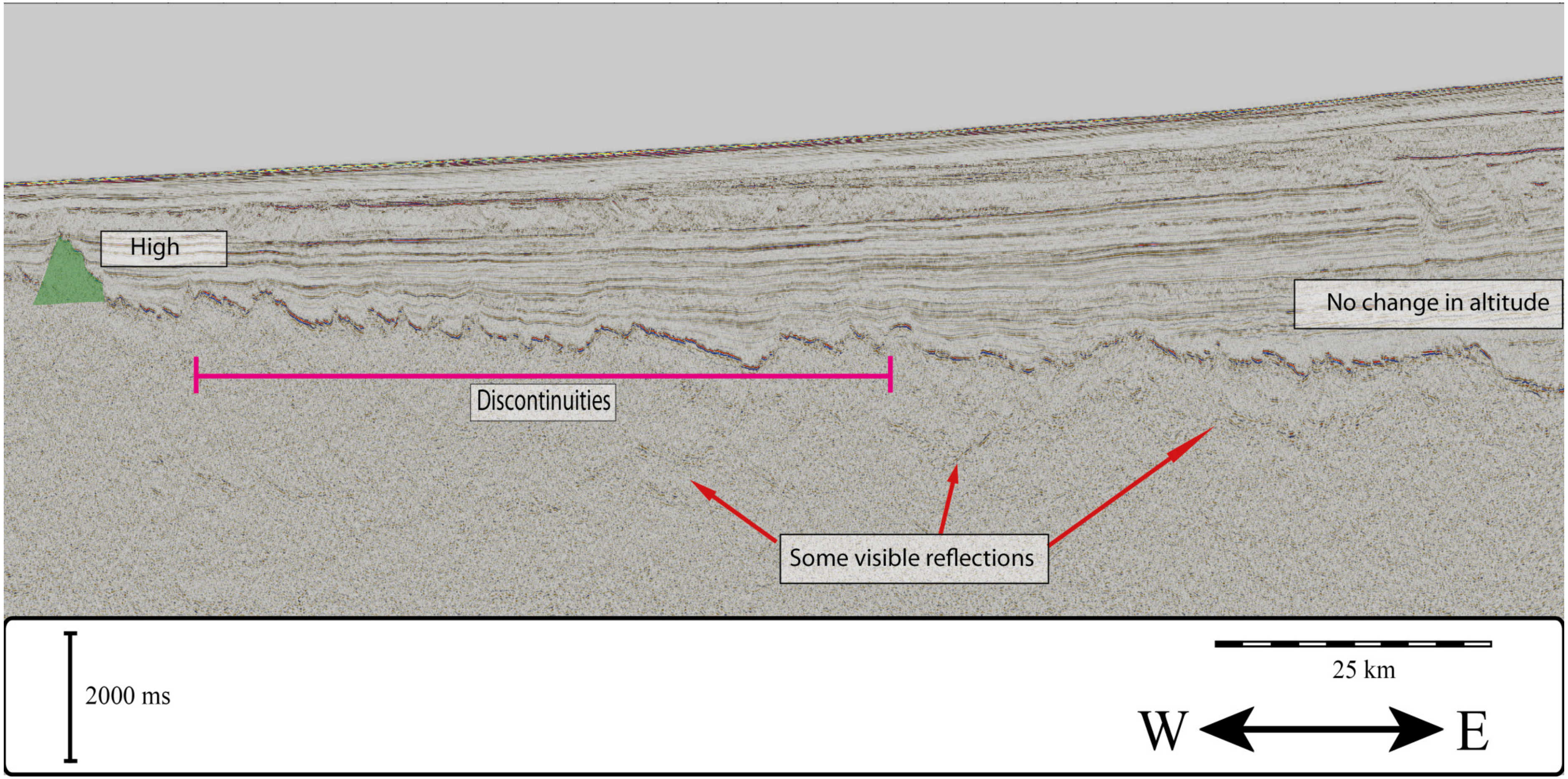

FIGURE 30: NPD-HB-4-96 WITH INITIAL OBSERVATIONS.

4.4.2 INTERPRETATION

As in the previous interpretations, HAS1 is interpreted to be the top basalt reflector of the oceanic crust. Since HAS1 can be followed all the way to the Mohns Ridge in this line, it is not hard to come to this conclusion. From Figure 5 in section 2.1.3, the change from sediment to basalt shows a great increase in velocity, which will result in an increase in impedance. This impedance change is seen here as a strong, positive reflection. The discontinuities are common features in the upper oceanic crust, and fit the profiles given in Figure 4. The discontinuities are interpreted as faults, made in the rift valley of the seafloor spreading zone. These faults were present before the overlying sediments accumulated, and are therefore not traceable upwards in the seismic profile.

The high indicated by the green color, is probably a result of voluminous volcanic activity in the spreading ridge. The rate of magmatism in the spreading ridge varies, and at times of large magma input, highs like this will be created. Because of the depth of the overlying ocean, erosion is not as high as on land or shallow marine environments, and the high is therefore noticeable on the seismic image.

The upper part of the section is interpreted to be the sediments eroded from the Barents Sea in the Cenozoic. These sediments were deposited after the generation of the underlying oceanic crust, and since the faults cannot be followed into the sediments, there is no indication that any movement has happened post deposition. The way the sediments onlap the highs is another indication of this. In some areas, the sediment reflections onlap the highs at an angle, but this is interpreted to be because of differential compactation in the sediments, and not because of any tectonic movement. In the east, Oligocene-Miocene sediments are interpreted.

Reflectors beneath the basalt are masked, and therefore very hard to see. Some reflectors are seen, but it is hard to interpret exactly what these reflectors are. They may be internal features in the top 3 layers of the oceanic crust, or they may even be the reflection of the Moho. The thickness of the oceanic crust varies, but the Moho is usually found between 5 and 7 km down into the crust.

In the eastern part of the seismic line, there is given no indication that there is any transition from the oceanic crust to continental crust. The signature of the reflector does not change, and no special events are seen in the oceanic crust or the sediments. It is therefore interpreted that this seismic line does not intersect the COB, and only images the oceanic crust with a thick sequence of Cenozoic sediments on top of it. What this line does, is help giving a good impression of what the oceanic crust looks like, and how faults and highs are a normal part of its structure.

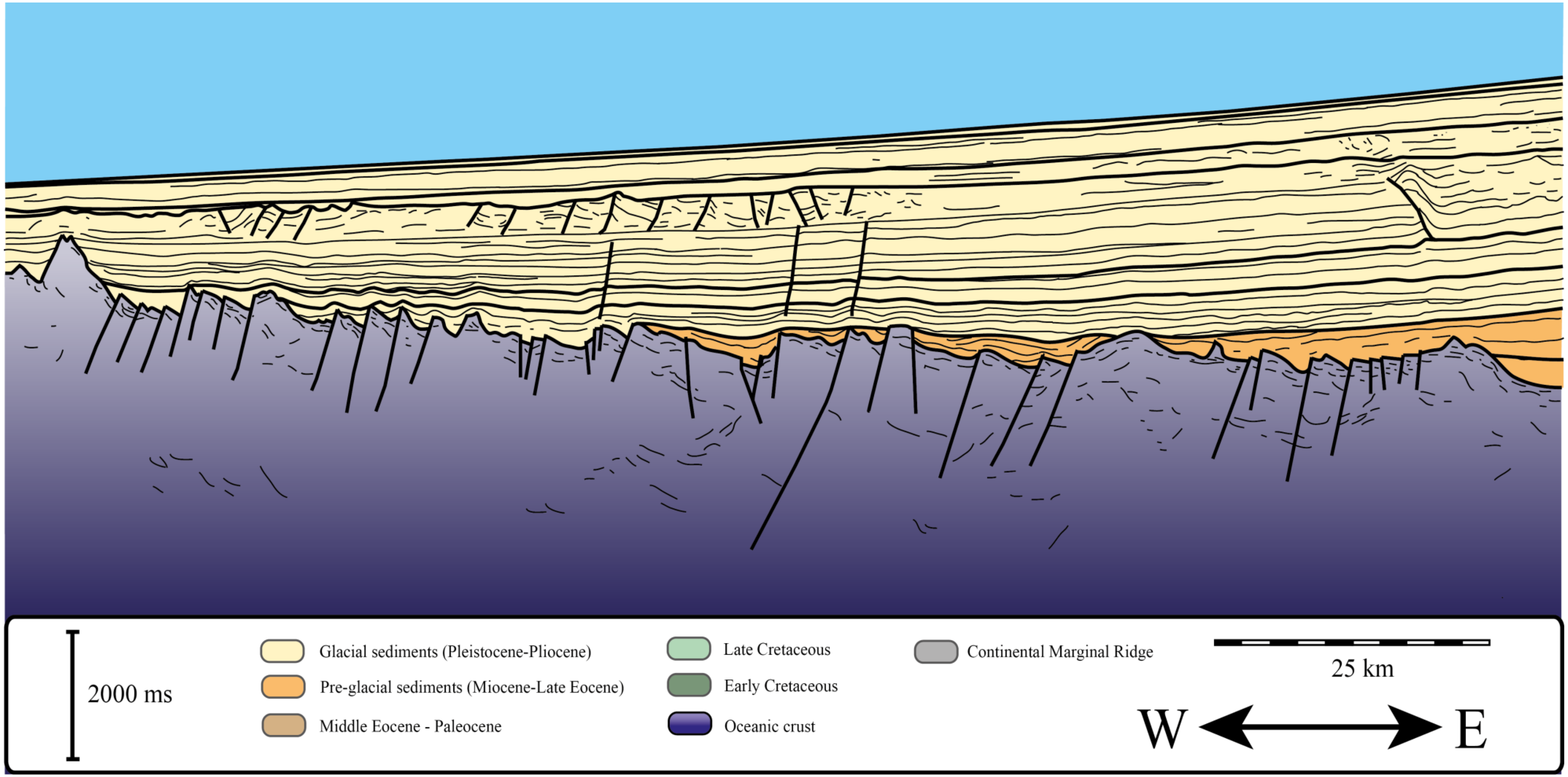

FIGURE 31: GEOSEISMIC INTERPRETION MODEL FOR SEISMIC LINE NPD-HB-4-96.

4.5 NPD-HB-5-96

The HB-5 line is one of the two lines directed from SW to NE, imaging the Bjørnøya Fan and the Vestbakken Volcanic Province. It is intersected by HB-1300, HB-3, HB-4 and HB-6. This is the observations from the northeastern corner of the line

4.5.1 OBSERVATIONS

The observations made in this chapter are referring to Figure 32. As the other lines, this also shows the separation between two different areas: the upper area with distinct reflections stretching from one end of the line to the other, and a masked, noisy area where little information is found. These two areas are separated by a positive high amplitude reflection sequence, divided into HAS1 in the SW and HAS2 in the NE.

The first impressions of the High Amplitude Sequences are that they contain a lot of high structures. Not as many displacements in depth are found in HAS1, but it seems to contain more highs than seen in the other lines. As usual, it is in most part observed as a single positive high amplitude reflection with negative sidelobes – indicating an increase in impedance. Closer to the middle of this line, the amplitude decreases, and becomes vaguer. This seems to be in connection with the high structures in this area.

The transition to HAS2 is hard to observe, but one clear feature is seen. HAS2 is first observed at the right side of a large high in the middle of the seismic line. HAS2 appears as a sequence of high amplitudes with a thickness of 200 – 350 ms, masking the reflections beneath it. HAS2 can be followed to the NE end of the seismic line. As in HB-3, it rises into a steep slope, and distinct high structures are observed. The area of transition between HAS1 and 2, in addition to the highs in HAS2 will be closer studied in the two subsections seen in Figure 32.

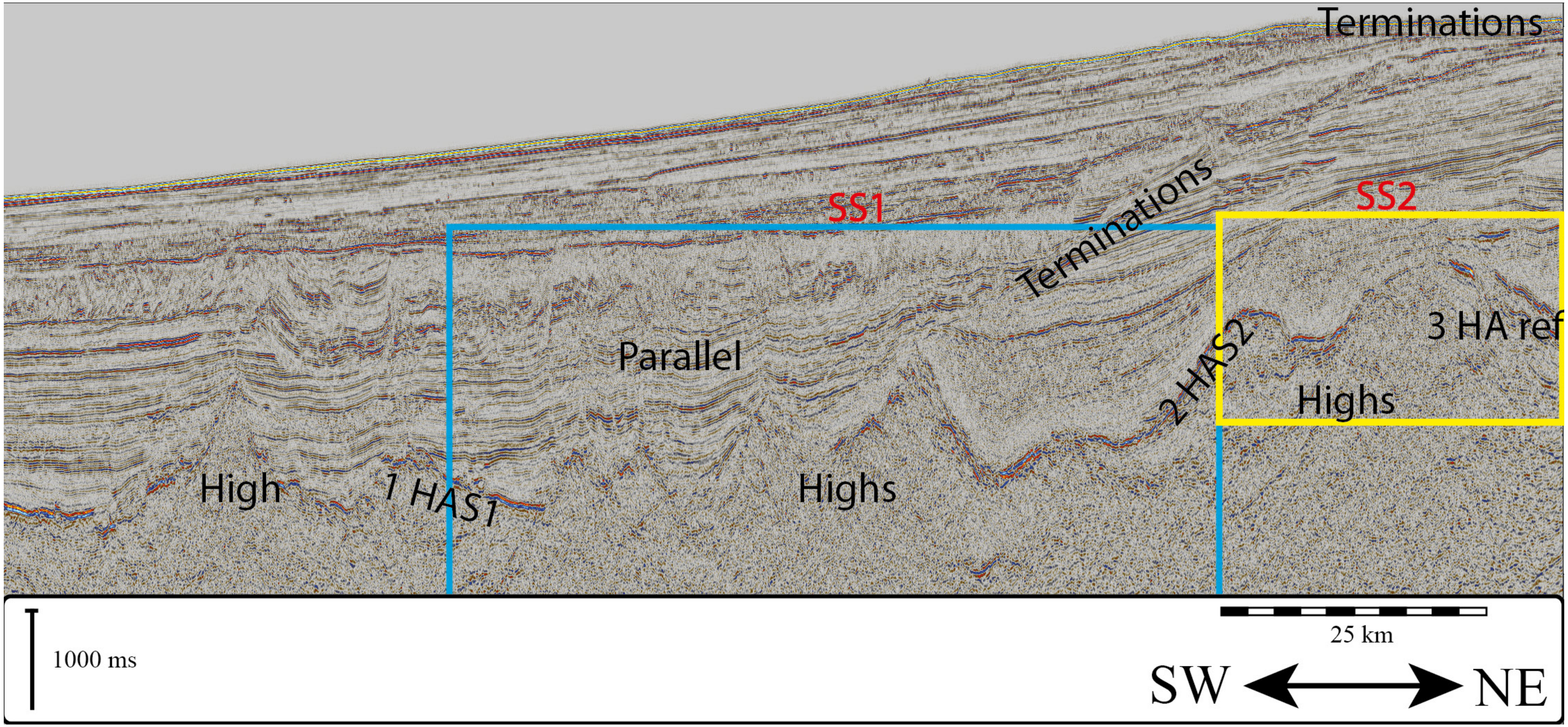

FIGURE 32: NPD-HB-5-96 WITH INITIAL OBSERVATIONS. SUBSECTION 1 INDICATED BY BLUE RECTANGLE, AND SUBSECTION 2 INDICATED BY YELLOW RECTANGLE.

HB-5-SS1

HB-5-SS1 focuses on the transitional zone where the COB is thought to be found. Observations are made from left to right in Figure 33.

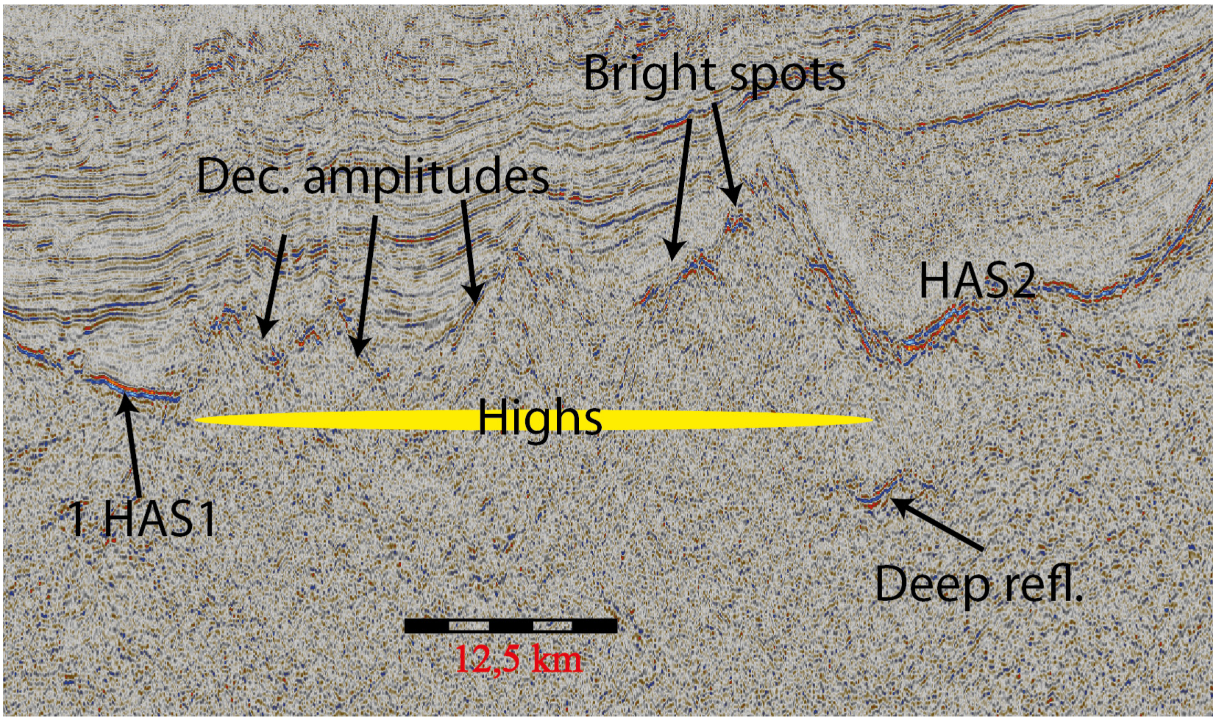

FIGURE 33: SUBSECTION 1 FROM HB-5.

HAS1 is a single strong positive reflection in the left side of the subsection, and is tilted at an angle. It terminates abruptly, but is found at the top of the high to its right. This indicates that it has been displaced. The highs that follow are not of the very large, approximately 500 ms, measured from the top to the bottom of their slopes. The signature of these highs, in which the amplitude of HAS1 decreases, are in some places only seen because of the difference between the overlying continuous reflections and the chaotic, noisy reflections beneath.

There are three of these smaller highs, with a low amplitude top reflection, before the characteristic of the reflection is again altered. A forth high rises, but here, strong amplitudes are seen in bright spots on the SW flank. The angle of the slope is steep, and it rises 1300 ms over the reflection at its sides. Continuous strong reflections are seen in its NE slope, and these seem to be connected to the thick HAS2. Overlying reflections are dimmed close to this high, and the onlaps of reflections are not seen. Beneath HAS2, a deeper reflection is seen, with a similar angle of inclination.

HAS2 rises from this point upwards towards the two large highs in the NE corner of the seismic line. Just beneath HAS2, another distinct sequence is seen, with unusually high amplitudes to be located in the normally masked area beneath HAS2.

HB5-SS2

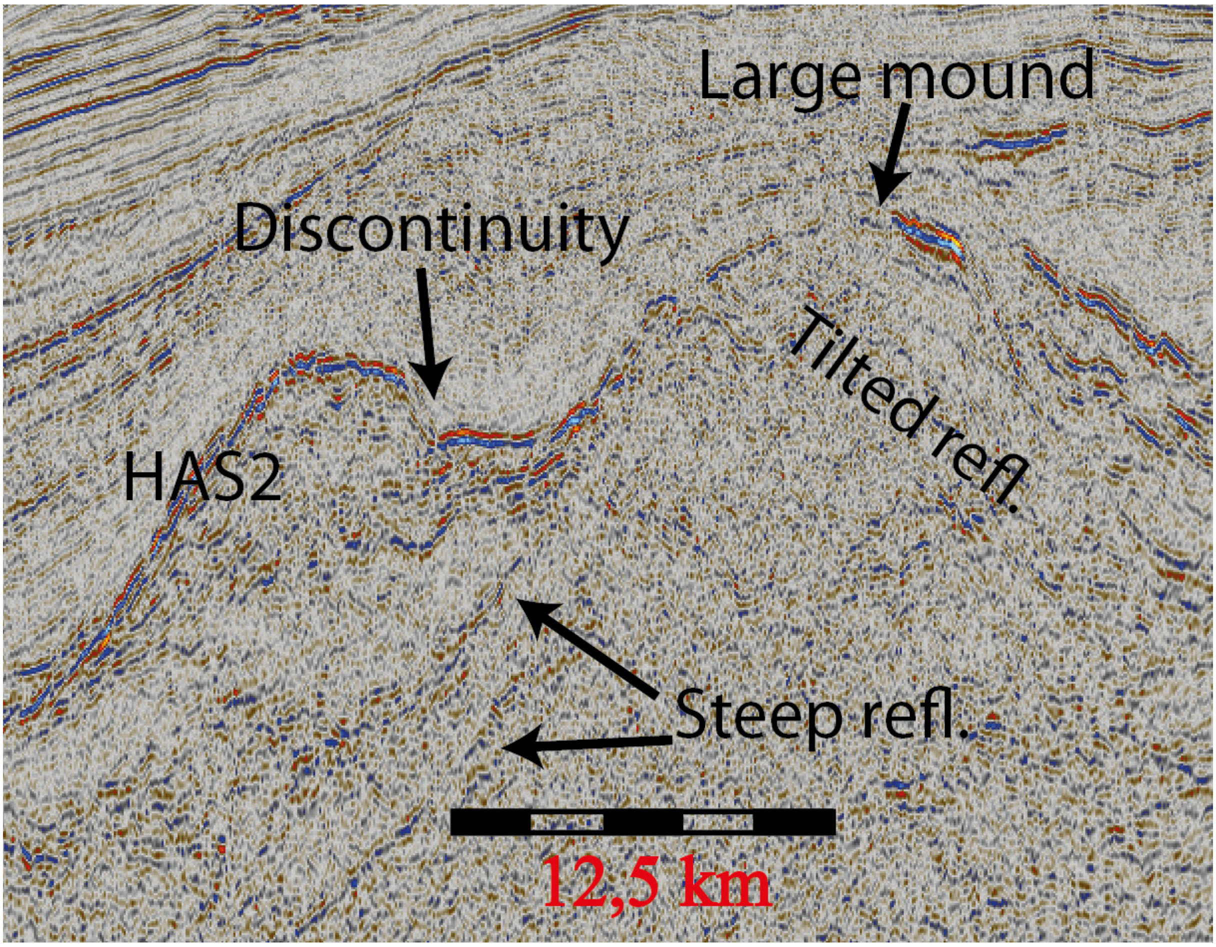

FIGURE 34: SUBSECTION 2 FROM HB-5.

Observations in HB-5-SS2 start on the left side with the steep slope in HAS2. The slope flattens and forms a high. The internal reflectors are visible in this high, and not as masked as the reflections beneath HAS2 have used to be. On the left flank, the internal reflections are directed in a similar direction as HAS2, but at the top and on the right flank they are horizontal. At the top of this high, HAS2 is shifted downwards.

Deeper down, internal reflections are seen, and these also have a steep angle, rising against the large mound shape structure in the right side of the seismic image. It appears that the internal reflections in the mound are tilted downwards towards the right, but this is hard to determine because of the lack of continuity in the reflections.

4.5.2 INTERPRETATION

The final interpretation is found in the geoseismic model in Figure 37.

Cenozoic sediments

Since the focus of this thesis is locating the COB, the sediments in the upper part of the seismic are not as relevant, and therefore not as thoroughly interpreted as the lower reflections. The whole upper part described in the observations is interpreted to be Cenozoic sediments, and the majority is thought to be deposited in the glacial period in Pleistocene and Pliocene, named the Nordland Group. This is interpreted on the basis of well data and the numerous articles written on this theme, e.g. Vorren et al., 1988, Dimakis et al., 1998 and Dahlgren et al., 2005. From well 7316/5-1, intersecting the HB-5 line, the erosive surface between the glacial sediments and preglacial sediments in the Sotbakken Group is found. This surface is observable in the seismic data as well, and is used to distinguish the two different lithologies. Separating the different ages of sediments overlying oceanic crust is difficult, and this interpretation has a lot of uncertainty to it. Several erosive surfaces are found from the termination and truncation of underlying layers, which would imply periods of uplift.

Oceanic Crust

Like the majority of the seismic lines in the Havretst Bjørnøya Vest survey, this line also depicts the oceanic crust far out in the Lofoten Basin. The line does not intersect the Mohns Ridge, as it is directed subparallel to it. This indicates that the oceanic crust is of the same age, and the age is found to be Oligocene (Libak et al., 2012, Lundin and Doré, 2002). HAS1 is the reflection found in the observation part that correlates to the top oceanic crust interpretation. In this line, as in several of the others, the top oceanic crust is mostly observed as a single strong positive reflection, caused by an increase in impedance in the transition between the low velocity shale layers above, and the high velocity basalts in the oceanic crust.

The discontinuities observed are interpreted as faults, which is common feature of the oceanic crust. Several highs are found in the oceanic crust, the most noticeable is located at the SW end. This is believed to be caused by increased magma production in periods, erupting more lava onto the surface. Rapid cooling of the volcanic deposits builds up high hyaloclastite structures, preventing the basalt to flow for long distances.

Masking of underlying layers is apparent, and few interpretable structures are observed beneath the top reflector. Reflections observed here seem to be linked to the highs or faulting in the upper crust. The Moho is not observed, at least not as a continuous feature, and therefore not interpreted. It is incorporated in the interpretation of Oceanic crust in the geoseismic model.

Continental Crust

HAS2 is interpreted to be flood basalt from the volcanic activity related to rifting in Early Eocene. This extrusive unit is what defines the area of the Vestbakken Volcanic Province. Other studies and well data give a strong basis for this interpretation. HAS2 is heterogeneous, as the separate layers of basalt are not very thick. This is what may cause the large impedance contrasts within the sequence. An interesting observation is that on the far right side of the seismic line, the flood basalts seem to be inclined towards the northeast, which is the opposite direction of what have been found in the other lines. One interpretation of this is that the mound observed in SS2 is close to the eruption center of the volcano, because flows in both directions are found and the sequence is thinner on top of the mound. It is important to be careful when interpreting directions of layers in 2D data, as a cross section does not reveal enough information to be certain. Still, it can interpreted that these extrusives are not lying in the same direction in this 2D line. Other factors that can be the cause of the different tilt of the flows are that the shape of HAS2 has been formed by periods of uplift/subsidence, faulting and erosion between Early and Late Eocene. As observed in SS2, the internal reflections in the highs are not the same as in HAS2, which may imply that erosion of has occurred.

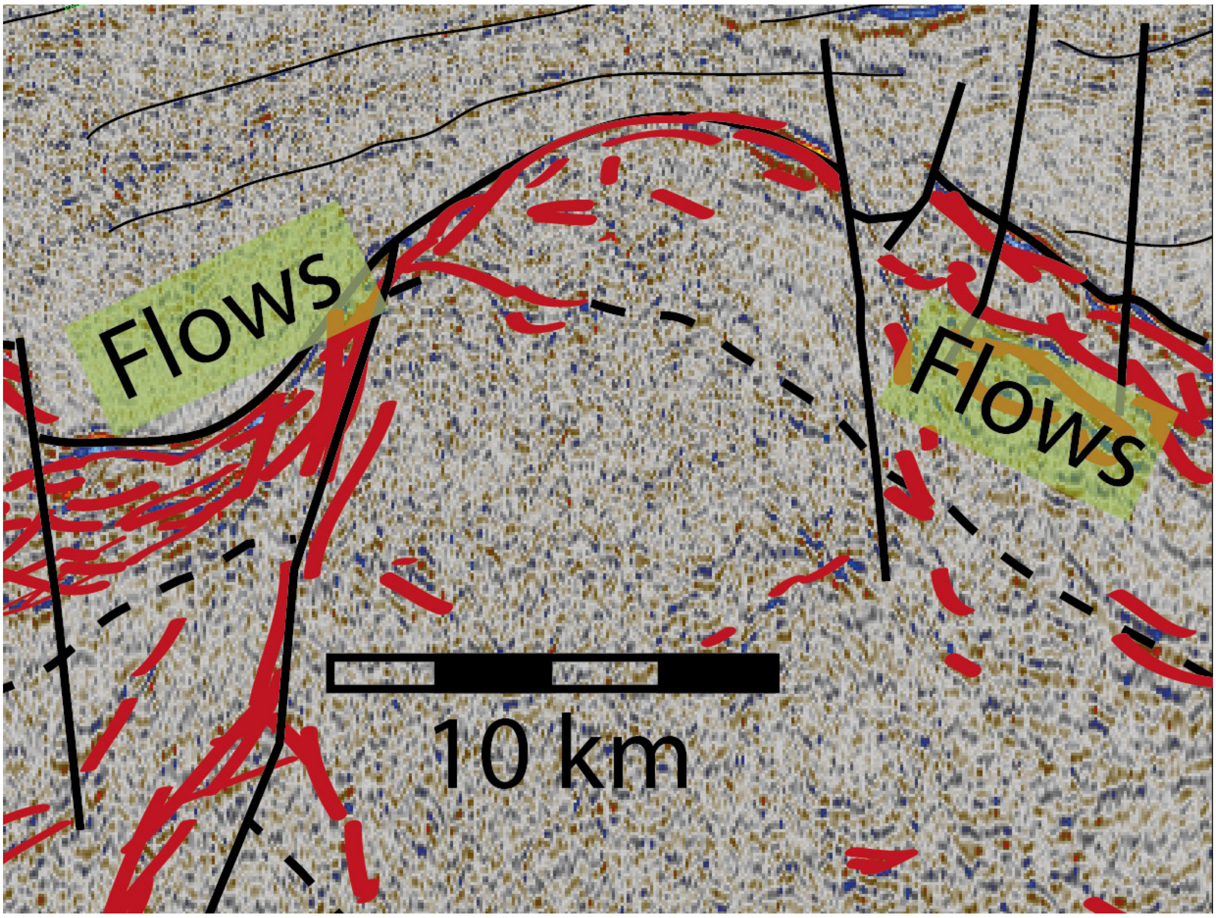

FIGURE 35: INTERPRETATION OF VOLCANIC FLOWS AND INTRUSIVES IN RED, OBSERVED IN SS2. DOTTED LINE IS THE INTERPRETATION OF THE CENOZOIC-CRETATCEOUS BOUNDARY.

The boundary between Cenozoic and Cretaceous is based on estimation from well 7316/5-1, and intersections from the other seismic lines. In the large mound, the boundary is interpreted to be tilted at an angle. Strong reflections within the Cretaceous interval are interpreted to be volcanic intrusions associated with the volcanic activity in VVP in Eocene. Several of the faults interpreted in the area are traced through the Middle Eocene – Paleocene interval, and into the Cretaceous layers. This can be interpreted as reactivation of older faults. Masking of the underlying layers because of the volcanic makes this interval hard to interpret, and uncertainties are high.

Continent-Ocean Boundary

The COB is thought to be found in subsection 1 (Figure 33). This profile shows HAS1 and HAS2 on opposite sides, and a sequence of highs in the middle. The largest of the highs, lying furthest to the NE, is interpreted to be a part of the marginal continental ridge which is found along the shear margin of SFZ. The top reflector of this high seem to be connected to HAS2, but the reflections have been tilted upwards. An interpretation of this is that it has been caused by uplift, after deposition of HAS2. Uplift of this ridge may have been caused by heat transfer from the juxtaposed oceanic crust, but this theory has uncertainties, and the ridge formation may be a result of other constructional factors (Bird, 2001). The timing does not seem to match, as the overlying unit should be affected by this as well. The narrowness of this ridge is also a factor creating uncertainty of this interpretation.

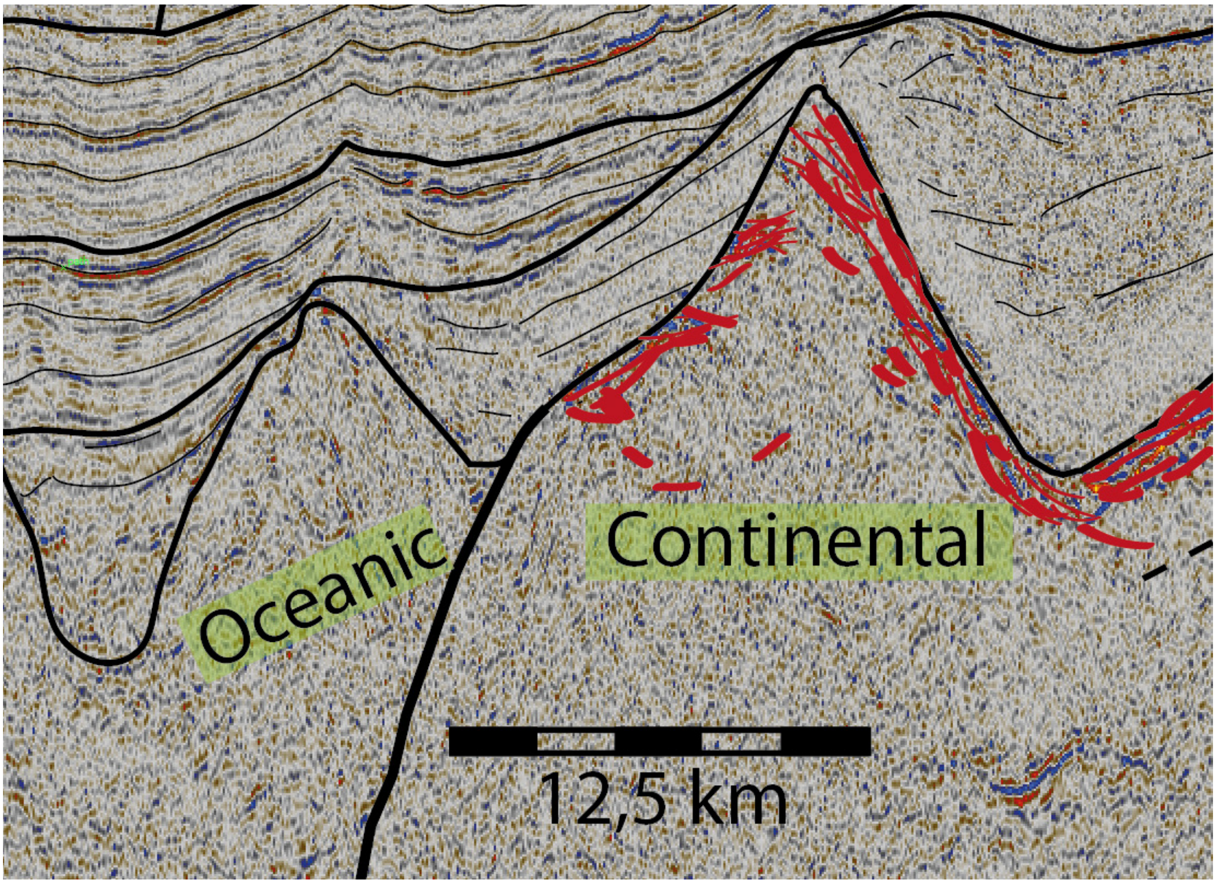

FIGURE 36: CONTINENT-OCEAN BOUNDARY. THE NE HIGH IS CAPPED WITH VOLCANIC EXTRUSIVES, AND THE LOWER PART OF THE PRE-GLACIAL SEDIMENT SEQUENCE TERMINATES AGAINST ITS SIDE. OCEANIC CRUST ON ITS SOUTHWESTERN FLANK.

Another theory is that this high has been formed by volcanic activity in.. Volcanoes may create this kind of reliefs, and the top reflector may be flows of basalt from the eruption center. The internal composition of this high should be the same as the continental layers interpreted, finding both the Cenozoic and Cretaceous intervals. Volcanism may be both Eocene and Oligocene.

The bright spots on the SW flank of the continental marginal ridge are interpreted to be erosion of the volcanic flows on top of the high. This erosion is interpreted to have happened in Eocene-Oligocene, and is probably related to the uplift. Erosion may have happened before the formation of the ridge.The lower sediments lying on the oceanic crust is thought to be Oligocene and Miocene sediments.

These arguments are the basis for the interpretation of the COB located at the base of the NE high in SS1. The smaller highs are interpreted to be related to variations in magma input in the creation of oceanic crust, and the changes in impedance contrasts found in SS1 may be related to local differences in the oceanic crust or in the sediments. It is hard to come to a good conclusion from these amplitude differences, as it may be because of several reasons.

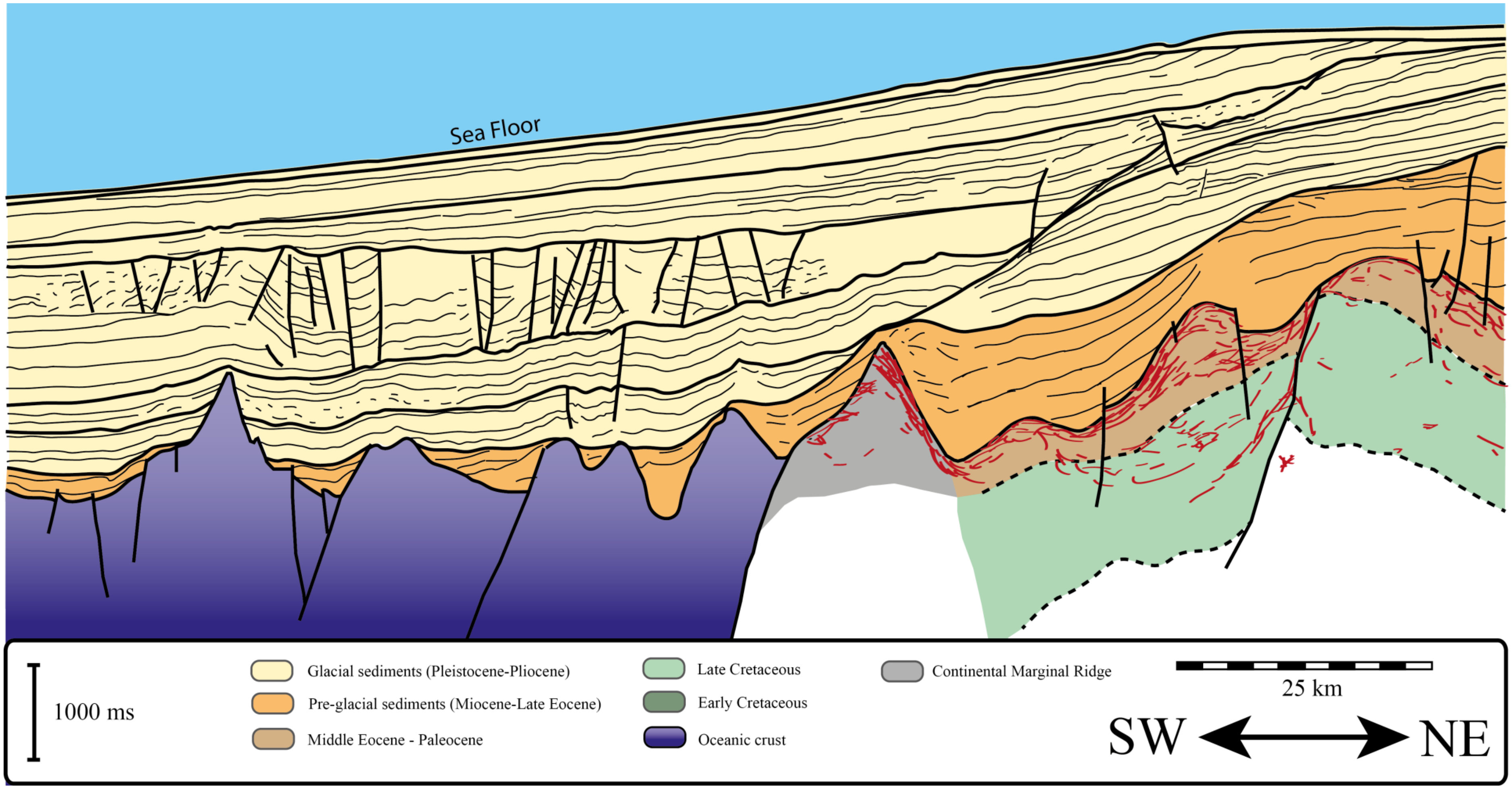

FIGURE 37: GEOSEISMIC INTERPRETION MODEL FOR SEISMIC LINE NPD-HB-5-96.

4.6 NPD-HB-6-96

HB-6 is the sixth and last seismic line to be interpreted in this study. It stretches west to east, from the Mohns Ridge in the Atlantic to the Sørvestsnaget Basin in the Barents Sea. The line is intersected by HB-5, HB-1300, HB-2 and HB-4. The observations from this line will be divided in two parts, one general for Figure 38, and one for the highlighted subsection, where a more detailed look is necessary.

4.6.1 OBSERVATIONS

The following observations are referring to Figure 38.

1. As HB-3 and HB-4, this line is also intersecting the Mohns Ridge (not shown in the figure), and the high amplitude HAS1 reflection known from the other lines is identified. This reflection is easily traced through the line. It separates the parallel reflections from the lower noisy, low amplitude reflections. HAS1 is shifted upwards or downwards several places, which separates it in sections. However, because of its amplitude, it is not a problem to follow it. In this image, no large highs are found, only some minor ones. These highs, colored green in Figure 38, are a lot smaller than the mounds and highs found in some of the other lines, but have similar characteristics. They are steep, their internal reflections are chaotic, they are onlapped by overlying reflections and they emerge from HAS1.

2. Following HAS1 eastwards, the reflection suddenly terminates, and disappears. East of this point, no reflections are of the same strength as the high amplitude of HAS1. Observations made in reflections lying on top of HAS1 shows that these are also terminated. In this termination zone, the structure of the reflections is tilted at a steep angle downwards. The terminated reflections are more horizontal.

3. On the easternmost side of the seismic line, the transition from the upper parallel reflections to the noisy bottom reflections is found. It has been shifted significantly upwards. What is noticeable is that there are no high amplitude reflections when entering the more shaded reflections. This means that the acoustic impedance contrast is not big, and is significantly different from what is found at the other seismic lines, where HAS2 is found at this depth. This area will be studied in more detail in SS1.

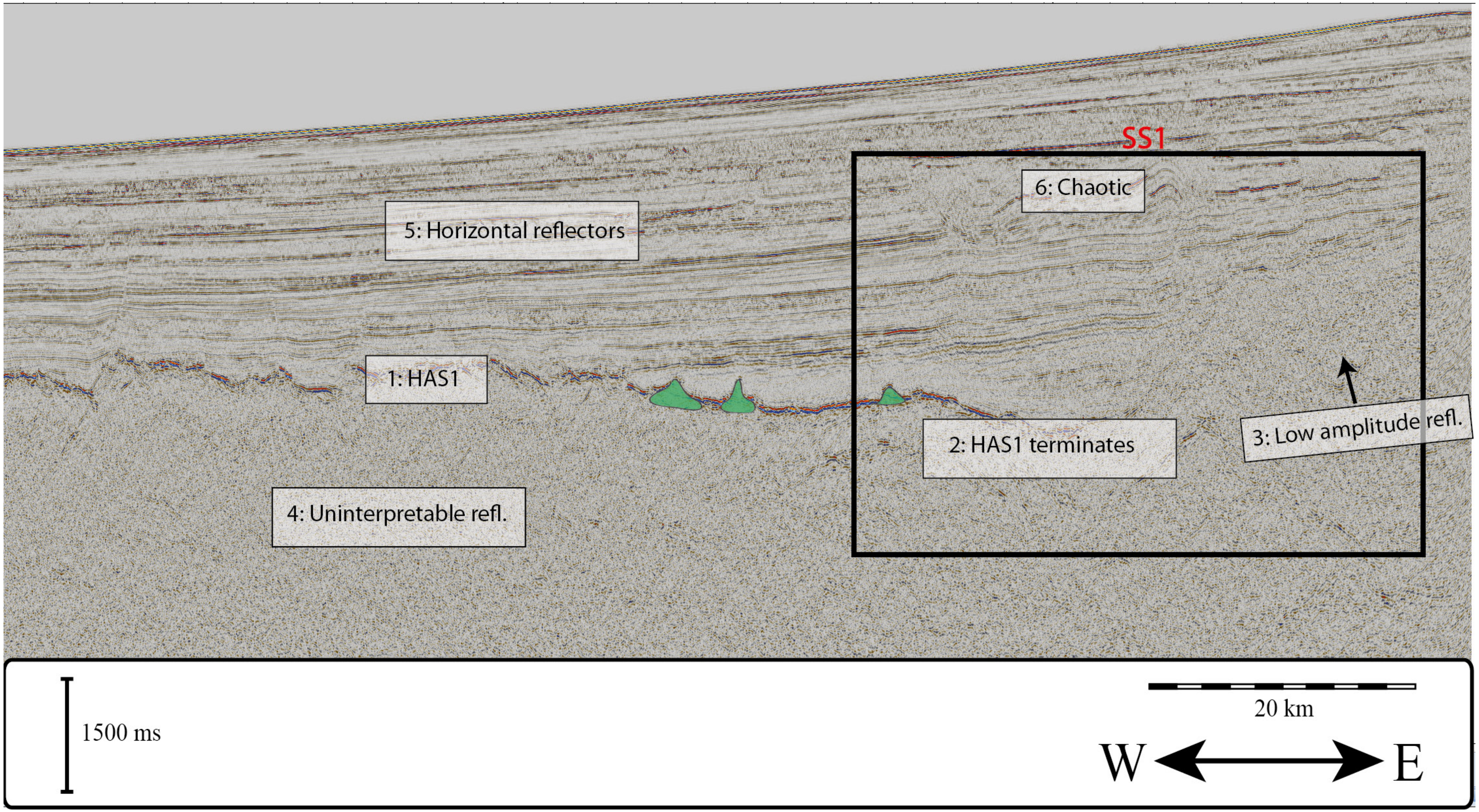

FIGURE 38: NPD-HB-6-96 WITH INITIAL OBSERVATIONS. GREEN HIGHLIGHTS ARE SMALL HIGHS. SS1 IS SHOWN BY THE BLACK RECTANGLE.

4. The bottom section of the seismic line is, as all the other lines, noisy and structureless. Some reflections stand out from its chaotic surroundings, but these are hard to track and make an interpretation of.

5. The resolution in the upper section is good, and many strong, continuous reflections are identified. As a whole, the reflections in this part are mostly parallel, but the thickness of the sequence is thinning westwards. This means that most of the reflections have to be terminated at some point, which is seen at several places. Thickness of this section is largest right above the termination of HAS1.

6. At the eastern side of the seismic line, a chaotic area is found admits the parallel reflections in the upper section. Reflections are terminated, displaced and the internal structure looks like a wave. This continues for a about 20 kilometers, then it goes back to parallel reflections. The top reflection in this interval has a higher amplitude than it has in the rest of the seismic line, and this indicates some larger impedance differences between the overlying lithology, and the lithology in this section in this area. As this is a 2D line, it is very hard to say what kind of structure this is, and how it continues in another plane. It is easily seen that this stands out from the rest of the upper section. Some minor areas like this are found several places.

HB-6-SS1

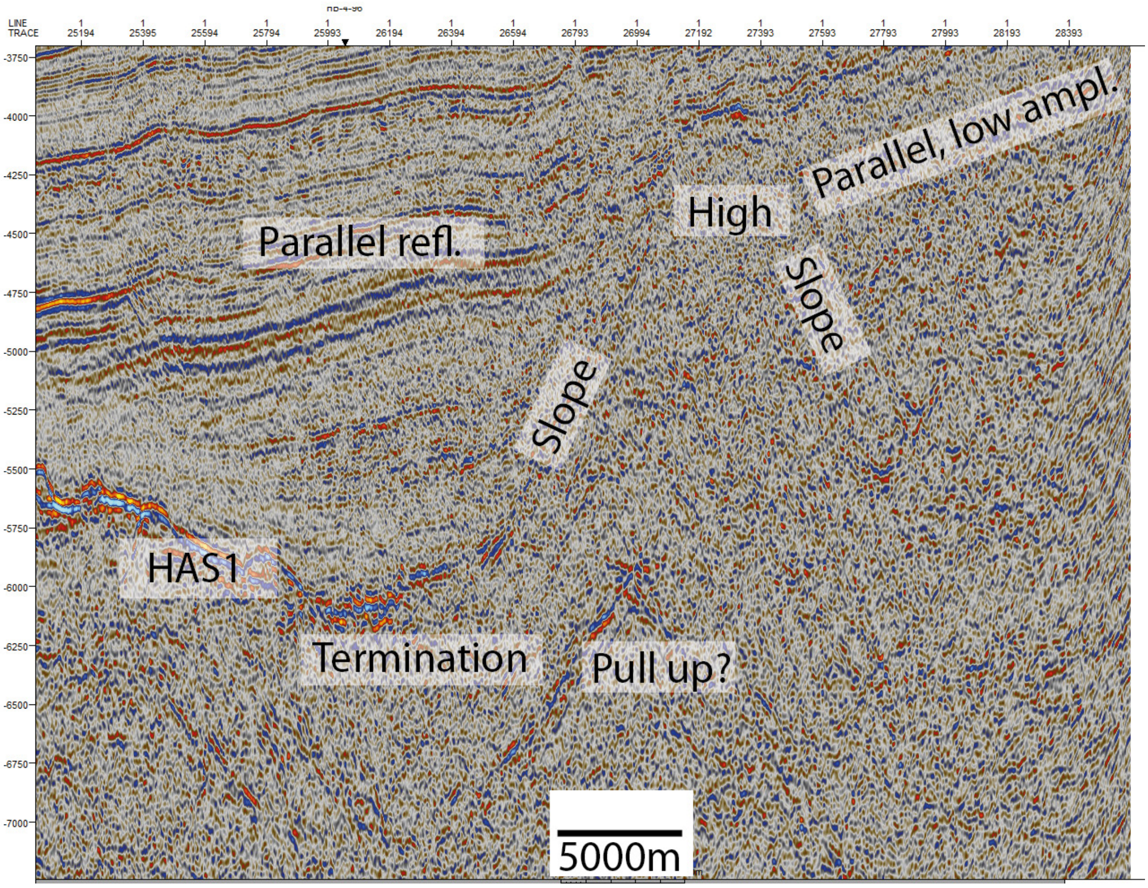

FIGURE 39: SUBSECTION 1 FROM HB-6.

HAS1 terminates into a slope like feature, which begins at the middle of the subsection. The amplitude of HAS1 is a strong positive, and is easily seen. The termination seems abrupt, and a reflection of the same strength is not found further east. The slope is steep, and is observed from its start at ~6000 ms to its end at ~4250 ms. At the top, the angle of the slope decreases, and forms a high. The reflection strength is low at the top of this high, and it is hard to observe the area east of it. It seems that a new slope begins, going downwards at a steep angle, better seen in Figure 40. This is seen by the termination of the parallel, low amplitude in the upper right corner of the subsection, and the steep sidewall reflections. Internally, at the base of the high, a structure looking like a high is seen, which may be a pull up.

At the right side of the subsection, it is hard to see any clear structures, but two reflections with a synform shape are observed.

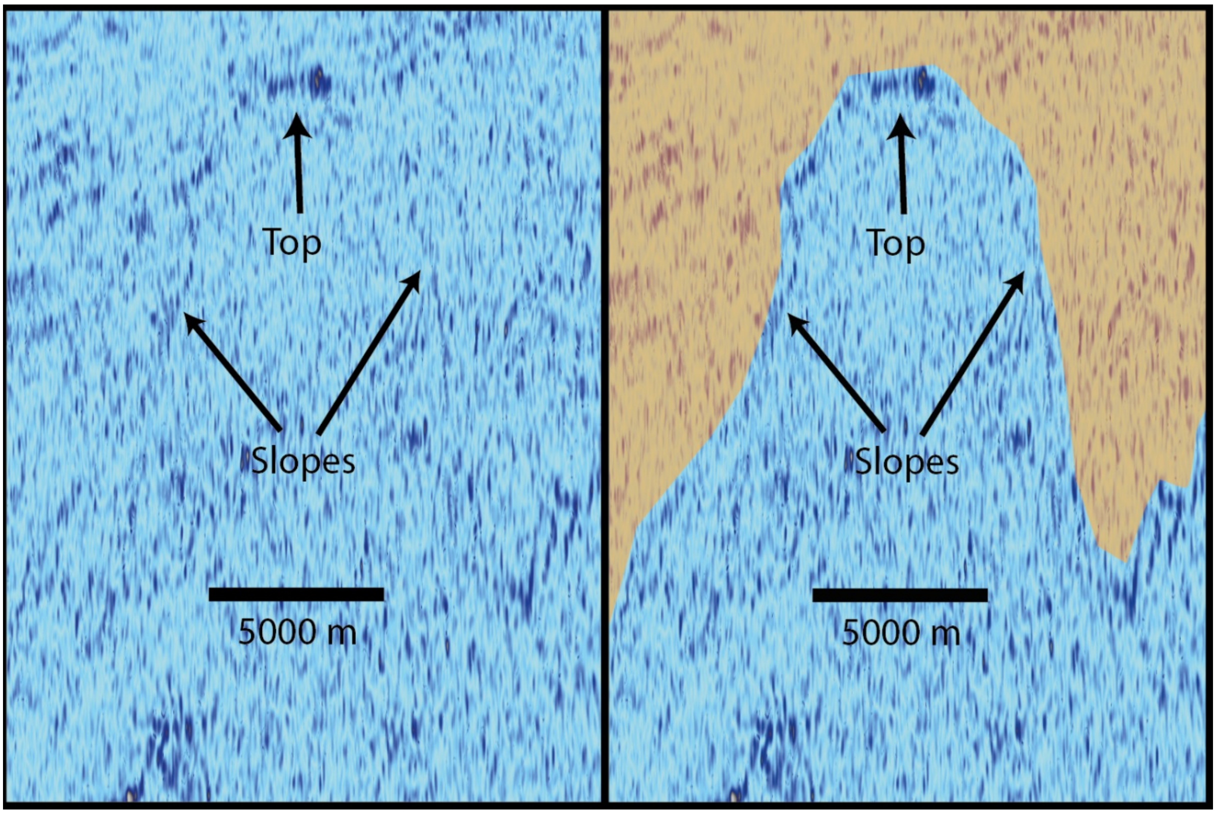

FIGURE 40: SWEETNESS VOLUME ATTRIBUTE ON THE HIGH STRUCTURE FROM HB-6-SS1. IN THE RIGTH PICUTRE, THE SURROUNDING REFLECTIONS ARE DIMMED TO BRING FOCUS TO THE RELIEF OF THE HIGH.

4.6.2 INTERPRETATION

The final interpretation model is found in Figure 41.

Cenozoic sediments

Parallel reflections in the upper part of the seismic line are interpreted as Cenozoic sediments. The majority are glacial sediments from the ice age periods in Pliocene and Pleistocene. This layer is very thick, and in areas faulted and folded. Several unconformities are found within this layer, implying periods of erosion. The unconformity between the glacial and pre-glacial sediments are found in the eastern side at about 3500 ms, and tracked seawards through the marginal high. This layer is much thinner than the glacial sediments, specially overlying the oceanic crust. The glacial sediments are part of the Nordland Group, while the Miocene-Late Eocene layer is part of the upper Sotbakken Group.

Continent-Ocean Boundary

While this part of HB-6 does not show it, the line is imaging the underburden all the way out to the Mohns Ridge. This gives a strong certainty to the interpretation of HAS1 as the top oceanic crust. The top reflector is caused by the increase in acoustic impedance going from low velocity sediments to high velocity magmatic rocks, in this case basalt. The small highs found are interpreted as volcanic buildups generated from an increase of magma to the surface, but not as voluminous as the larger highs seen in other lines, e.g. HB-5.

HAS1 is easy to track, as it is continuous and strong in most parts of the seismic line. The termination is abrupt, and is interpreted to be the end of the oceanic crust. As the reflectors lying over the Oceanic crust are also terminated, the interpretation is that they are all onlapping a fault. The sediments seem to be filling the relief, and not affected by the structure they are onlapping, and therefore interpreted to be deposited after the continental breakup.

HAS2 is not found in this seismic line, and this is interpreted to be because of lack of volcanic extrusives in this area. It is thought that the continental part of this line images the Sørvestsnaget Basin, south of the VVP. This would explain the lack of volcanic facies, as the VVP is a limited area with volcanic flows from Eocene volcanoes. It is apparent though, that the reflections beneath the glacial sediments are very weak, and show no high reflectivity, indicating masking. An observation of a high is interpreted to be the continental marginal ridge, also found in HB-2 and HB-5. The interpretation of this high is more uncertain than in the other lines, because of the low reflectivity of the structure. Figure 40 shows the seismic signature of what is interpreted as a high.

The origin of it is complicated to interpret, but several theories may explain it. Heat transfer from the oceanic crust, when the neovolcanic was at lying juxtaposed to this part of the SFZ. This heat may have lifted the continental crust, and deformed its internal composition. If this is the case, the internal stratigraphy of this high should contain the same lithologies asin the Early Cenozoic and Cretaceous layers.

The origin of this high may also be volcanic, but no strong positive reflectors are found in the lower continental part of this line. This raises questions to a volcanic origin forming this high. It is thought that the high is connected to the highs in other lines, forming a ridge, and if this ridge was formed by the same geological events, a volcanic interpretation is weakened.

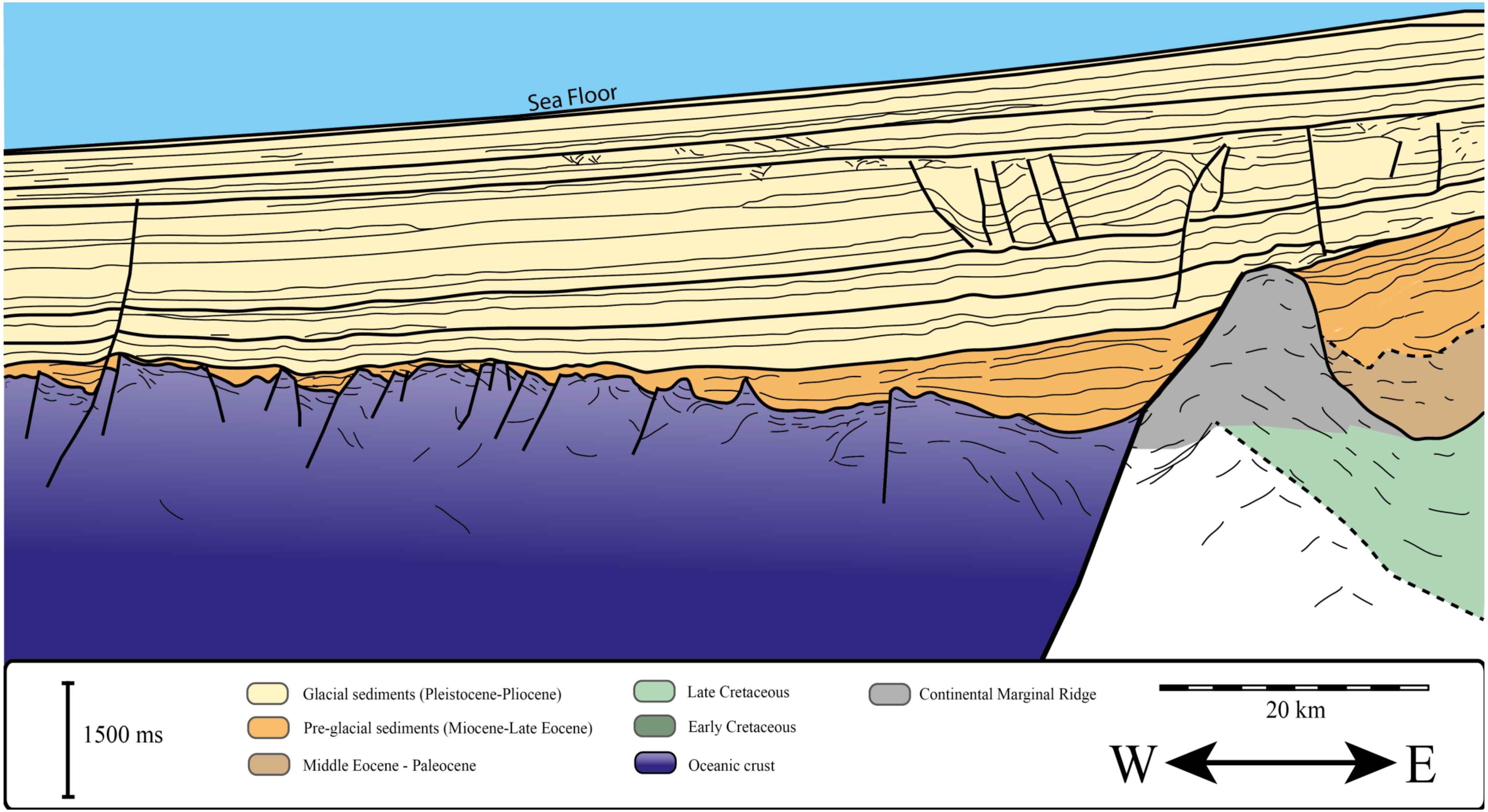

FIGURE 41: GEOSEISMIC INTERPRETION MODEL FOR SEISMIC LINE NPD-HB-6-96.

5 DISCUSSION

5.1 OCEANIC CRUST

Oceanic crust was identified from the HAS1 reflection, and found in all the seismic lines. The seismic lines in this survey extend far off the continental margin, out in the Lofoten Basin. Several hundred kilometers of oceanic crust give a good basis for the description of its signature. First, the oceanic crust is seen as a strong, positive amplitude reflection. As the data in this survey is zero phase, the signature of the oceanic crust is similar to the sea floor reflection: Two negative sidelobes with a positive peak in between. A positive reflection is expected, as the wave velocity is very high in basalts compared to sand and shale dominated sediments. The strength of the reflection signature varies, and this may be because of local effects, for example variations in overlying lithologies, topography of the crust etc.

Besides the reflection signature of the top oceanic crust, several features have been found that distinguishes it from other horizons:

- **Normal faults**: The strong top reflector has been found to be discontinuous, and this is interpreted to be caused extensional movements, resulting in normal faulting in the crust. What distinguishes these from normal faults found in the continental crust is that the top of the foot and hanging wall does not seem to be noticeably eroded. This may be because of the low erosional forces at large sea depth, where the oceanic crust is generated. Good examples of these normal faults are found in Figure 26 and 30**.** Inward normal faults is an indicator of a slow spreading rate in the ridge (Macdonald, 2001).
- **Highs:** Another common feature in the Oceanic crust, are highs rising several hundred meters, sometimes kilometers. Some of these highs are related to uplift from faulting, but others seem to be constructed from volcanic activity. The latter ones are the ones that are highest. Increase in magmatic input, leading to voluminous volcanic activity near the spreading center is believed to construct them. Creation of these highs depends on the oceanic crust being thick enough to support the weight of them (Macdonald, 1982). Highs in the Mohns Ridge can be seen in Figure 42.

- **Masking:** The top basalt reflector of the oceanic crust is in many areas the only interpretable horizon of the deeper layers. Layers beneath are masked. This is a common problem when imaging beneath basalt, and is caused by many different factors. Absorption is one of the main causes. As the seismic wave front is entering the basalt, which is composed by several different materials, the wave front is "crushed" by these irregularities within the basalt, making it hard to interpret the layers beneath (Landrø, 2008). As the top oceanic crust is a deep horizon, geometrical spreading and transmission loss is also significant factors to the damping of the seismic signal. The sum of all the effects causes structures beneath the top basalt to be very hard to interpret.

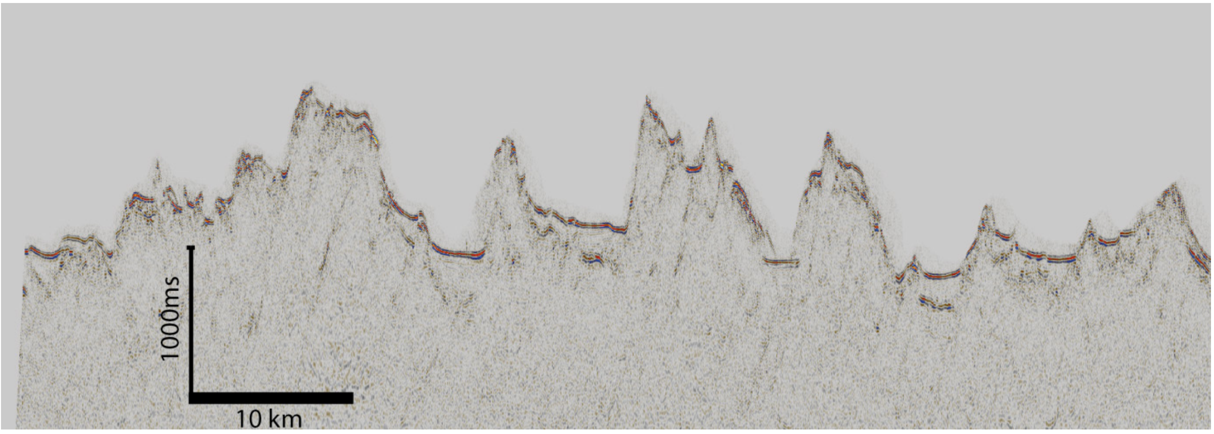

FIGURE 42: OCEANIC CRUST AT THE MOHNS RIDGE.

5.2 VOLCANIC FLOWS

The continental crust is defined as the layers of igneous, metamorphic and sedimentary rocks which form the continents, and is overlying the denser mantle beneath. In this report, the volcanic extrusions and intrusions play a big role in separating the continental and oceanic crust. Studies late in the 1980's suggested that the COB was located at the eastern boundary of VVP, and that VVP was underlain by oceanic crust (Eldholm et al., 1987, Libak et al., 2012). Exploration well 7316/5-1 showed Cretaceous layers underlying the volcanic flows, proving that the transition was further towards the west (Semple and Bulman, 1993).

Volcanic activity in VVP was initiated by the continental breakup. Generation of oceanic crust began south of the SFZ, and was spreading parallel to the SFZ (Knutsen and Larsen, 1997). This means that the flows did not flow onto the oceanic crust, as the oceanic crust was several hundred kilometers away. The fact that the volcanic extrusives in VVP erupted onto the continental crust, is of key important for the interpretation in this report: The volcanic flows are underlain by older sediment layers, making it a part of the continental crust. As long as the volcanic flows are present, the underlying layers are interpreted as continental. The well also shows volcanic intrusions in the Cretaceous layer, establishing the basis for the interpretation of intrusives when observing high amplitude reflections beneath the volcanic flows.

HAS2, found in the observation stage, is interpreted as volcanic flows. This unit is found in HB-2, HB-3 and HB-5, and these lines make the basis for the interpretation of the extent of VVP (Figure 46). HAS2 is recognized as a sequence of high amplitudes, with varying thickness, usually between 50-400 ms. HAS1 is never seen as thick as 400 ms. The top reflection is a strong positive peak with negative sidelobes, indicating an increase in acoustic impedance. Increase in impedance matches the geological interpretation of a transition from low velocity sediments to high velocity basalts. HAS2 is thicker in some areas, and this may be interpreted to because of a larger accommodation space in these areas. Differences in the amount of erosion may also cause the thickness difference, and this is supported by a thinner sequence on the local highs. As HAS2 is believed to have been erupted from a volcano, the tilt of the flows may be of help to interpret the location of the volcano. The observations and interpretations in of highs and mounds in chapter 4 give the foundation for the interpreted location of the volcano in Figure 46.

The volcanic flows are interpreted to be Landward Flows, described in chapter 2.1.4, because of matching description of the signature and setting. This report argues that this is the only stage of volcanism found in the VVP. The inclined parts of the HAS2 may look like SDRs, especially the one seen in HB-2, but having seen the several kilometers thick SDR sequences on the Vøring Margin, these do not look similar at all. The volcanic flow layer in VVP is very thin in comparison, and the inclination is believed to be because of deposition on a uneven surface in combination with later uplift and erosion. The whole HAS2 is interpreted as Landward Flows. The reason the five stages of break-up volcanism is not found, is interpreted to because of the shear margin setting in the area, and not a rifted margin setting.

NPD-HB-6-96 does not show any signatures similar to HAS2, and this is interpreted to be because this seismic line does not intersect the VVP. The distance between HB-2 and HB-6 is about 100 kilometers, and somewhere in this interval the boundary between the VVP and Sørvestsnaget Basin is found, and the interpretation is seen in Figure 46.

HAS2 is also a contributor to the masking of underlying layers, and this is interpreted to be because of the same reasons as the oceanic crust masking (chapter 5.1).

5.3 CONTINENT-OCEAN BOUNDARY

The interpretation of the Continent-Ocean Boundary has been established in each of the six seismic lines, and the final interpretation of the boundary in a map view is presented in Figure 46**.** Four of the seismic lines, HB-2, HB-3, HB-5 and HB-6 image the COB.

To locate the boundary between oceanic and continental crust, several different factors played a role. Most important has been the signatures of HAS1 and HAS2, as they are interpreted as the oceanic crust and the continental crust respectively. The main problem has been to distinguish the two, as they both are quite similar in some areas, and most in the boundary between the crusts. Following HAS1 from the Mohns Ridge and in to the transition zone was the first step, then tracking the HAS2 seawards. The termination of sediments and deeper features in the seismic was the last step.

HB-3 shows a transition where HAS2 suddenly terminates. In this case, the termination is interpreted as the end of the volcanic flows because the generation of oceanic crust along the SFZ "pushed" the volcanic flows on the North American Plate away, resulting in this escarpment. This is interpreted as the COB (Figure 28).

HB-2, HB-5 and HB-6 do not show the same type of a sudden transition. The volcanic flows are not found in HB-6, but the COB can be found from the termination of HAS1 into what appears to be a high .This kind of highs in the transition from continental to oceanic crust is also found in the more complex HB-2 and HB-5 lines. The HB-2 line images a distinct high structure, which is interpreted to be on the continental side. As in HB-6, the COB is interpreted to be located on the western side of this high. The high in HB-5 has a triangular shape, resulting in a very narrow section on its top. Combining these interpretations in a map view, it is possible to map it as a continuous high, shown in Figure 46. It looks seemingly as a ridge lying along the COB. Since both the COB and this Continental Marginal Ridge (CMR) is located along the Senja Margin, it is assumed that the creation of this ridge may be linked to the shear margin setting. An old interpreted line from the NPD also shows a high south of HB-6, seen in Figure 43 (Gabrielsen et al., 1990). This strengthens the interpretation of this being a continuous feature along the shear margin.

The origin of this high is of importance to the interpretation of the COB because it is what seems to be the feature that is closest to the oceanic crust, and there are uncertainties to especially the HB-2 and HB-5 interpretation of it.

There are several theories to what may have caused the rise of this ridge. The first is the theory of heat transfer from the juxtaposed oceanic crust (Bird, 2001). As oceanic spreading occurs at a shear margin, the neovolcanic zone will move along it. When this happens, heat may transfer from the mantle plume beneath the oceanic crust, forming a ridge along the shear margin (Figure 45). Examples of this have been described by Dale Bird (2001), as can be seen in Figure 44.

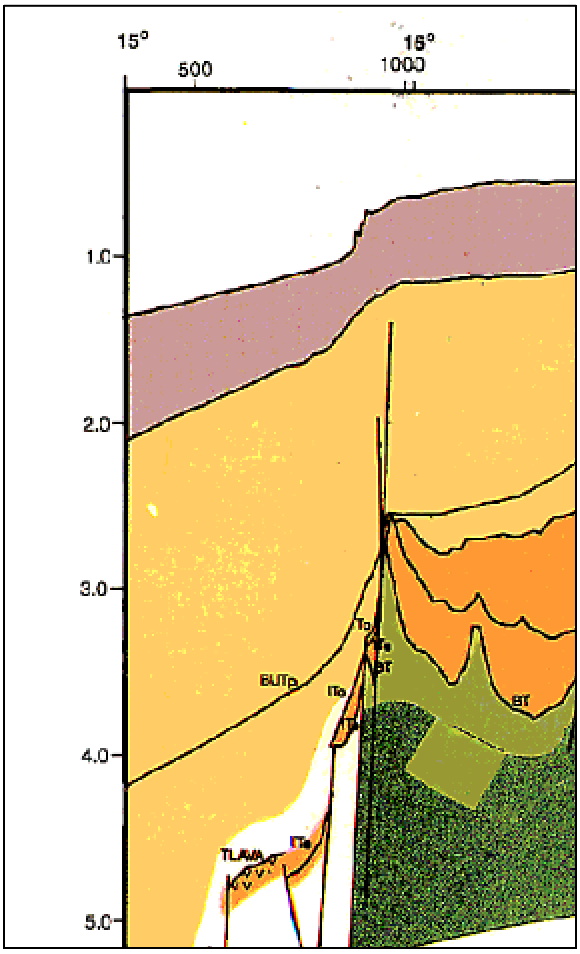

FIGURE 43: COB INTERPRETED IN NPD BULLETIN N.6. THE HIGH IS OBSERVED WITHIN THE CRETACEOUS LAYERS. MODIFIED FROM (GABRIELSEN ET AL., 1990).

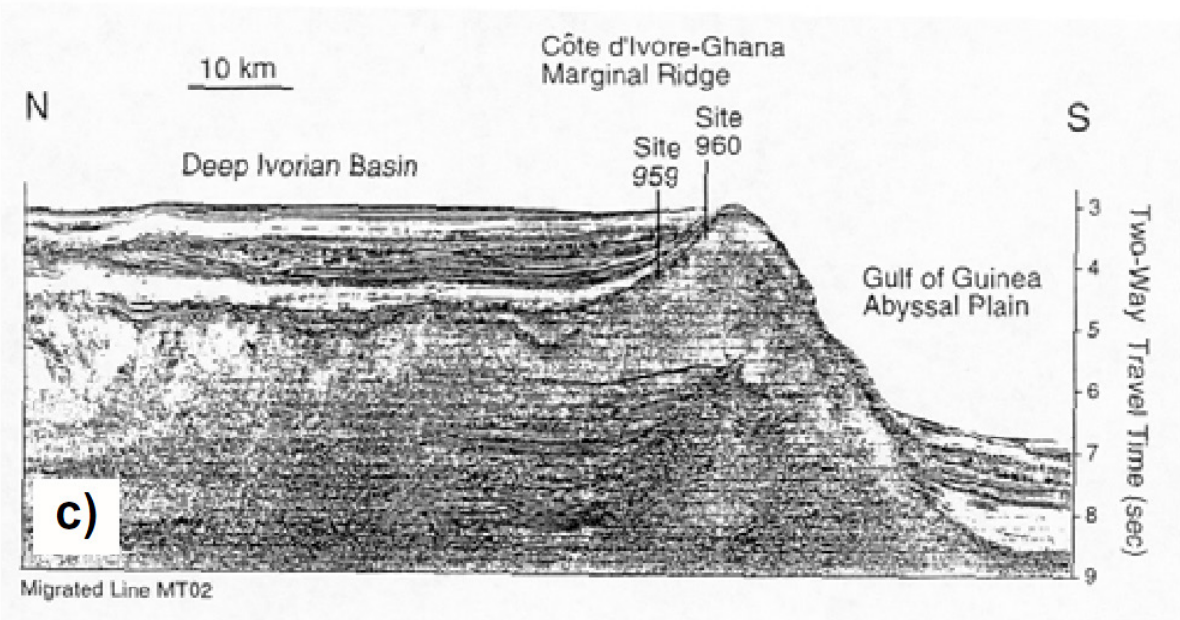

FIGURE 44: SEISMIC LINE OVER THE CÔTE D'IVOIRE-GHANA TRANSFORM MARGIN. THIS HIGH LOOKS SIMILAR TO THE ONE FOUND IN HB-2 AND HB-6. FROM BIRD (2001).

Figure 44 displays a similar looking high to the ones found in this report, especially the highs in HB-2 and HB-6. The difference is of course the low amounts of sediments in Figure 44 in comparison to the HB survey. This is good for the image quality and processing, and deep features are observable. Notice that the top of the high is about 5 kilometers wide, and the basal structure is about 25 km wide. This correlates well to the size of the highs found in this study. Figure 44 may compare to the setting in the Barents Sea before the glacial sediments deposited on top of a similar relief. Bird mentions that the shear margin setting is complex, and that constructional components cannot be ruled out (Bird, 2001).

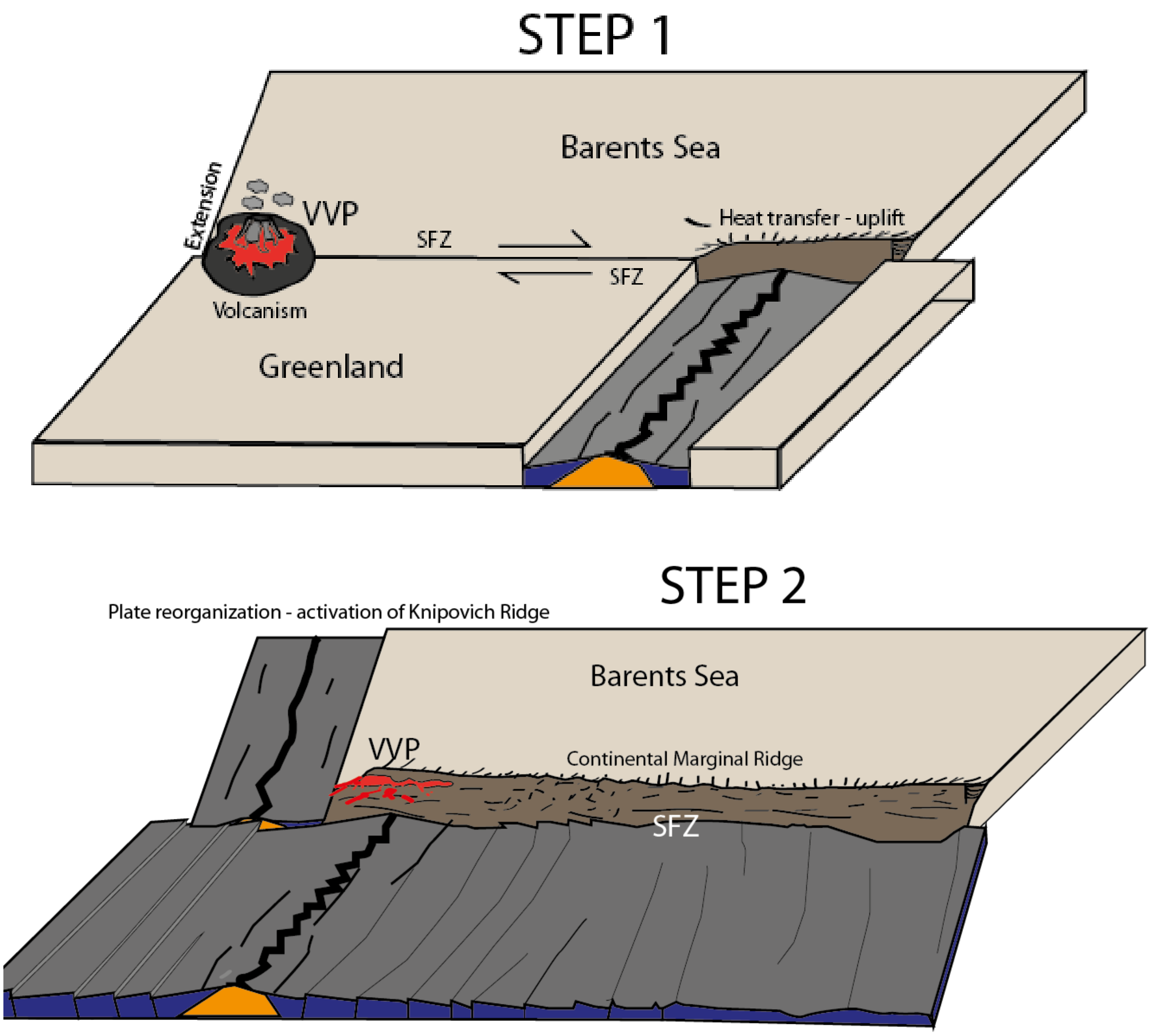

FIGURE 45: SEAFLOOR SPREADING ALONG THE SENJA MARGIN. A RIDGE ALONG THE SHEAR MARGIN IS FORMED BY HEAT TRANSFER FROM THE JUXTAPOSED OCEANIC CRUST. THE HEAT IS CENTERED AROUND THE NEOVOLCANIC ZONE.

This interpretation may explain the ridge formation, but it has several uncertainties. Firstly, uplift from heat will often subside as the crust cools, and not be stuck in place. It is hard to say if this has happened or not. The ridge may have been much higher at the time of the uplift. Secondly, the timing is not perfect. Formation of the ridge in VVP would have happened in Oligocene. Interpretation of the Miocene-Late Eocene (Sotbakken Gp) shows that this layer is terminating against the highs, but from the well data it is known that where the well is placed, most of this formation was deposited in Late Eocene. If this is the case further out, towards the Continental Marginal Ridge, the Late Eocene sediments should also be uplifted together with the layers inside the high. The amount of Miocene and Oligocene sediments in the outer part of the margin is hard to estimate from seismic interpretation, as the reflectivity of the internal reflections in this interval is not optimal. Bird (2001) also states that the marginal ridge is wider, about 50-100 kilometers, but this interval is very dependent on where the width is measured. The ridge interpreted in this report is 20-25 kilometers wide.

Another interpretation of this ridge is that has been created by volcanic activity in Eocene or Oligocene. Eocene volcanic flows are identified, proving volcanic activity, and the formation of the ridge may have been caused by the buildup of a volcano. The seismic signature of the ridge in HB-2 and HB-5 is quite similar to the volcanic highs in the oceanic crust, making this interpretation plausible. However, the high seen in HB-6 does not show a signature indicating a volcanic origin. Its signature has a low peak amplitude, indicating a low contrast between it and the overlying sediments. It does show masking of the deep reflections, but this may be caused by other factors than volcanic layers.

The CMR may also have been constructed by Oligocene volcanism, which has been described by Faleide et al.(1988), Jebsen (1998) and Libak et al. (2012), related to the tectonic activity in VVP in this period. Libak et al., 2012, argues that the Oligocene volcanism did not produce regional volcanic flows, but were centered close to the eruption centers. This may be an explanation of why the relief of the observed highs is steep, but does not fit with the interpretation of a continental ridge. As mentioned, Oligocene volcanism does not explain the high observed in HB-6.

The last reason worth to mention is friction between the crusts, leading to a friction and compression resulting in uplift of the continental layers. The shear movements in the transform fault along the SFZ would create stress on the surrounding layers, possibly creating this kind of high.

The distance between the seismic lines in this study is large, and there are uncertainties to the interpretation of a CMR. A denser grid of seismic lines would be preferable to make this interpretation.

Interpreted Map

The COB is mapped in Figure 46 as a red colored line. Interpretations made in this report are mapped as a solid line, and the dotted lines are interpretations based on the map by Libak et al., 2012 and NPD's factmap. The interpretation shows that the COB is almost linear in the area of study, in a NNW-SSE direction, and follows the edge of the VVP and Sørvestsnaget Basin, which matches the interpretation made by Libak et al. (2012).

The volcanic flows of the Vestbakken Volcanic Province are interpreted with a dark grey color. Again, solid lines represent interpretations from this report, and stippled lines are estimated from the work of Libak et al., 2012. Comparing the boundaries of the VVP, the interpretations in this study are confirming his interpretation.

In dark red, the Eocene volcano is interpreted to be located along the HB-3 line, and ending before the HB-2 line. This interpretation supports the location of the Eocene volcano by Libak et al. (2012) but as his study contains several 2D surveys and an ocean bottom seismic line, his interpretation may be more accurate.

The Continental Marginal Ridge is interpreted along the COB on the continental side in a light orange color. This interpretation embraces the whole width of the highs, from the beginning of the slopes on both sides. The part of the ridge lying in the VVP is capped by basaltic flows. This ridge is not mentioned or mapped by Libak et al. (2012).

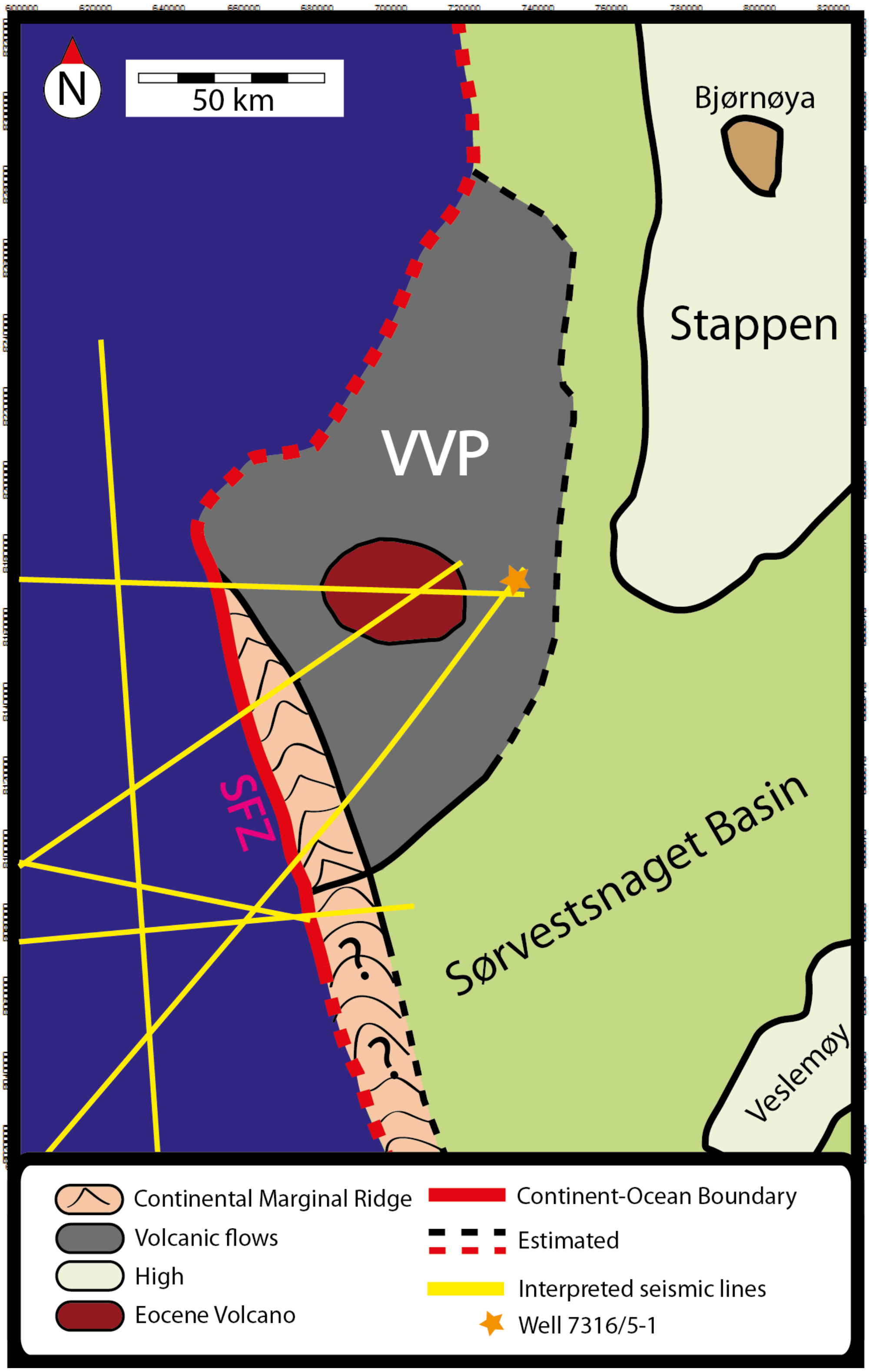

FIGURE 46: FINAL MAP INTERPRETATION OF THE COB IN THE HAVRETST BJØRNØYA VEST SURVEY. VVP: VESTBAKKEN VOLCANIC PROVICE. SFZ: SENJA FAULT ZONE.

6 CONCLUSION

In this study the multichannel seismic “Havretst Bjørnøya Vest” survey has been examined and interpreted in an attempt to locate the Continent-Ocean Boundary (COB), and identify seismic signatures associated it, in the passive continental margin in the southwestern Barents Sea. This has been conducted through a detailed seismic interpretation process divided into three stages: Observations, Interpretation and Discussion.

All the seismic lines depict the oceanic crust, and it can be tracked as far out as the Mohns Ridge. Its signature is characterized by a strong positive reflection with negative sidelobes, similar to the sea floor. Normal faults and volcanic highs have been found to be common features in the oceanic crust. The seismic reflections beneath the top oceanic crust are masked by the basalt, resulting in chaotic, low amplitude reflections resembling noise.

The oceanic crust is underlain by a several kilometers thick sequence of sediments. Most of these sediments were deposited during the Pleistocene-Pliocene glacial periods. This sequence is thinning landwards, where a larger part of the depositional space have been filled with sediments from Miocene – Late Eocene.

Beneath the sediments of Miocene – Late Eocene, on the continental crust, Early Eocene volcanic flows are observed in the Vestbakken Volcanic Province (VVP). The volcanic flows are characterized by a 50 - 400 ms thick sequence of high amplitude reflections, masking the underlying reflections. Mounds and highs are found in the volcanic layer, forming the basis for a large Eocene volcano as the origin of the flows. Highs are not as steep as the ones found in the oceanic crust. Study of the well 7316/5-1 shows intruded Cretaceous sediments beneath the volcanic extrusives, indicating that the lava erupted onto the continental crust. The basaltic flows are therefore interpreted as a continental feature.

Following the volcanic flows seaward, and the oceanic crust landward, leads to the transition between the crusts. Here, the geology is complex. Three of the lines show a high feature interpreted as a ridge following the COB along the shear margin setting of the Senja Margin. This ridge is interpreted as continental, and its western boundary marks the Continental-Ocean Boundary. The origin of this ridge may be explained by several theories, from heat transfer from the juxtaposed mantle plume beneath the spreading ridge, to volcanic activity. All the interpretations of how this ridge was generated have uncertainties.

The final result is six geoseismic models and a map of the area of study. This map is based on the interpretations in this report, and compared with the map by Libak et al. (2012). The interpretations corresponds, apart from the Continental Marginal Ridge, which is not described by him.

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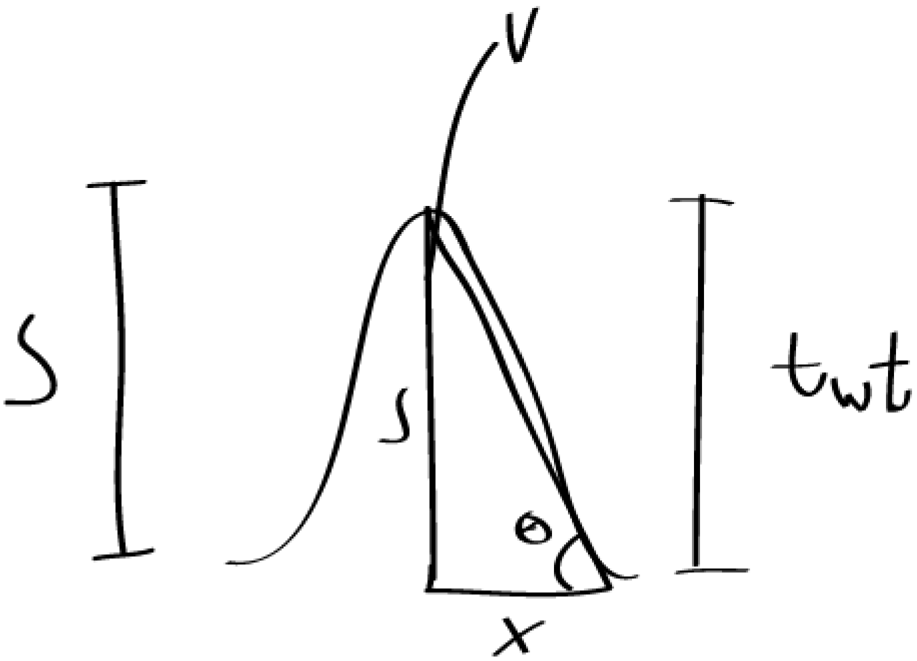
APPENDIX

Estimating the angle of the slope by using this technique.

S=height, twt= two way traveltime, v=velocity of layer, x=distance to the middle of the high, θ = approximate angle of slope.



$$S = \frac{1}{2} twt \cdot V$$

$$\theta \approx \tan^{-1}\left(\frac{S}{x}\right)$$