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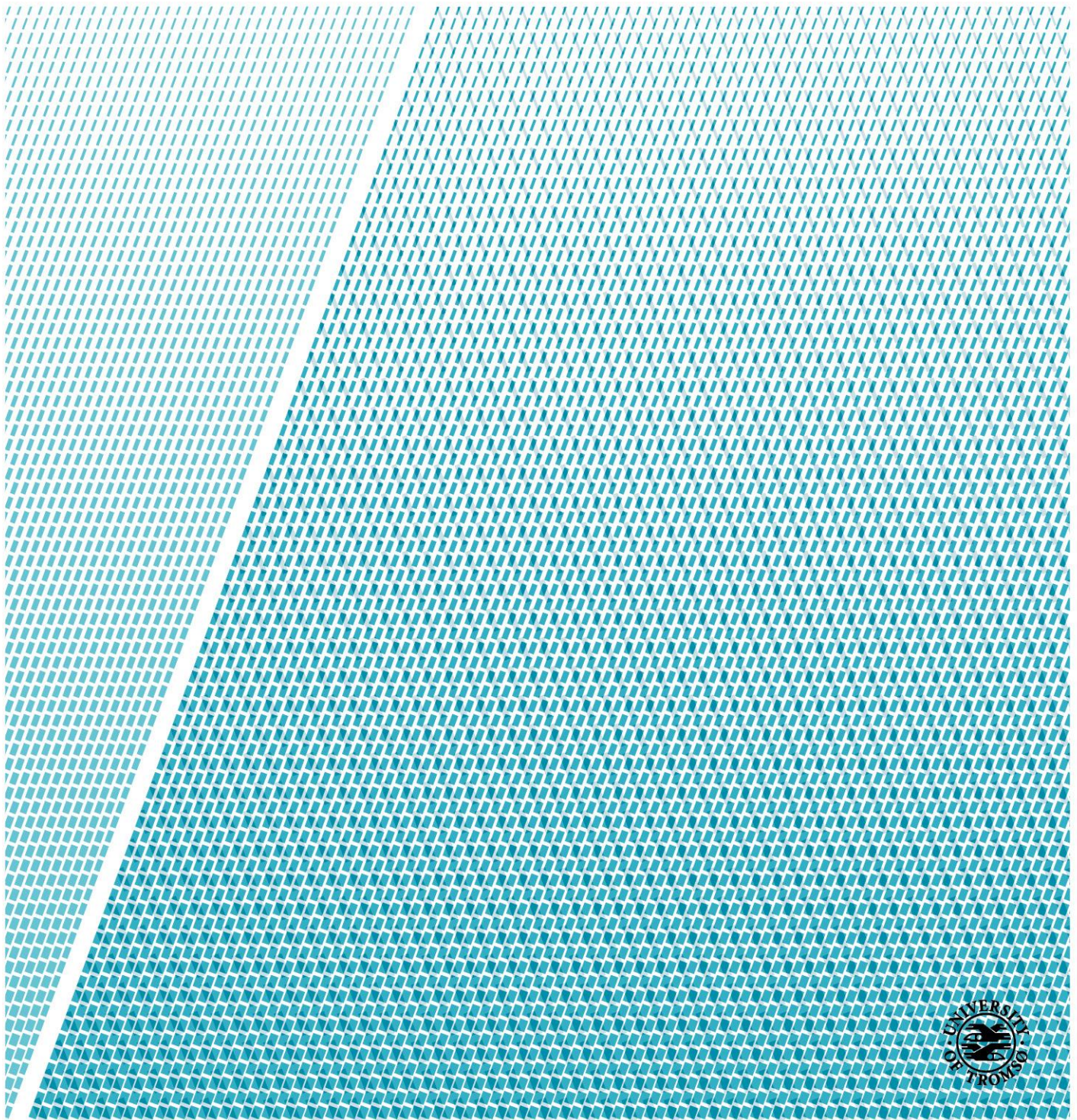
Department of Geosciences

The upper Paleozoic regional development of the Ottar basin from seismic 2D interpretation

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Abstract

The Ottar basin is not yet formally defined, but is a known structural element situated under the Bjarmeland Platform in the southwestern Barents Sea, buried beneath thick, flay-lying Mesozoic strata. This thesis focuses on delineating the informal upper Paleozoic Ottar basin. The delineation presented, is based on lateral/vertical variations in lithology and the surrounding tectonic setting of the Ottar basin. Several 2D seismic surveys were utilized and interpreted for this task, with the aid of well-ties from two wells penetrating the upper Paleozoic succession (7226/11-1 and 7124/3-1) located at the Norsel High and the Nysleppen Fault Complex, in close proximity to the Ottar basin.

The study includes three seismic units encompassing four different lithostratigraphic units of the upper Paleozoic succession (Billefjorden-, Gipsdalen-, Bjarmeland- and Tempelfjorden-Groups). An enclosed delineation and a geological development model of the Ottar basin has been proposed.

Acknowledgement

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1 Introduction

1.1 Objective

The Ottar Basin is usually regarded to be located underneath the Permian succession on the southern part of the Bjarmeland Platform, delineated by the Loppa High to the west and the Norsel High to the east, in the Barents Sea.

The main task is to identify and delineate the Ottar Basin as it is not to this day formally defined.

The overall goal will be to investigate the upper Paleozoic delineation of the basin and to link this in a larger tectonic setting. The Ottar Basin was formed during the Paleozoic era, consequently key tasks will be to identify and map groups of sediments from this era e.g. Billefjorden-, Gipsdalen-, Bjarmeland- and Tempelfjorden Groups. To achieve these goals, 2D seismic data will be used and interpreted. Published wells will be used to well-tie the sediment groups in near proximity to the Ottar Basin and use these ties as lead-horizons.

1.2 Study area

The water depths of the Barents Sea are generally less than 500m and is one of the Earth's largest continental shelves (Figure 1.1). It is located off of the northern coasts of Russia and Norway and is delineated by the eastern border of the Norwegian-Greenland Sea, the north Norwegian and Russian coasts and the Novaya Zemlya, Franz Josef Land and Svalbard archipelagos (Smelror et al., 2009) (Figure 1.1).

The Barents Sea is one of the least explored parts of the Norwegian offshore territory. The area was opened for drilling in 1980 by the Norwegian authorities and has since then had 144 exploration wells and 41 production wells drilled (NPD, 2018).

The process of delineating the Ottar basin includes utilizing: 2D seismic, surrounding structural geology, lateral/vertical lithology variations etc.



Figure 1.1 Overview bathymetric-map, position of study area indicated with a red square.

2 Geological background

2.1 Tectonic development

The Barents Sea is generally subdivided into two major geological provinces; the eastern part and the western part. The two provinces are distinguished by an extensive monclinal structure with an orientation north to south, located towards the central part of the Barents Sea. The western province of the Barents Sea was affected by major post-Caledonian rifting phases and also later periods of rifting, these tectonic events along with local and regional variations have established the geology of the western province we can observe today. These events combined also led to the continental break-up along the northwestern margin of the Eurasian plate. The eastern province has a different geologic history and has been primarily influenced by the complex tectonic regime of the Uralian Orogeny, the Timan-Pechora Basin and by the island Novaya Zemlya located at the western border of the Kara Sea.(Smelror et al., 2009)

As this thesis concentrates on the western province of the Barents Sea, the eastern province will not be further discussed.

It appears that old inherited structures are the controlling parameters of rifts and basins in the western Barents Sea when it comes to their internal architecture. There is also a correlation between the rifts and basins in this area when it comes to the crystalline thickness (Moho). Where there are deep basins, there is usually a thin crust beneath.(Smelror et al., 2009)

2.1.1 Paleozoic

The collision between the Laurentian and the Baltican plates resulted in the enormous Laurasian continent. The compressional regime at approximately 400Ma naturally brought the Caledonian orogeny to reach its climax and also resulted in the closing of the Iapetus Ocean. An extensional regime followed, resulting in structural trends with the dominant orientation varying between north-south in the western Barents Sea, while in the southwestern Barents Sea the dominant trend was northeast-southwest (Figure 2.1). In Devon and early Carboniferous the collapse of the Caledonian orogeny started to take place. (Smelror et al., 2009)

In the western Barents Sea, the Carboniferous period was generally dominated by a widespread intracratonic rifting (Figure 2.1). The long period of extension resulted in substantial rift structures in the area, which are recognizable in modern-day seismic as faulted structural relief at depth, which is then filled with sediments from syn-rift deposits (Faleide et al., 2015; Gudlaugsson et al., 1998).

This was the start of the Paleozoic-Mesozoic pre-opening rifting episodes that took place in the North Atlantic (Smelror et al., 2009).

The reorganization of tectonic plates started the slow mobilization of Svalbard towards its present day location. Moving from a humid tropical area, to a more arid climate. The climate alterations together with fluctuating sea-level changes due to deglaciation of the Gondwanan, resulted in carbonate and evaporite deposits on the platforms and the structural highs (Smelror et al., 2009; Worsley, 2008). The depositional areas includes the Ottar Basin, Tromsø Basin, Bjørnøya Basin and Nordkapp Basin (Smelror et al., 2009).

Structural elements that are present today due to the different rifting phases of this period are especially grabens and half-grabens that gave rise to the many different basins located in the south-western Barents Sea (Smelror et al., 2009).

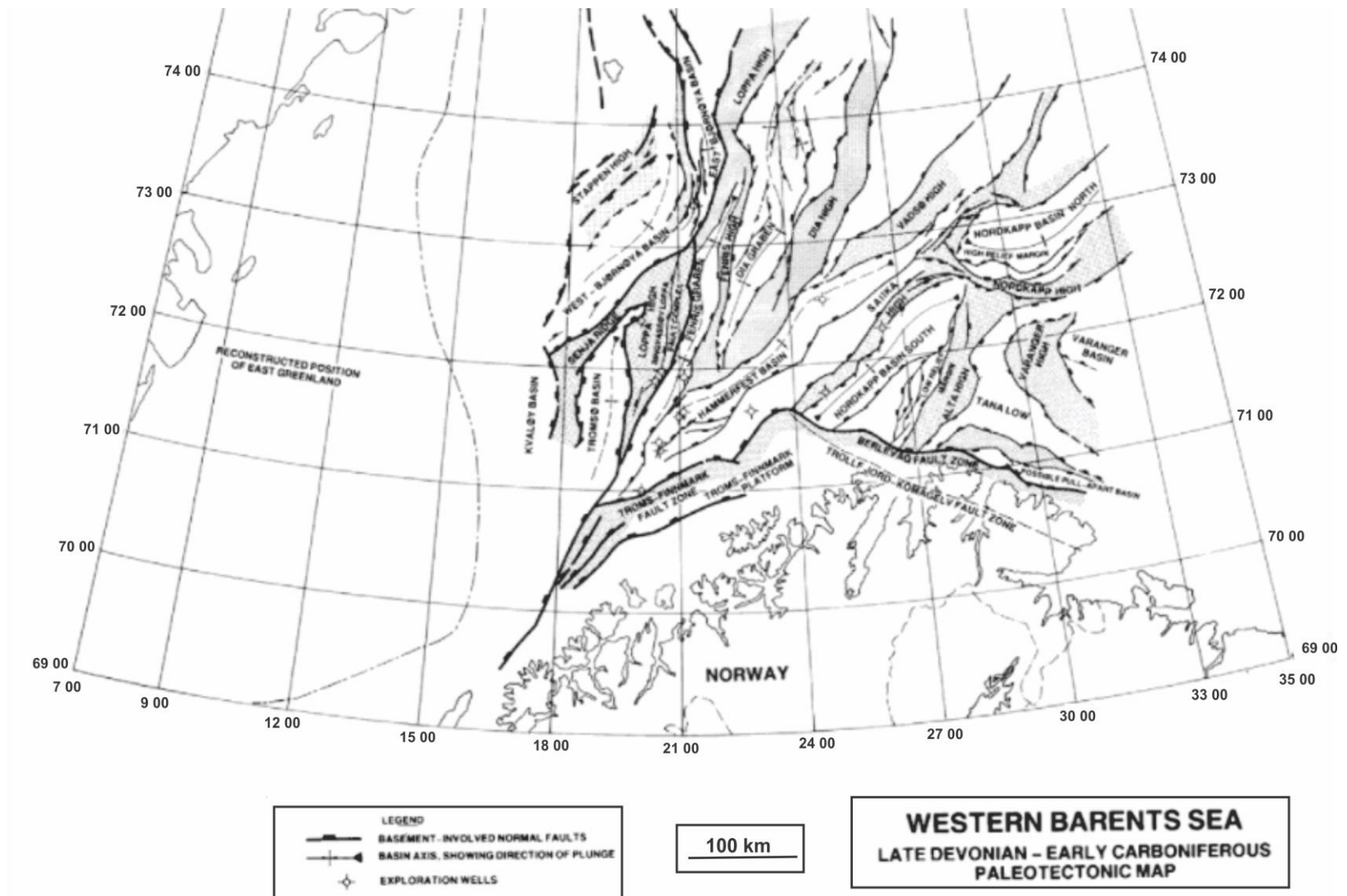


Figure 2.1 Late Devonian-Early Carboniferous paleo-tectonic map, areas in grey represent basement highs, adjacent to basins. Modified from Dengo and Røsland (1992)

2.1.2 Mesozoic

The Triassic period is generally characterized as a tectonic quiet regime compared to the latter era, with traces of some minor tectonic events (Glørstad-Clark et al., 2010). The Early Triassic is an exception, where a major rift episode occurred which is also recorded in the geology of numerous parts of the North Atlantic and the Arctic regions (Smelror et al., 2009). Throughout the Triassic era fluctuating cycles of transgressive and regressive events followed, generating sediments of marine, deltaic and continental clastic origin. The earlier deposited evaporites are alleged to have started its mobilization in the Nordkapp Basin at this time, and continued its movement towards Late Triassic times (Smelror et al., 2009).

Between Middle Triassic to earliest Jurassic time, gradual uplift of the northern, southern and eastern Barents Sea occurred. Consequently, widespread alluvial plains and coastal settings covered the western Barents Sea, accumulating clastic sediments from the Fennoscandian Shield. During Middle Triassic, fault initiation of the Barents Shelf appears to have been more substantial than the uplift and erosion processes. In Late Triassic the uplift of the eastern Barents Sea bordering the Kara Sea appears to have been the controlling factor of westward prograding coastal settings, reaching all the way to the Svalis Dome located in the Ottar Basin (Isaksen, 1995; Smelror et al., 2009).

During Middle Jurassic (Bajocian) there was an event of central uplift along with maximum regression, exposing large parts of the western Barents Sea causing it to be more susceptible to erosion. In Late Jurassic (Tithonian) an episode of maximum transgression took place. During the transgression, anoxic conditions could be found within basins and at local submarine barriers that were created by the tectonic events in the Cimmerian period (Smelror et al., 2009).

Further development of the many basins that are recognized on seismic in the southwestern Barents Sea (i.e. Bjørnøya, Harstad, Tromsø basins) occurred during late Middle Jurassic to Early Cretaceous (Figure 2.2). Widespread rifting re-activated old structural lineaments further subsiding the rift-basins, resulting in an increase of accommodation space (Glørstad-Clark et al., 2010).

For the duration of Middle Cretaceous (Albian) significant uplift of the northeastern Barents Sea took place, making it vulnerable to erosion. Considerable amounts of sediments were consequently transported and deposited into deeply subsiding basins to the west. The trend of uplift in the eastern province and subsidence along with deposition in the western province, continued into Late Cretaceous. There was also an incident of major rifting in Late Cretaceous, initiating continental break-up along the North Atlantic rift and followed up to the Amundsen Basin in the north. The outcome from this episode of rifting formed a dextral (eastern) stress field along the Senja-Hornsund lineament. The mega-fracture that was formed, worked as a relay zone between the spreading centers (Smelror et al., 2009).

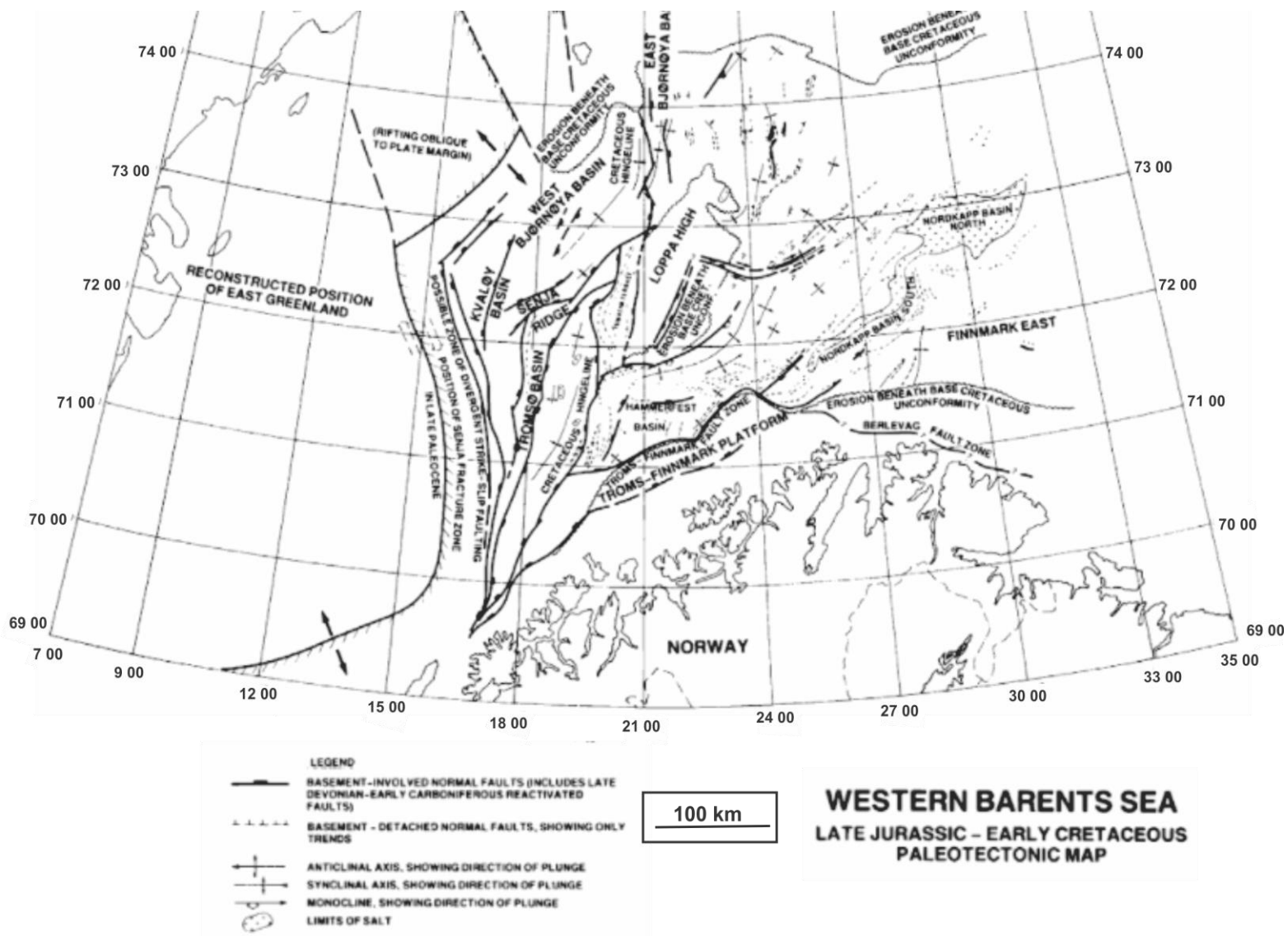


Figure 2.2 Late Jurassic-Early Cretaceous paleo-tectonic map. Modified from Dengo and Røsslund (1992)

2.1.3 Cenozoic

In Paleogene, the western province was under the effect of transtensional and transpressional tectonic forces. The forces worked along the earlier mentioned mega-fracture located on the western border of the Barents Sea. This resulted in the initial opening of the Norwegian-Greenland Sea which finished in Oligocene (Worsley, 2008).

The Neogene period is characterized by fluctuating isostasy due to glaciation on the entire shelf. Uplift during deglaciation followed by removal of various material (i.e. bound water, sediments) and vice versa for subsidence. Accumulation of eroded sediments were for the most part restricted to the western border of the Barents Sea, but also isolated basins. In addition, the Hammerfest Basin and the southwestern part of the Nordkapp Basin are parts of the Barents Sea that have been the least affected by the uplift (>2km). Platforms located north from the latter locations have experienced uplift up to 3km. The entire Barents Sea region have gone through extensive uplift and erosion and are very important factors to account for when it comes to present day petroleum exploration (Worsley, 2008).

2.2 Depositional environment and stratigraphy

In the western Barents Sea, deposits ranging from tropical/equatorial Late Paleozoic (420 Ma) sediments, to Quaternary (2Ma) glacial sediments can be found (Stemmerik & Worsley, 2005).

The objective of the thesis is to map out the Ottar Basin located in the western region of the Barents Sea. To do so, it is important to understand the depositional environments that took place in the various basins and areas surrounding the Ottar Basin. Understanding the stratigraphic units and depositional setting can function as a tool in order to distinguish an area from another.

2.2.1 Paleozoic

The basement in the western province of the Barents Sea is assumed to stem from the Caledonian orogeny. The collision between the two continents consolidated the basement rocks which formed the foundation of where the varied of sediments accumulated.

Throughout the Paleozoic era there are especially four lithostratigraphic groups that are easily distinguished. The lithostratigraphic groups represents a time of distinct depositional regimes, which culminates by changes in the climatic and tectonic conditions as well as sea-level changes (Larsen et al., 2005) (Figure 2.3). The change in conditions stem from the Gondwanan glaciation and deglaciation, and also the increased subsidence rates which related to the culmination of the Uralide orogeny (Stemmerik & Worsley, 2005).

2.2.1.1 Billefjorden Group (Latest Devon – Early Carboniferous):

In the late Devonian (Famennian) subtle deposition took place at the Barents Sea; including Bjørnøya, Spitsbergen and in the East Greenland. It is also assumed that the deeper basins with anoxic conditions were areas of deposition. The sediments that seemingly accumulated were of fluvial and lacustrine origin, but it was not yet large amounts (Figure 2.3). Extensive deposition occurred in the early Carboniferous (Viséan) and continued until middle Carboniferous (Serpukhovian). The western part of the Barents Sea was then a part of a large humid flood plain. The sediments deposited at this time are known as the “Billefjorden Group” and influence from marine is only seen in the topmost part of the group. The overall thickness of the Billefjorden Group varies from 400m on the Finnmark Platform and up to 2500m in the Billefjorden trough. Half-graben development continued in the western region which were also the features to characterize the area in the future (Worsley, 2008).

2.2.1.2 Gipsdalen Group and Bjarmeland Group (Middle Carboniferous – Middle Permian):

The transition to the Gipsdalen Group is represented by an unconformity between the Billefjorden Group and the Gipsdalen Group, this contact reflects a major regional uplift. A relative abrupt climatic shift did also take place, going from a humid and warm climate, to a warm but arid climate (Figure 2.3). This naturally altered the depositional patterns, accumulating shallow marine carbonates along with sabkha evaporites and local siliclastics. The deep and large basins were excellent sites for halite deposition, working as salt pans. Frequent sea-level fluctuations also affected the deposits, and had an association with the Gondwanan glaciation. Tectonics within the period reactivated the lineaments along the

earlier half-grabens further subsiding the Nordkapp and Tromsø basins (Worsley, 2008).

The Bjarmeland Group were deposited within the same period, overlying the Gipsdalen Group (Figure 2.3). The sediments were deposited during a major flooding event in the Early Permian (Sakmarian-Artinskian), which is assumed to mark the end of the Gondwanan glaciation. Frequent fluctuation of the sea-level were consequently not so common anymore. The transgressive event naturally, transformed the depositional setting from shallow warm waters, to deep cold waters, which consequently altered the composition of the carbonates which accumulated in the area. Temperature changes in the water also had a connection with changes in the circulation of the ocean currents (Worsley, 2008).

2.2.1.3 Tempelfjorden Group (Late Permian):

The Tempelfjorden Group consists of organic rich siliceous shale deposited under colder conditions than older/below lying stratigraphy (Figure 2.3). The colder conditions stemmed from the developing Uralian Orogeny causing cold-water upwelling due to oceanic circulation patterns shifting. An increase of subsidence and sedimentation rates were an additional effect of the progressively culminating Uralian Orogeny (Worsley, 2008).

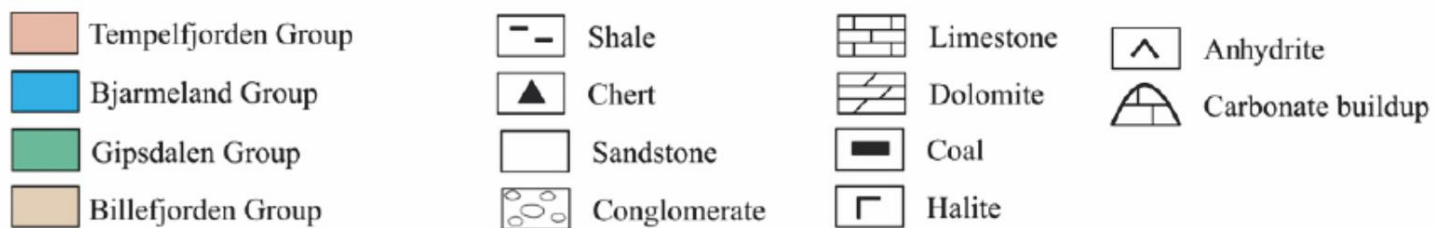
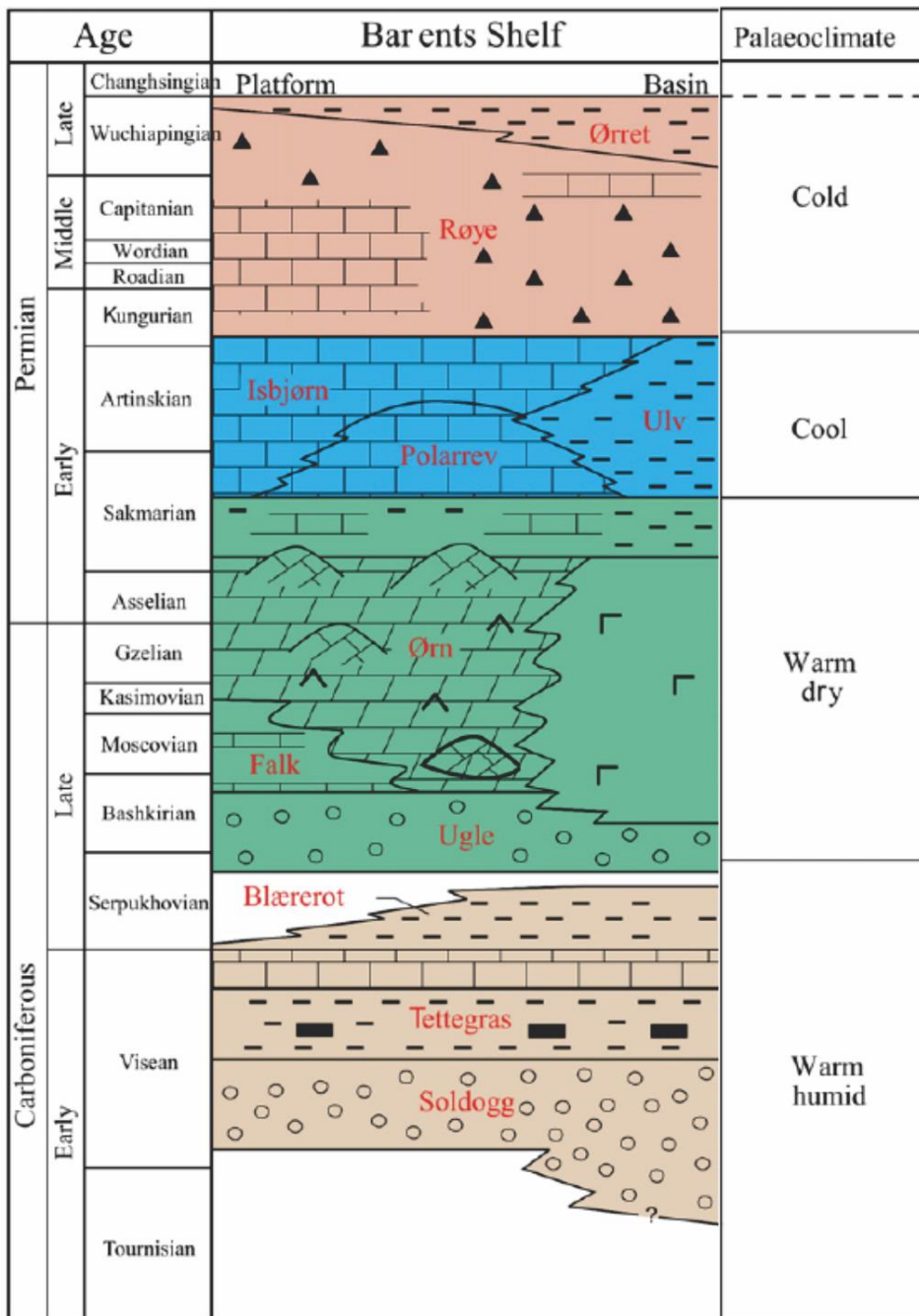


Figure 2.3 Lithostratigraphic chart summarizing general trends of age, groups, formations and climate from the Barents Sea during the Paleozoic era.. From (Larssen et al., 2005; Rafaelsen et al., 2008)

2.2.2 Mesozoic

A strongly contrasting deposit from the underlying siliceous shale (Tempelfjorden Group) marks the shift to Triassic times. Shales and mudstones deposited at this time had no siliceous content, but still organic rich. Triassic had a general transgressive trend; rise of sea-level, interrupted by repeated costal progradation. Thicknesses of sediments up to 1500m were deposited in the south-western Barents Sea, along with high rates of sedimentation, subsidence rates followed the same pattern (Glørstad-Clark et al., 2010; Worsley, 2008).

Late Triassic to Late Jurassic was a depositional phase with several sandstone units, many of them containing high organic content, giving rise to possible hydrocarbon potential. During Middle Jurassic there was an episode of regional transgression, the increase in sea-level gave rise to organic-rich shale deposits, especially in the Late Jurassic succession (Worsley, 2008). A change in depositional environment occurred at the Jurassic/Cretaceous boundary, where a regional regression took place. A more open marine environment with better circulation was established. This meant worse anoxic conditions, except for some basinal areas. Some of the sandstone fans that were deposited under higher sea-level settings prograded into adjacent basins. The overall depositional trends of the Cretaceous period are; thick shales with some of the intermissions being enriched with organic content in the basinal areas, while the platform successions are more influenced by carbonate-deposits.

From Middle Cretaceous until Paleocene (Early Cenozoic era) a significant uplift of the region took place, resulting in a hiatus of deposition in most areas. However some of the westernmost basins of the Barents Sea region still received sediments from the east with thickness of the claystone/limestone sequence increasing towards the west (Tromsø Basin; 1200m, Hammerfest Basin; 50-250m) (Worsley, 2008).

2.2.3 Cenozoic

The Paleogene was a period dominated by transpression and transtension, these tectonic events were restricted to the western margin resulting in the opening of the Norwegian-Greenland Sea (Worsley, 2008). The final opening of the Norwegian-Greenland Sea in the

Early Oligocene had significant effect on the sedimentation rates and also the structural regime on the southwestern Barents Sea (Ostanin et al., 2013). In the Cenozoic era there were especially three episodes of uplift (Paleocene 60-55 Ma, Late Eocene 36-35Ma and Late Miocene 7-5Ma), revealing large parts of the shelf, and causing the exposed land-parts to be susceptible to erosion (Ostanin et al., 2013). Prograding clinoforms are evidently some of the depositional structures related to the uplifted local highs.

Sediments from the Neogene period are absent in the southwestern Barents Sea due to uplift in the Miocene, resulting in removal of up to 1000m of sediments.

The Pliocene-Pleistocene period was dominated by large ice sheets covering large parts of the Barents Sea. Numerous MSGLs (Mega-Scale Glacial Lineations) are evidently mapped out on the seafloor, and can often be seen on any seismic line from the region (Ostanin et al., 2013). The estimated removal of sediments by erosion are on average 1000 meters and was caused by glaciers and fast flowing ice streams, large parts of these sediments have been transported to the western region of the Barents Sea; more precisely the Bear Island trough-mouth fan (Ostanin et al., 2013).

2.3 Structural setting

The Ottar basin is located between several structural elements, in the following a description of the relevant surrounding elements and their development will be presented, relevant due to time the elements were tectonically active (Figure 2.4).

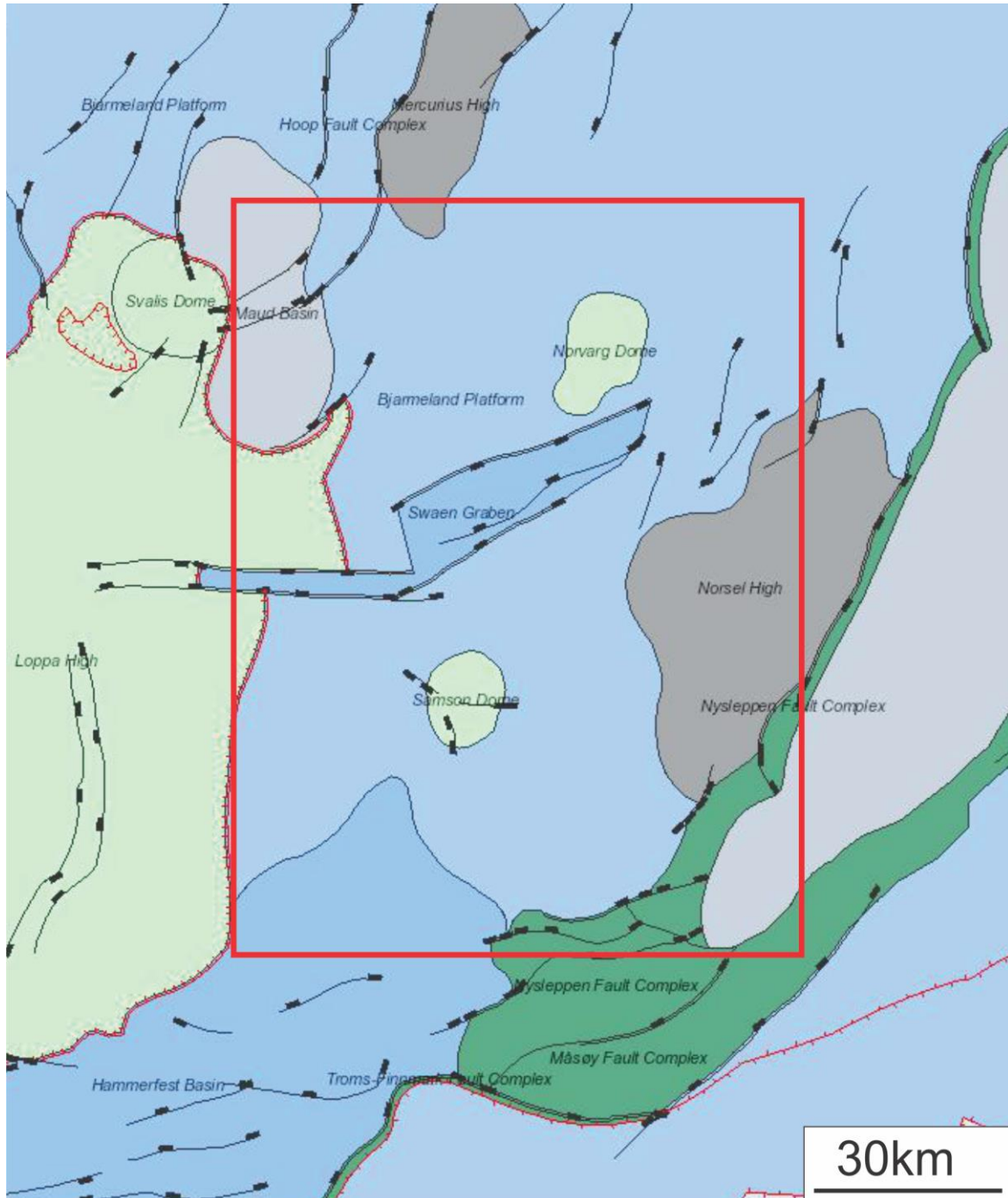


Figure 2.4 Overview map of the structural setting surrounding the Ottar basin. The Ottar basin is located approximately within the red square.

2.3.1 Bjarmeland Platform

The Bjarmeland Platform covers a large area in the Barents Sea and represents a relatively stable tectonic platform since Late Paleozoic. The platform includes the Mercurius High, the Norvarg Dome, the Samson Dome and the Norsel High and was developed during Late Carboniferous. The Ottar basin, which is not heavily affected by halokinesis is located underneath this stable platform and can be distinguished by the carbonate boundary (Gabrielsen et al., 1990).

2.3.2 Norsel High

The Norsel High follows a northeast-southwest lineation and is connected to the Nordkapp Basin and the Nysleppen Fault Complex to the east, and the Bjarmeland Platform to the West. Towards the north and the west the boundaries are characterized by faults and flexures. The high stems from Early Carboniferous tectonics and was probably developed during the adjacent Nordkapp Basins rifting and subsidence (Gabrielsen et al., 1990).

2.3.3 Loppa High

The Loppa High is situated north from the Hammerfest Basin separated by the Asterias Fault Complex. Loppa High's outline has a diamond-shape and is delineated within these coordinates; 71°50'N, 20°E, 71°55'N 22°40'E , 72°55'N, 24°10'E and 73°20'N, 23°E. To the east the Loppa High borders the Bjarmeland Platform. The northeastern limit of the high is the Maud Basin, which lies northwest of the large salt structure; Nordvarg Dome (Gabrielsen et al., 1990).

The Loppa High has been formed by repeated uplift, the latest tectonic events took place in Cretaceous-Tertiary (Gabrielsen et al., 1990).

2.3.4 Nordkapp Basin

The Nordkapp Basin is of great extent and has its origin stemming from the Paleozoic era and has similar basin dimensions as the Ottar basin (Breivik et al., 1995). Surrounding the basin there are platforms with slightly dipping strata. The basin contains large volumes of evaporites and layers above has been comprehensively affected by the mobilization of these,

the process is called halokinesis. The extensive salt diapirism of the basin has made it hard to reconstruct the original setting of the basin, as subsidence and reactivation of faults has occurred several times. The basin is delineated within the coordinates: 71°30'N, 25°E and 73°30', 34°E (Gabrielsen et al., 1990).

2.3.5 Hammerfest Basin

The Hammerfest Basin is a relatively shallow basin, with an axis striking from east-northeast to west-southwest. The Hammerfest Basin is generally subdivided into 2 parts; a western and an eastern part due to the effects tectonic have had on the basin. Whereas the northeastern boundary of the basin borders to the Bjarmeland Platform and the Nysleppen Fault Complex. Within the Hammerfest Basin the depth to basement is estimated to be 6-7 km. Structural predecessors with similar strike orientation can be traced back to Late Devonian to Early Carboniferous times. This understanding is supported with the separation of the Hammerfest Basin from the Finnmark Platform, which occurred in the Late Carboniferous. The basin is delineated within these coordinates; 70°50'N, 20°E, 71°15'N, 20°E, 72°15'N, 23°15'E and 71°40'N, 24°10'E. (Gabrielsen et al., 1990)

2.3.6 Mercurius High

The Mercurius High is a structural element situated on the eastern border of the Hoop Fault Complex, the exact position is within; 73°15', and 73°45'N, and 24°40' and 26°05'E. The high has a north-northeast to south-southwest orientation, visible in seismic at Carboniferous – Permian levels. The structure is regarded as a positive element related to Early Carboniferous tectonism(Gabrielsen et al., 1990).

2.3.7 Nysleppen Fault Complex

The Nysleppen Fault Complex is a large structure that divides the Bjarmeland Platform from the Nordkapp Basin and is of Early Carboniferous origin. The fault complex is located within 71°45'N, 24°E and 73°05'N, 29°E and surrounds the western boundary of the Nordkapp Basin entirely. The Nysleppen Fault Complex is a zone that consists of numerous fault sets, which increases in complexity northwards (Gabrielsen et al., 1990).

3 Data and method

3.1 Seismic surveys and well data.

In this study 28 seismic datasets have been applied (Table 3.1). The data was provided by the Norwegian Petroleum Directorate (NPD). All of the data used in this thesis are open to the public, due to the extraordinary transparency of the Norwegian model of handling petroleum resources. The seismic 2-D lines creates a resolution of approximately 5x5km in good areas, the more remote areas has a coverage of approximately 10x10km (Figure 3.1).

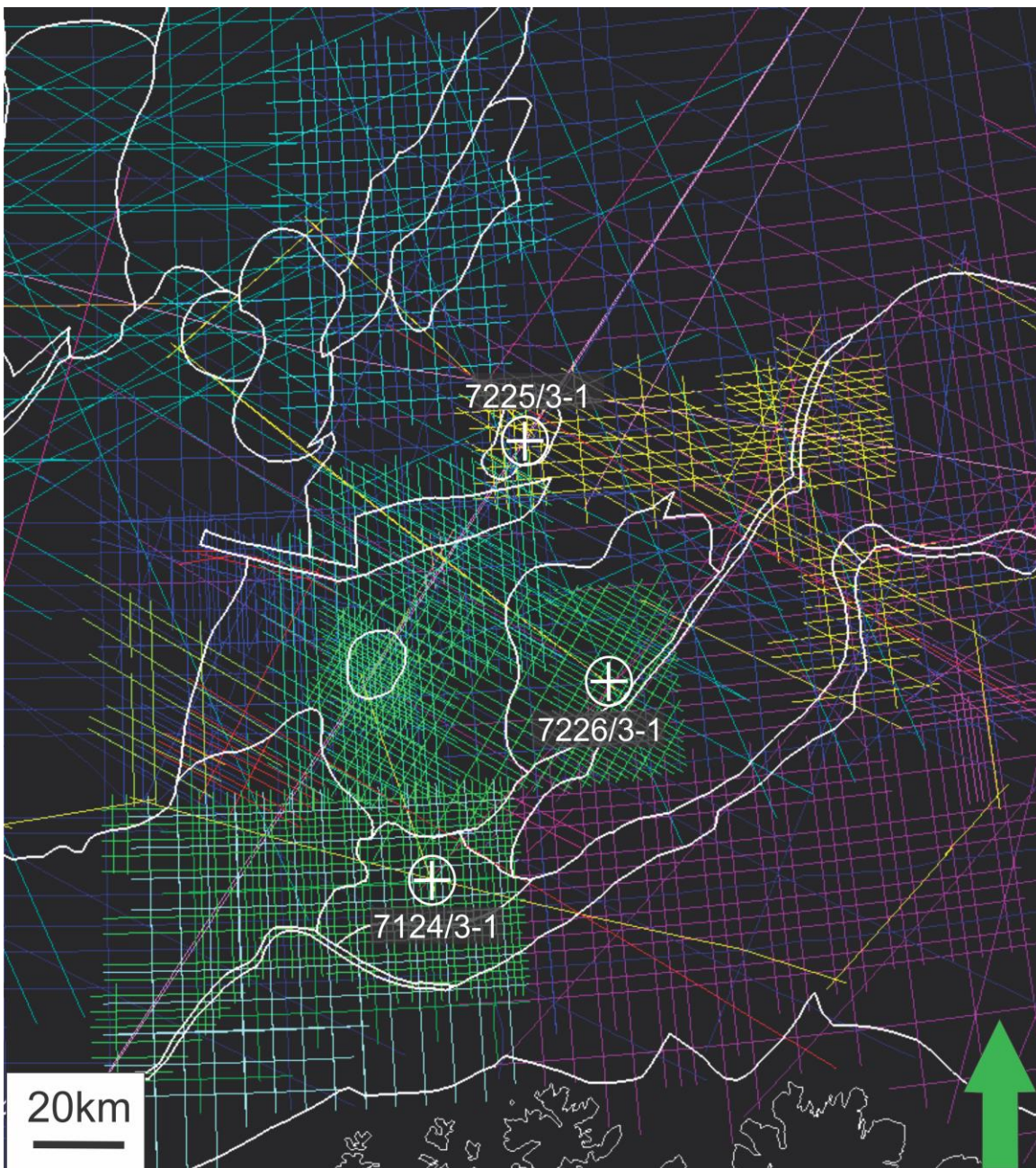


Figure 3.1 Seismic line coverage of the study area, one color indicates one seismic survey. Well locations are included

Table 3.1 2D seismic surveys used in this thesis. Dataset received by the Norwegian Petroleum Directorate (NPD).

Survey name	Number of lines	Polarity	Company – responsible	Year
AN88-9Q6-1	16	SEG-Reverse	Amoco Norway Oil Company	1988
AN88-9Q6-4	35	SEG-Normal	Amoco Norway Oil Company	1988
BARE02	124	SEG-Normal	Fugro-Geoteam AS	2002
BARE05	150	SEG-Normal	Fugro-Geoteam AS	2005
EL-8703	43	? SEG Normal	Elf Petroleum Norge AS	1987
FWGS-84	59	SEG-Normal	Statoil ASA	1984
GLR2-86			WesternGeco AS	1986
GNB-87	95	SEG-Normal	WesternGeco AS	1987
IKU-84	5	SEG-Normal		1984
IKU-85	6	SEG-Normal	???	1985
MN87-4	4	SEG-Normal	Mobil Exploration Norway INC	1987
MN89-1	5	SEG-Normal	Mobil Exploration Norway INC	1989
NBR06	20	SEG-Normal	Fugro-Geoteam AS	2006
NH9806	4	SEG-Normal	Norsk Hydro Produksjon AS	1998
NH8413	4	SEG-Reverse	Norsk Hydro Produksjon AS	1984
NH8707	14	SEG-Normal	Norsk Hydro Produksjon AS	1987
NPD-BA-79			Oljedirektoratet (NPD)	1979
NPD-BJRE-84	36	SEG-Normal	Oljedirektoratet (NPD)	1984
NPD-FI-83	11	SEG-Reverse	Oljedirektoratet (NPD)	1983
NPD-FI-84	24	SEG-Reverse	Oljedirektoratet (NPD)	1984
NPD-NOLO-85	91	SEG-Normal	Oljedirektoratet (NPD)	1985
SBL-86	74	SEG-Normal	WesternGeco AS	1986
SG8737	13	SEG-Normal	Saga Petroleum ASA	1987
SG8837	11	SEG-Normal	Saga Petroleum ASA	1988

SG9715	11	SEG-Normal	Saga Petroleum ASA	1997
SH8604	1	SEG-Reverse	Shell Norge A/S	1986
ST8611	65	SEG-Reverse	Statoil ASA	1986
ST8813	11	SEG-Normal	Statoil ASA	1988

Well data used in this thesis are summarized in Table 3.2. The well data contributes to the 2D-seismic and assists to give correct lead-horizons for specific formations in the subsurface. Well 7124/3-1 is located in the southeastern part of the study area located on the Nysleppen Fault Complex (Figure 3.1). The well tops were given slight adjustments to match the corresponding horizons (Figure 4.1).

Well 7226/11-1 is located in the eastern part of the study area situated on the Norsel High, on the western side of the Nordkapp Basin (Figure 3.1). The well tops were given slight adjustments to match the corresponding horizons (Figure 4.2). Both of the wells are located on structural highs close to the Ottar basin margin.

Well 7225/3-1 with corresponding well tops was inserted to Petrel manually, the well is located in northern part of the study area, in the Nordvarg Dome (Figure 3.1). This was done so that the interpreted horizons would be more precise, however the two wells (7124/3-1 and 7226/11-1) mentioned above was the main wells that were used in this thesis. The oldest penetrated formation of the 7225/3-1 well was; Isbjørn Formation (Permian), information and data was retrieved from (NPD).

Table 3.2 Well-data used in the thesis to interpret lead-horizons. Well-data received from the Norwegian Petroleum Directorate (NPD).

Well number:	Well location:	Drilled by:	Year drilled and duration:	Oldest penetrated age/ formation:	Total depth (MD)	Final vertical depth (TVD)
7226/11-1	Norsel High	Statoil ASA	1987-1988 (173 days)	Pre-Devonian/Basement	5200,0m	5200,0m
7124/3-1	Nysleppen Fault Complex	Saga Petroleum ASA	1987 (144 days)	Late Carboniferous/Ørn Formation	4730,0m	4727,0m

3.2 Reflection seismology theory

Reflection seismology is a basic technique used to explore and map the subsurface and is the most important tool to do so. It involves generating seismic waves with an artificial source (e.g. water gun, explosion, sledgehammer etc.) which propagates through a medium followed by observing the arrival time of the reflected waves created by the interfaces in the underlying rocks. The interface between the rocks where the wave scatters, is created due to the difference in their acoustic properties; density and internal velocity (Equation 3.1) (Badley, 1985).

$$Z = \rho * v$$

Equation 3.1: The acoustic impedance, Z , of any layer in the subsurface is defined as its density $=\rho$ (kg/m³) multiplied by its internal velocity $=v$ (m/s).

If there is sufficient contrast between two layers the acoustic sound waves will be reflected and propagate in a different direction than its primary direction. This contrast or reflection strength can similarly be calculated (Equation 3.2) and is generally called the reflection coefficient and is measured at the boundary of two contrasting mediums (Badley, 1985).

$$R = \frac{(Z_2 - Z_1)}{(Z_2 + Z_1)} = \frac{(\rho_2 * v_2) - (\rho_1 * v_1)}{(\rho_2 * v_2) + (\rho_1 * v_1)}$$

Equation 3.2: The reflection strength at a boundary is given by the difference in acoustic impedance between the two layers. Z_1 , ρ_1 and v_1 are respectively acoustic impedance, density and velocity in the upper layer whereas Z_2 , ρ_2 and v_2 are respectively acoustic impedance, density and velocity in the underlying layer (Badley, 1985).

The R, reflection coefficient tells us about the properties of the boundary between the overlying- and underlying –layer. When describing this phenomenon a different term is usually applied; polarity. In Table 3.1 the polarity of the 2D seismic used in this thesis is presented. Red is usually positive, R (peak) and blue is usually negative R, (troughs), which is called SEG-normal polarity. If the situation is reversed, e.g. red is negative R, (trough) and blue is positive R, (peak) it is called SEG-reversed polarity and can be changed by the interpreter in Petrel. An example is given below where the acoustic impedance increases from layer Z_1 to Z_2 (Badley, 1985) (Figure 3.2).

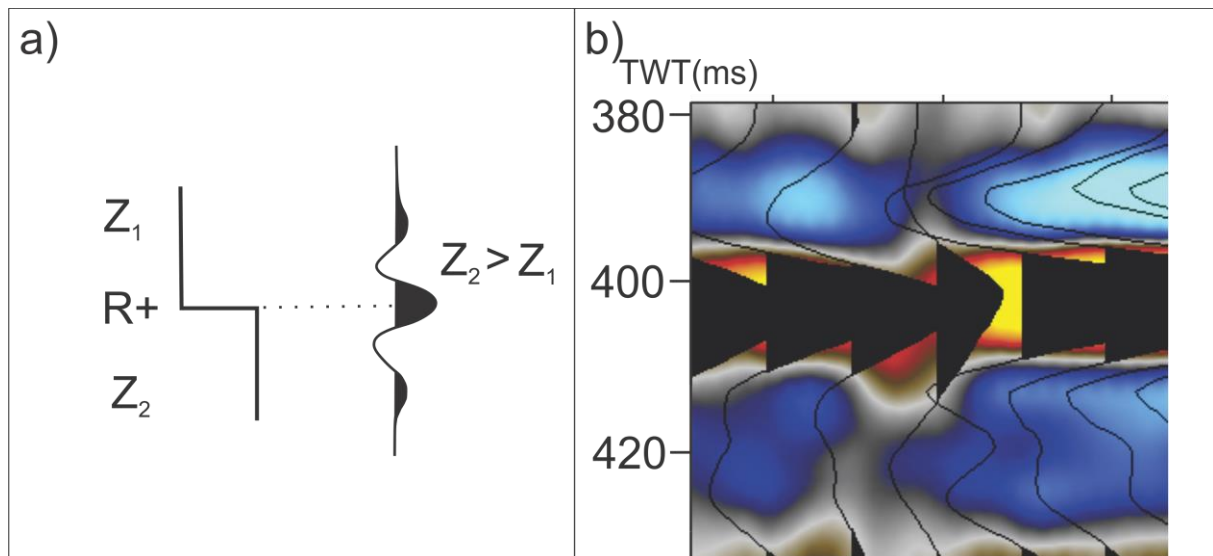


Figure 3.2 a) Theoretical illustration of Sheriff's polarity convention (zero phase signal; peak exactly at boundary) b) displaying seismic example of a seafloor reflection where the reflection coefficient is positive (red/yellow), resulting in a peak. TWT = Two-Way-Time. Figure modified from (Sheriff, 1985)

3.3 Seismic resolution

The seismic resolution is the limit where one can extract stratigraphic detail from the seismic data. Any boundary where the contrast in acoustic impedance is great enough has the potential to create a seismic reflection, however it is dependent on the seismic acquisition

equipment and the post-processing system applied. The best resolution is acquired by shooting 3D seismic, but is far more expensive than 2D seismic (Sheriff, 1985).

Seismic resolution is usually subdivided into two aspects, horizontal and vertical resolution. The ability to vertically separate reflecting interfaces is regarded as the vertical resolution. Horizontal resolution is the ability of separating between structures that are displaced horizontally with respect to each other.

Both of the aspects are dependent on the seismic wavelength, which increases with depth due to the changes in frequency and velocity, shown in Equation 3.3 (Sheriff, 1985)

$$\lambda = \frac{v}{f}$$

Equation 3.3: Showing the relationship between wavelength; λ (m) which is given by dividing the velocity; v (m/s) with the frequency; f (Hz)

The wavelength increases with increasing depth, this is due to the lower frequencies that appears and is a result of faster attenuation of the higher frequencies along with the increasing velocity due to higher rates of compaction at increasing depths (Brown, 1999) (Figure 3.3).

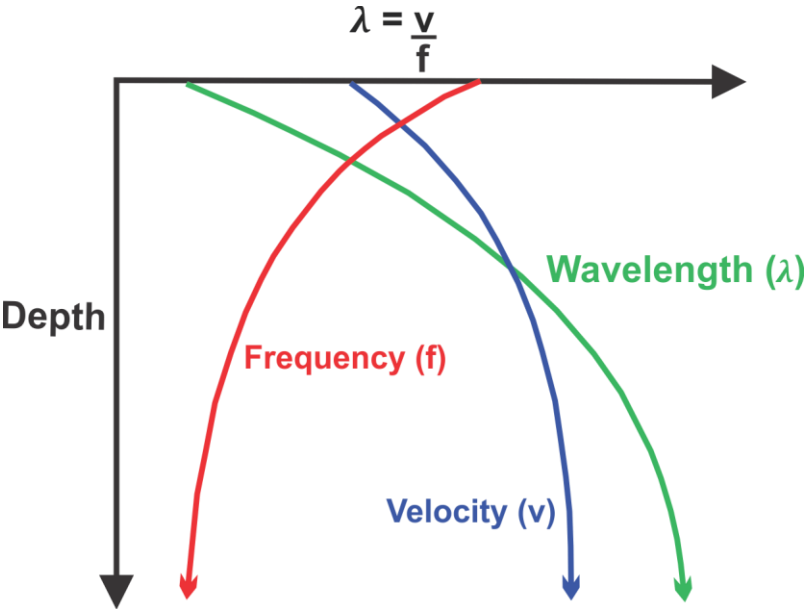


Figure 3.3 Graph showing the significant increase in wavelength as the waves propagates deeper into the subsurface, resulting in poorer resolution. Figure modified from Brown (1999)

3.3.1 Vertical resolution

The vertical resolution provides information about to what extent two reflecting interfaces with close proximity, can be distinguished and is given by Equation 3.4 (Brown, 1999; Sheriff, 1985). Vertical resolution of two selected horizons was calculated using the equations above for the dataset NBR06, necessary data was extracted from Petrel in close proximity of well 7226/11-1 for a more accurate resolution (Table 3.3).

$$R_V = \frac{\lambda}{4}$$

Equation 3.4: The vertical resolution; R_V (m) is given by the quarter of the wavelength; λ (m) and defines the limit of separability (Brown, 1999).

Table 3.3 Vertical resolution of a two selected horizons. Velocity was found from well 7226/11-1.

Dataset:	Horizon	Velocity (m/s)	Frequency (Hz)	Wavelength (λ)	Vertical Resolution
NBR06	Top Røye	4300 m/s	17Hz	253m	63m
NBR06	Top Ørn	3900 m/s	14 Hz	279m	69m

3.3.2 Horizontal resolution

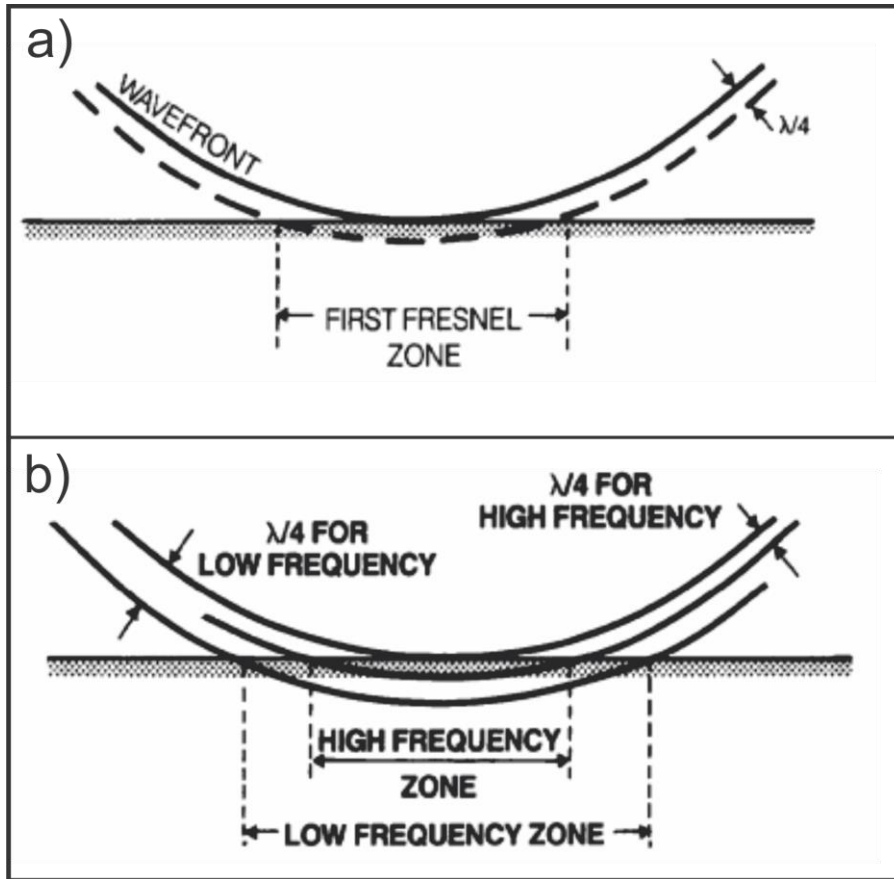


Figure 3.4: a) Illustrates the first Fresnel zone, which is a result of constructive interference of the reflected energy b) An illustration showing the importance of the frequency or indirectly; wavelength. Figure modified from Sheriff (1985)

The first Fresnel zone is the area from which the reflected energy reaches the detector within a half cycle, so that the interference would be constructive, instead of destructive which defines the limit of visibility (Figure 3.4) (Brown, 1999; Sheriff, 1985). To enhance the seismic imaging of the subsurface, migration of the seismic dataset is performed. The process of migration, aims to put the features in the subsurface to its proper position. The procedure can improve the S/N-ratio (signal-to-noise) dramatically (Brown, 1999).

For an unmigrated seismic section the Fresnel zone is given as in Equation 3.5.

$$r_F = \frac{v}{2} \sqrt{\frac{t}{f}}$$

Equation 3.5: Formula to find the Fresnel zone on an unmigrated seismic section where r_F ; radius of Fresnel zone (m), v ; average velocity of layer (m/s), t ; two-way-time (ms), f ; dominant frequency (Hz).

For a migrated seismic section the formula is much simpler; Equation 3.6 which is similar to Equation 3.4 used for calculating the vertical resolution. Migration can only be done along the seismic line for 2D seismic, whereas for 3D seismic, the process can be done in all directions collapsing the Fresnel zone significantly. The 2D seismic line and its corresponding Fresnel zone will be reduced to an ellipse, perpendicular to the seismic line. For the 3D seismic the entire Fresnel zone collapses to a much smaller circle (Brown, 1999) (Figure 3.5).

$$R_H = \frac{\lambda}{4}$$

Equation 3.6: The horizontal resolution; R_H (m) is given by the quarter of the wavelength; λ (m) on a migrated seismic section.

Horizontal resolution of two selected horizons was calculated using the equations above for the dataset NBR06, necessary data was extracted from Petrel in close proximity of well 7226/11-1 for a more accurate resolution (Table 3.4).

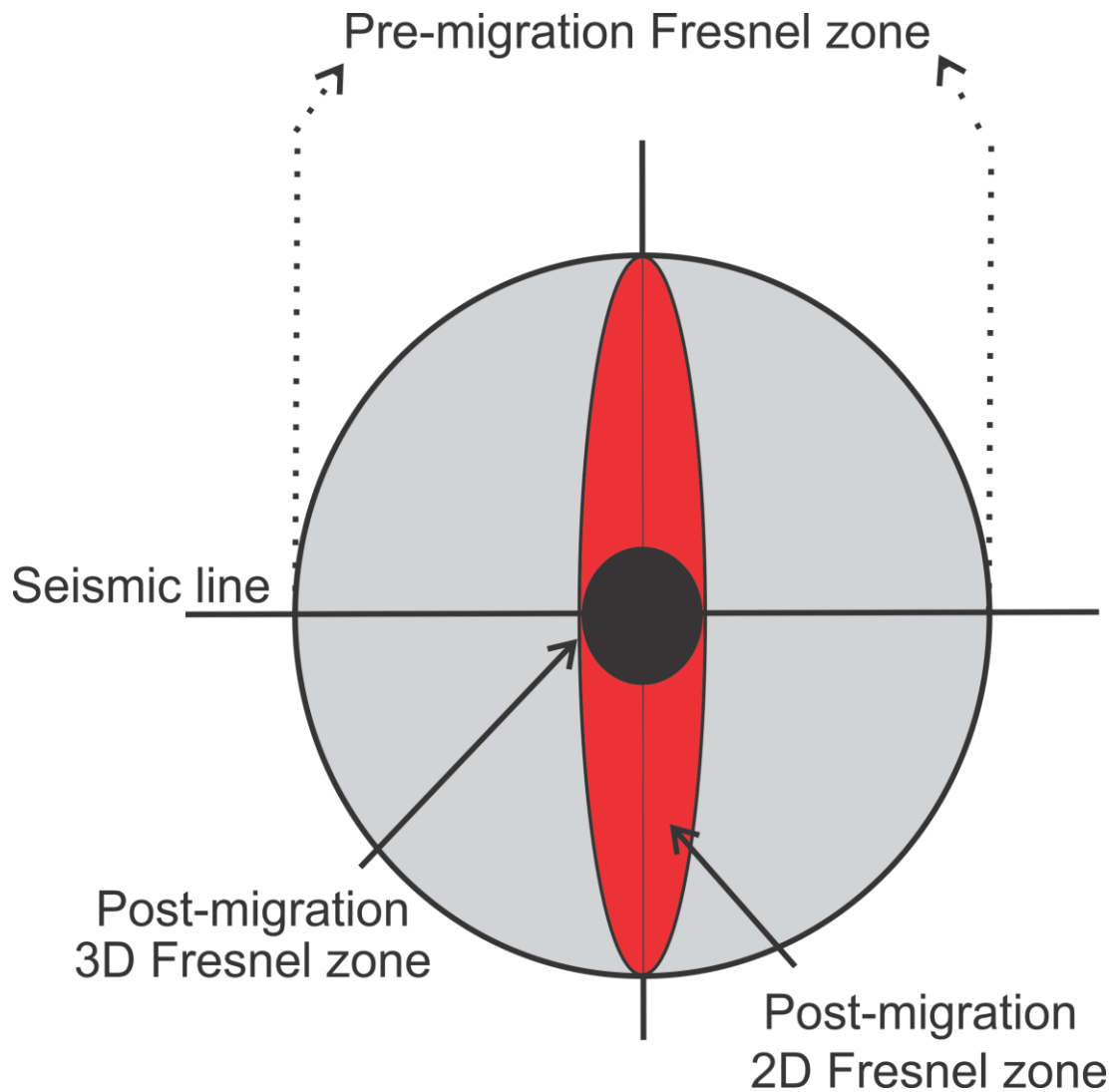


Figure 3.5 An illustration showing the effect of the migration process, for both 2D seismic and 3D seismic. Note that 2D line collapses mainly along the seismic line whereas the 3D seismic collapses in all directions, shrinking the Fresnel zone significantly. Modified from Brown (1999).

Table 3.4 Horizontal resolution of a two selected horizons. Velocity was found from well 7226/11-1.

Dataset	Horizon	Velocity (m/s)	Frequency (Hz)	TWT (two-way-travel-time)	Horizontal resolution
NBR06	Top Røye	4300m/s	17Hz	2530ms	829m
NBR06	Top Ørn	3900m/s	14Hz	2824ms	876m

3.4 Seismic interpretation method

In this thesis, observations from seismic were the most important tool to interpret the delineation of the Ottar basin. Several seismic reflection parameters were used to distinguish the basin area from the surroundings, such as: reflection configuration, reflection continuity, reflection amplitude, reflection frequency and the overall geological setting. All of the listed parameters will be explained further in this chapter.

3.4.1 Seismic observations

Basic principles of reflection configuration, continuity and frequency are displayed in Table 3.5.

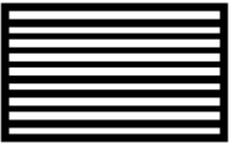
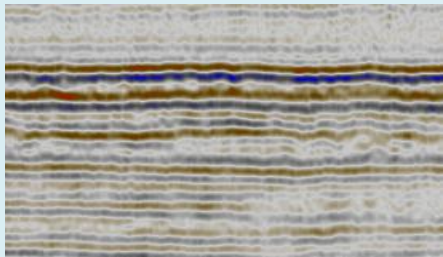

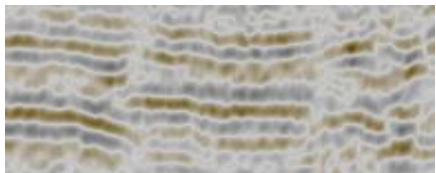

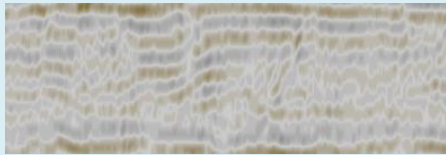

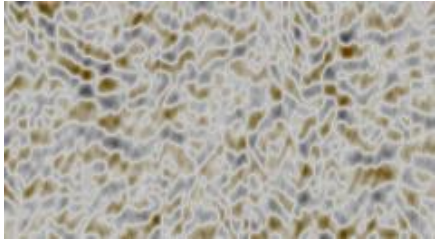

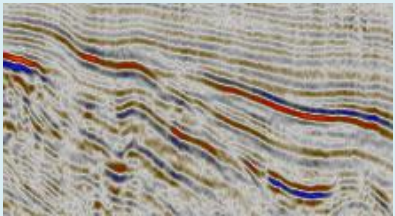
The reflection configuration is related to the bedding patterns geometry when it was deposited, which can give an understanding of the original depositional processes and paleo-topography (Veeken, 2007).

The reflection continuity is based on how the reflections act laterally e.g. a long clear reflection would be continuous, a reflection with frequent disappearance of content would be discontinuous. The continuity is related to the sedimentary processes and therefore also the environment of deposition (Veeken, 2007).

The reflection frequency within a unit tells us about the relative bed thickness, and is another useful parameter for separating seismic sections (Veeken, 2007).

Reflection amplitude can provide information about the reflection strength, lithology variations, fluid content, and bedding spacing (Veeken, 2007).

Table 3.5 Basic principles of reflection configuration (Veeken, 2007).

Reflection configurations	Explanation	Illustration	Examples from seismic
Parallel	Layers are parallel to each other.		
Parallel – discontinuous	Parallel layers but with slight discontinuity within the unit.		
Subparallel	Layers with slightly offset angles.		
Chaotic	Chaotic reflections, often caused by lithology with no clear layering e.g. salt, basement.		
Divergent	When layering stems from a common source.		

3.5 Petrel software

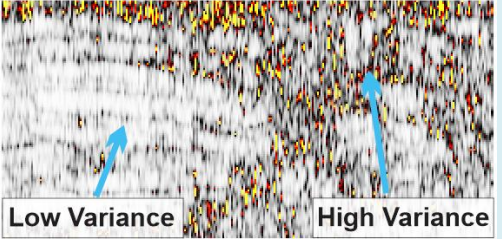
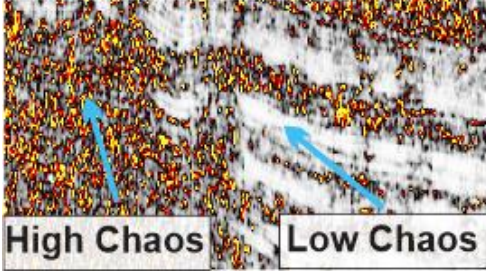
The 28 seismic surveys that was utilized in this thesis was visualized and interpreted by using the Petrel software (2016 version) (Table 3.1). Petrel contains numerous tools to aid with interpretation and visualization, some of the most used tools and attributes which can be

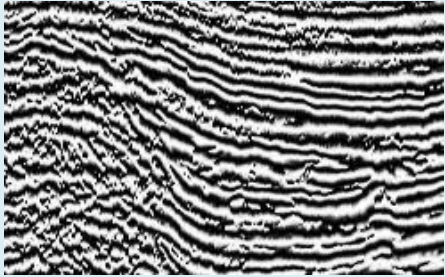
applied to the seismic lines will be further explained in this chapter. The process of how the Otter basin boundary was set, using the polygon-tool will also be presented.

3.5.1 Attributes

Petrel has numerous attributes, which can be applied to seismic lines to enhance certain features. Depending on which attribute is applied, the attribute can enhance features such as e.g. salt extents, structural features, fractures, channels etc. The most utilized attributes will be presented in this section (Table 3.6).

Table 3.6 The most frequently used attributes for this thesis. Based on literature of (Daber et al., 2011)

Attribute	Description	Enhanced features	Example from seismic
Variance (edge method)	Produces the same response for similar seismic signature, amplitude invariant	Stratigraphic terminations, structural lineaments, seismic facies	
Chaos	Maps the “chaoticness” of the seismic signal from statistical analysis dip/azimuth estimate	Salt extents, seismic facies, identify stacked reefs, basement location	

Cosine of instantaneous phase	Cosine function applied to the instantaneous phase (does not include amplitude data)	Lateral continuity of layers	
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3.5.2 Delineation of the Ottar basin

A manually interpreted polygon (Petrel-tool) was generated with the help of several seismic 2-D lines. Some of these 2D-lines were also applied different attributes to enhance features that made it more prominent where the basement underneath the Ottar basin was situated.

With knowledge about carbonate buildups often being located close to the Ottar basin's margins this was one of the things that was taken into account when setting the boundary for the Ottar basin (Gabrielsen et al., 1990).

Some of the 2-D lines provided had good resolution given the great depth, most of these lines went from northwest to southeast (dataset: NBR06) (Table 3.3, Table 3.4).

4 Results

4.1 Paleozoic well-tie

Many wells have been drilled in the southwestern Barents Sea, none of the publically released wells located within the Ottar basin penetrated deep enough to be utilized. Well 7124/3-1 located on the Nysleppen Fault Complex and well 7226/11-1 located on the Norsel High were used due to their last penetrated formations and also that they were released publicly by the NPD.

Four horizons have been interpreted regionally through the Paleozoic section. The Paleozoic horizons are in the study area situated at depths of 2750ms-3500ms (TWT), and thus the frequency and the seismic resolution is somewhat reduced. Consequently, an overview of the horizons throughout the many 2-D lines was needed to determine if the horizons could be mapped regionally in the basin. The horizontal and vertical resolution from the most used seismic survey is given in Chapter 3 (Table 3.3, Table 3.4).

The horizons were interpreted using the well tops in wells; 7124/3-1 and 7226/11-1, which the Norwegian Petroleum Directorate provided (NPD, 2017).

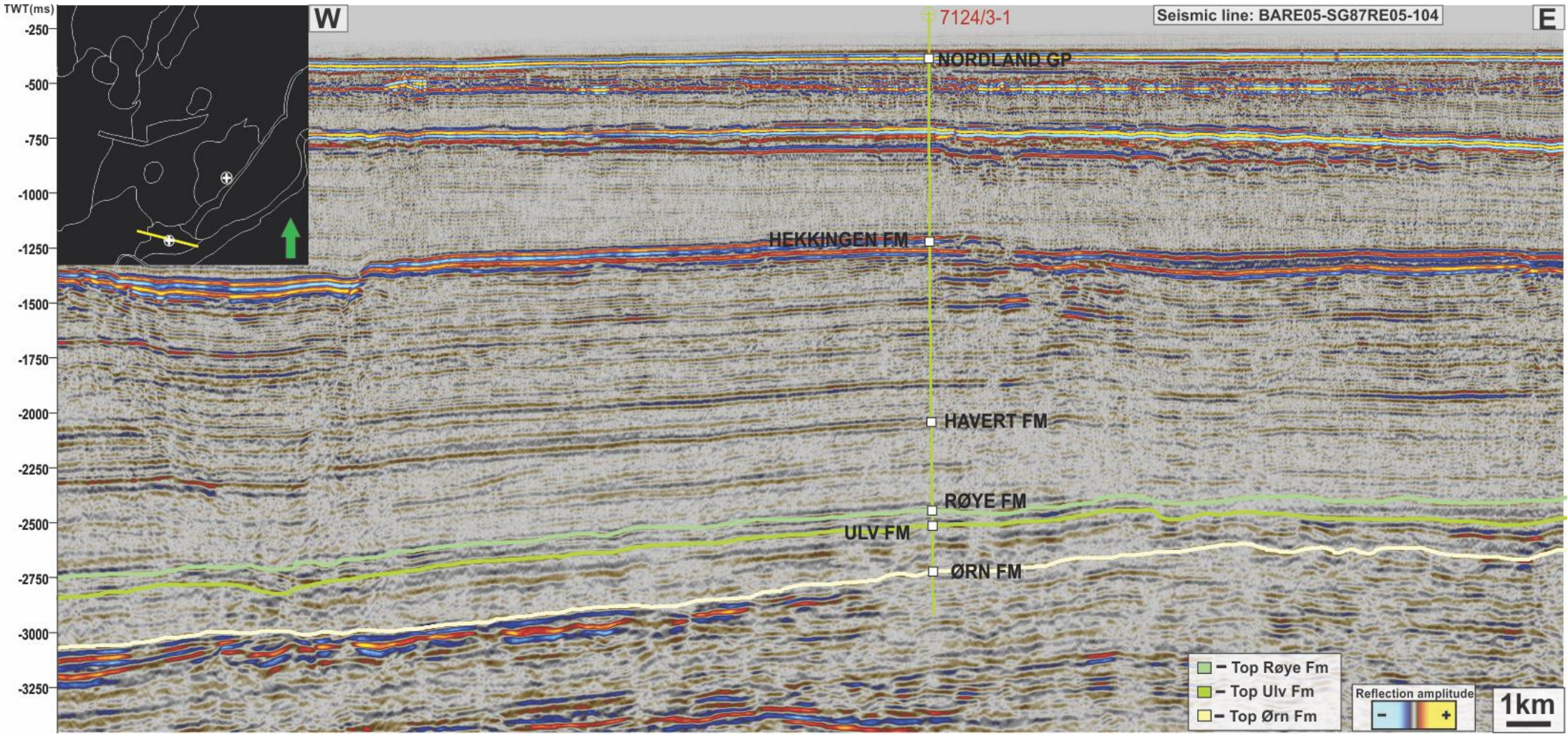


Figure 4.1 Well tops provided by the Norwegian Petroleum Directorate (NPD). Inserted figure indicates position of seismic line.

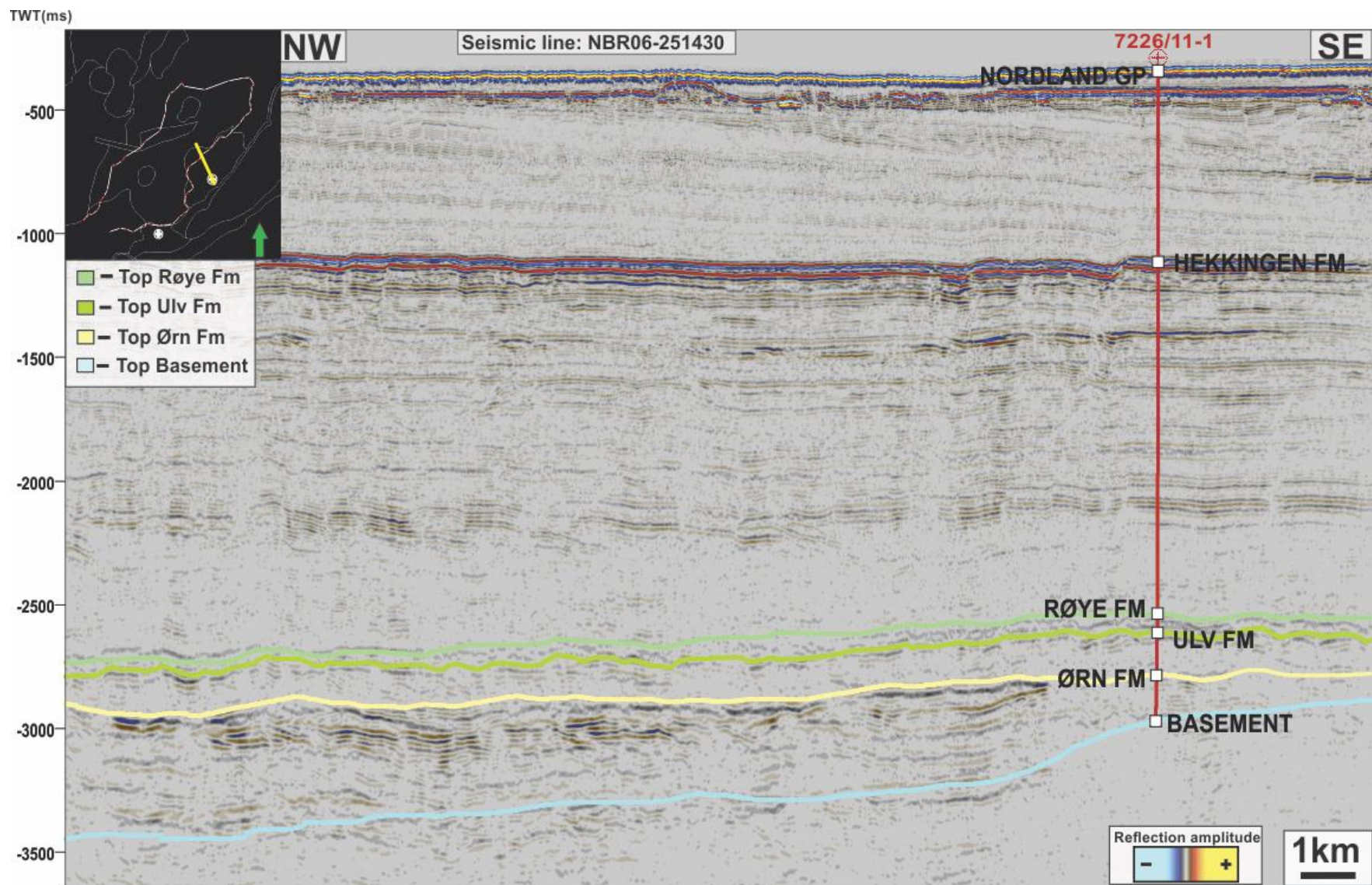


Figure 4.2 Well tops provided by the Norwegian Petroleum Directorate (NPD). Inserted figure indicates position of seismic line.

4.2 Paleozoic stratigraphy - horizons

This chapter presents the interpreted horizons and their general characteristics. They will be described starting with the oldest and moving towards the shallower and younger intervals.

4.2.1 Top basement horizon

The top basement horizon was interpreted with the help of one well-tie (7226/11-1) and also by observing the deepest visible continuous reflection within the Ottar basin (Figure 4.3).

Well 7226/11-1 penetrated the basement at 5137meters (m) consisting of crystalline bedrock of pre-Devonian age. In the seismic section it is located at 2962ms (TWT) (Figure 4.2).

Above the basement the Ørn Formation of the Gipsdalen Group is situated, consisting of interbedded carbonates and evaporites at this location (NPD).

With an estimate of where the basement is located, a better understanding of the basin's geometry is obtainable. The horizon represents the top of the basement, which can be described as a chaotic and irregular seismic pattern, which contrasts to the better and more homogenous seismically defined assumed sediment rocks above. Veeken (2007) accordingly also suggest that geological basement could give rise to reflections having variable amplitude and frequency and can also cause generation of multiples.

A depocenter with a large accommodation space can be seen near the central area of the surface which continues towards the southwest, with surrounding structural highs. A deepening trend towards the southwest is observed, with a maximum depth of approximately 5000ms (TWT) (Figure 4.4). Towards the northeast a shallower trend is observed, with an approximate depth of 3500ms (TWT). A steep transition of the top basement horizon is observed towards the Loppa High (west) going from approximately 4000ms (TWT) in the basin to approximately 3200ms (TWT). Towards the Norsel High (east) the transition of the horizon is more gradual (Figure 4.4). A more subtle updip of the top basement horizon is observed towards the Bjarmeland Platform (north) (Figure 4.4). The horizon indicates the available accommodation space in the study area.

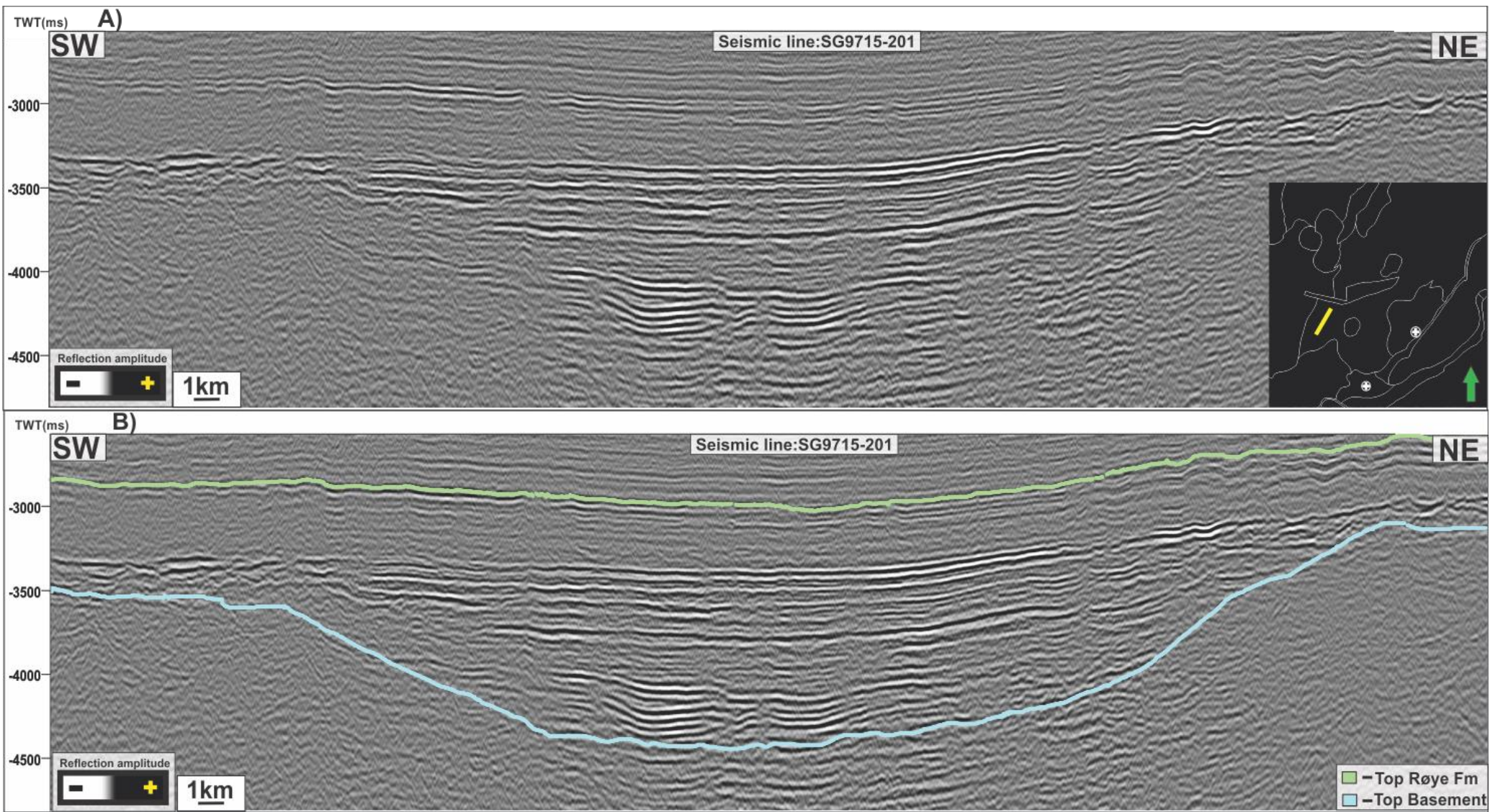


Figure 4.3 A) Seismic section displaying basement-horizon characteristic. Inserted figure indicates position of seismic line. B) Interpreted top basement horizon, top Røye horizon is also included to display the thickness of the Ottar basin.

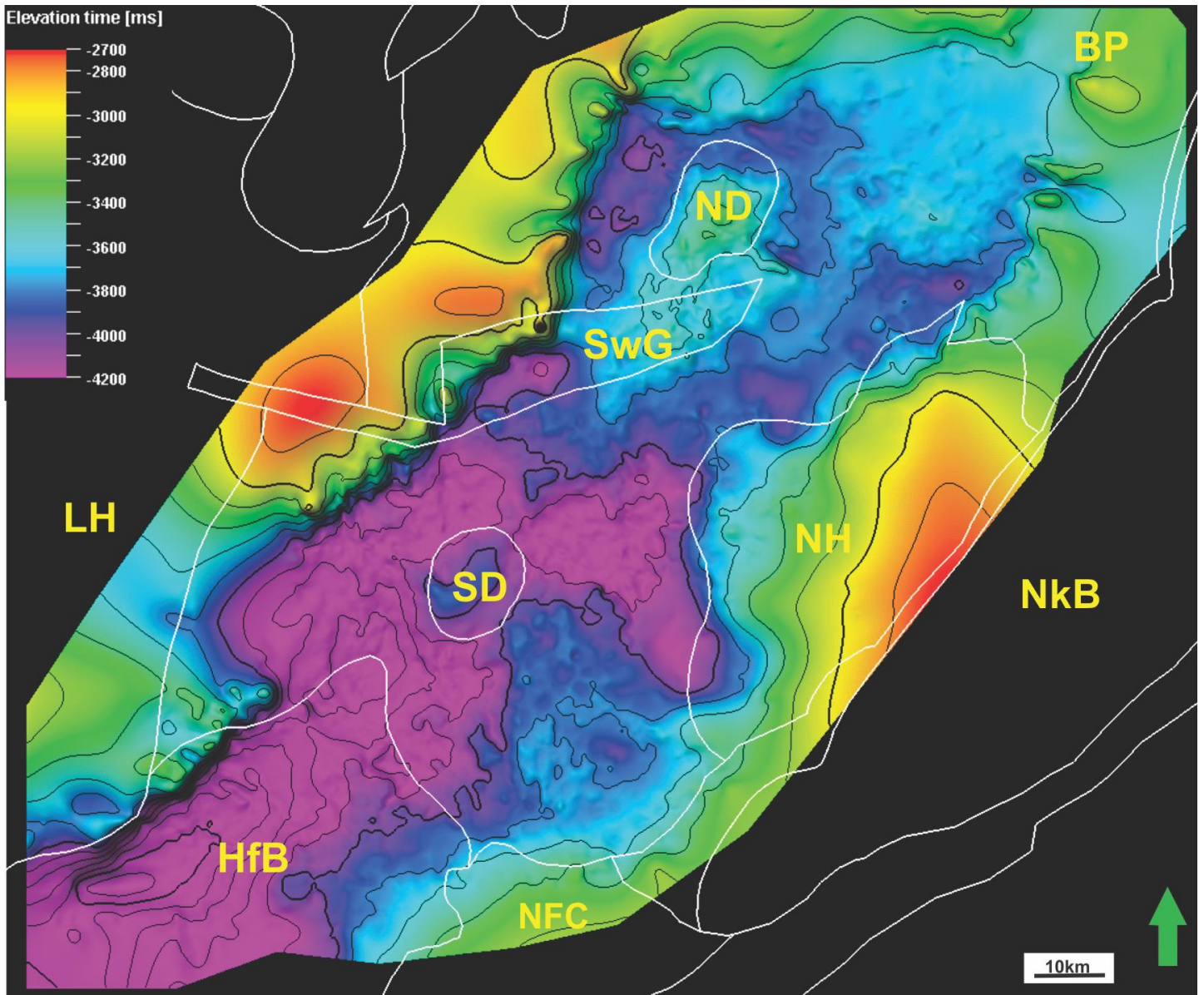


Figure 4.4 Surface map of the interpreted basement horizon. Relevant structural elements are included; HfB- Hammerfest Basin, LH- Loppa High, SD- Samson Dome, SwG- Swaen Graben, ND- Nordvarg Dome, BP- Bjarmeland Platform, NH- Norsel High, NkB- Nordkapp Basin, NFC- Nysleppen Fault Complex.

4.2.2 Top Ørn horizon

The top Ørn horizon was interpreted with the help of two well-ties (7226-11/1 and 7124/3-1).

Well 7226/11-1 penetrated the Ørn Formation of late Carboniferous age at a depth of 4334m, consisting of interbedded carbonates and evaporites at this location. In the seismic section it is located at 2781ms (TWT) (Figure 4.2). Above the Ørn Formation the Polarrev Formation of the Bjarmeland Group is situated, characterized by carbonate buildups at this location. The thickness of the Ørn Formation is 803m, below this Formation, the crystalline basement is found (NPD).

Well 7124/3-1 penetrated the Ørn Formation at a depth of 4271m and was the last entered Formation in this well. The content resembles of what is found in well 7226/11-1 with interbedded carbonates and evaporites. In the seismic section it is located at 2721ms (TWT) (Figure 4.1). Above the Ørn Formation the Polarrev Formation of the Bjarmeland Group is situated, characterized by carbonate buildups at this location (NPD).

Within the basin, the horizon is generally continuous and characterized by high amplitudes (Figure 4.5). The reflection coefficient has a positive value indicating an increase of acoustic impedance across the boundary.

The top Ørn horizon shows an overall dip from the north/northwest to the south/southeast in the investigated area (Figure 4.6). Two prominent highs are observed in the southern and northern part of the horizon, these highs represents the Samson Dome (south) and the Nordvarg Dome (north) (Figure 4.6). Southwest of the Samson Dome there seems to be a deepening trend of the horizon, continuing into the Hammerfest Basin. The deepest areas are located in the southwestern part of the study area and are approximately at 4200ms (TWT). The shallowest parts are located on the surrounding structural elements and the Nordvarg Dome with an approximate of 2750ms (TWT).

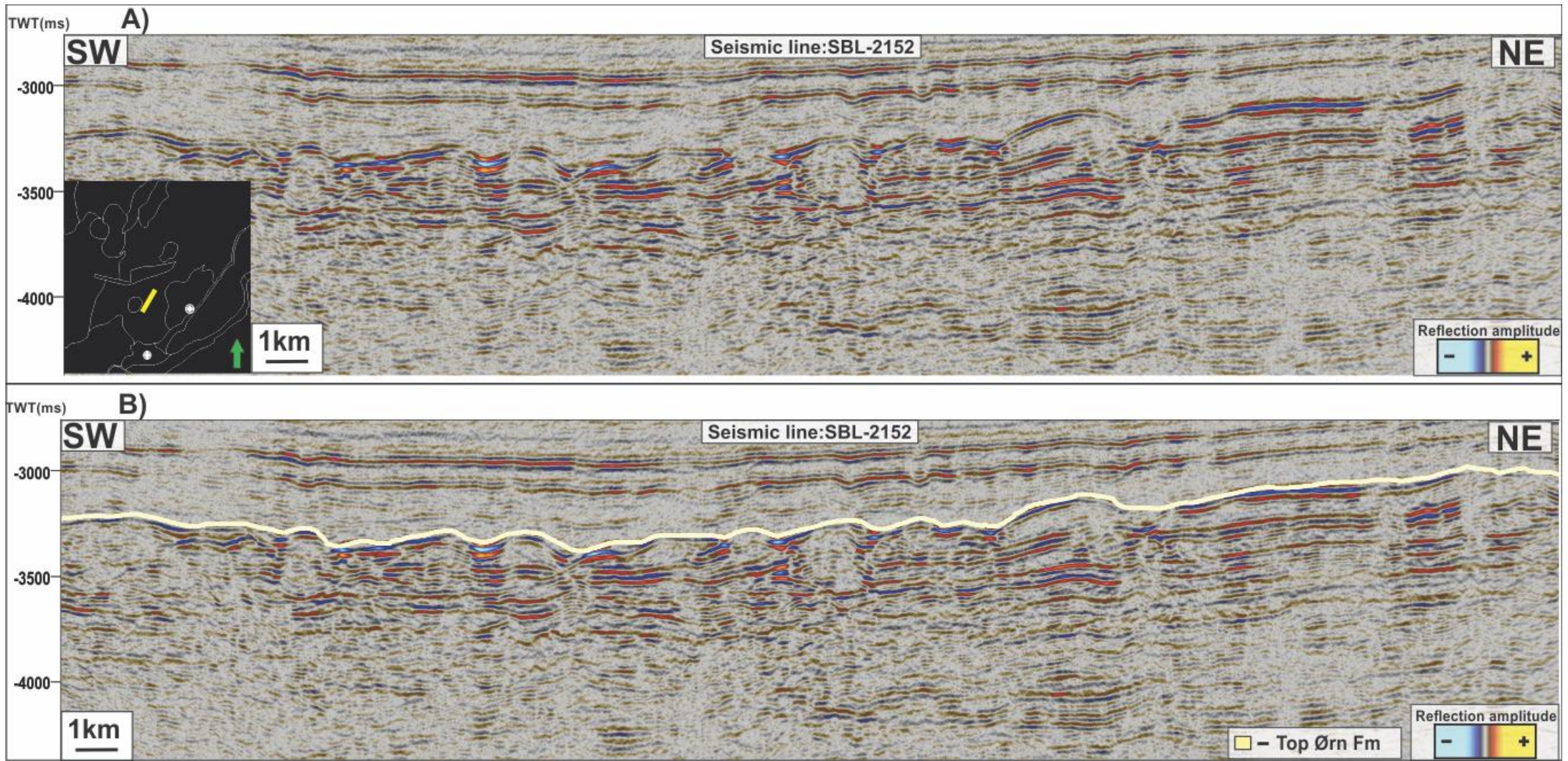


Figure 4.5 A) Seismic section displaying general characteristics for the top Ørn Formation. Inserted figure indicates position of seismic line. B) Seismic section with the interpreted top Ørn Formation

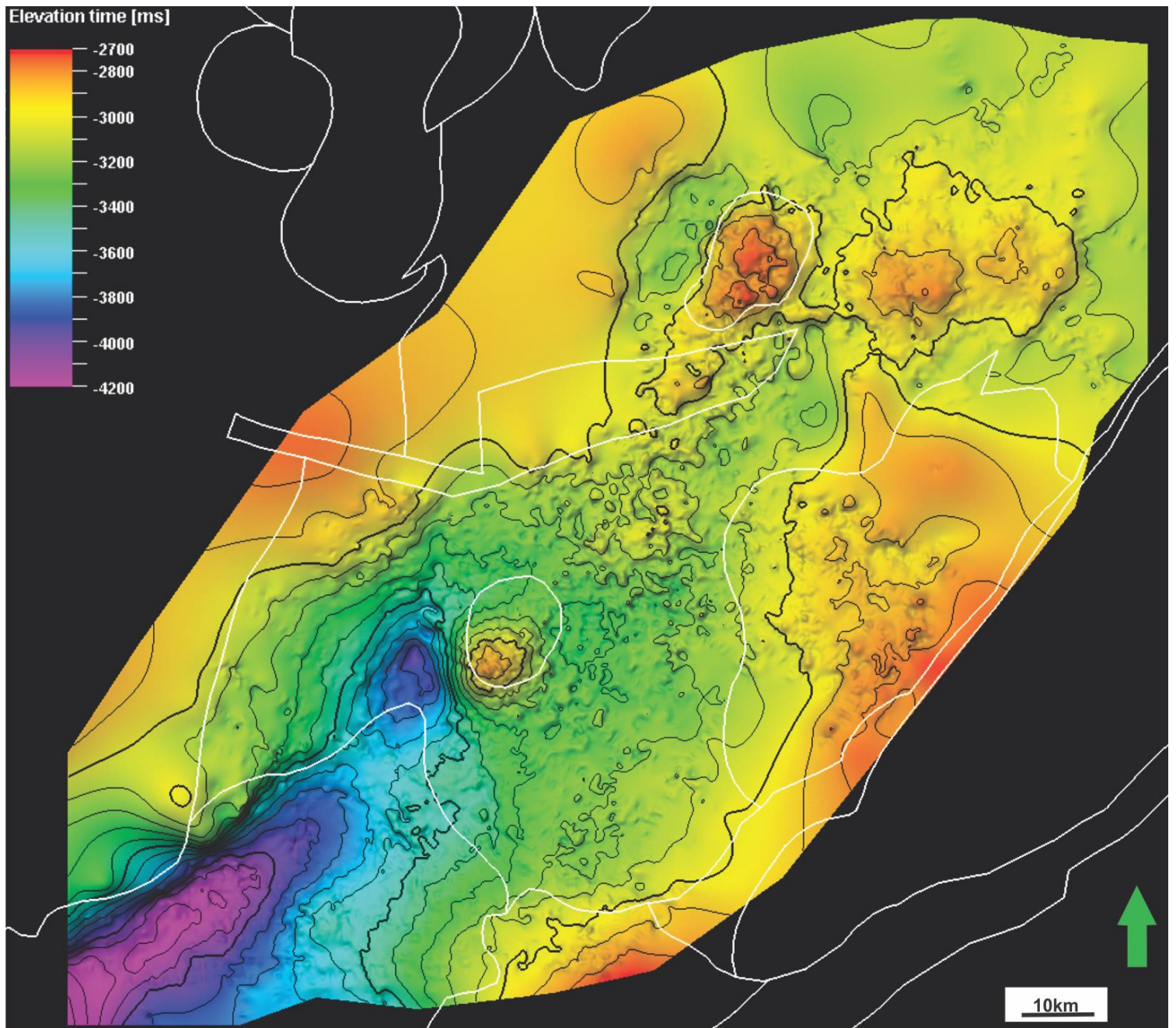


Figure 4.6 Surface map of the interpreted Top Ørn Formation- horizon. See Figure 4.4 for surrounding structural elements.

4.2.3 Top Ulv horizon

The top Ulv horizon was mapped with the use of two well-ties (7226-11/1 and 7124/3-1).

Well 7226/11-1 penetrated the Ulv Formation of early Permian age at a depth of 4103m, consisting of thinly bedded bioclastic limestone with thin silt laminae. In the seismic section it is located at 2617ms (TWT) (Figure 4.2). Above the Ulv Formation, the Røye Formation of the Tempelfjorden Group is situated, characterized by silicified sediments at this location. The thickness of the Ulv Formation is 79m, below this Formation, the Polarrev Formation is found (NPD).

Well 7124/3-1 penetrated the Ulv Formation at a depth of 3952m. The content resembles of what is found in well 7226/11-1 by thinly bedded bioclastic limestone with thin silt laminae. In the seismic section it is located at 2513ms (TWT) (Figure 4.1). Above the Ulv Formation the Isbjørn Formation of the Bjarmeland Group is situated, which is absent in well 7226/11-1. The thickness of the Ulv Formation is 46m, below this Formation, the Polarrev Formation is found(NPD).

The horizon is generally characterized by high amplitudes throughout most of the basin (Figure 4.8). On the surrounding highs (Norsel High, Loppa High) the amplitude is medium to high. The reflection coefficient is positive indicating an increase of acoustic impedance across the boundary. The horizon is generally continuous, however above the two dome features located within the basin, the horizon is observed as discontinuous.

The top Ulv horizon in general has a low dip in the Ottar basin, and is in large parts of the area found at about 3000-3200ms (TWT) (Figure 4.9). The two dome features within the Ottar basin are prominent on this horizon; the Svalis dome (southwest) and the Nordvarg dome (north). Adjacent to the Svalis dome towards the west the horizon deepens and is in these areas measured to be approximately 3650 ms (TWT) at the deepest part. The shallowest areas are located on the Norsel High and the Loppa High, however within the basin, the shallowest areas are located towards the northeast at 2800ms (TWT). The deepest parts of the Ulv horizon are located towards the southwest (3800ms TWT), this deepening trend appears to continue into the Hammerfest Basin (Figure 4.8).

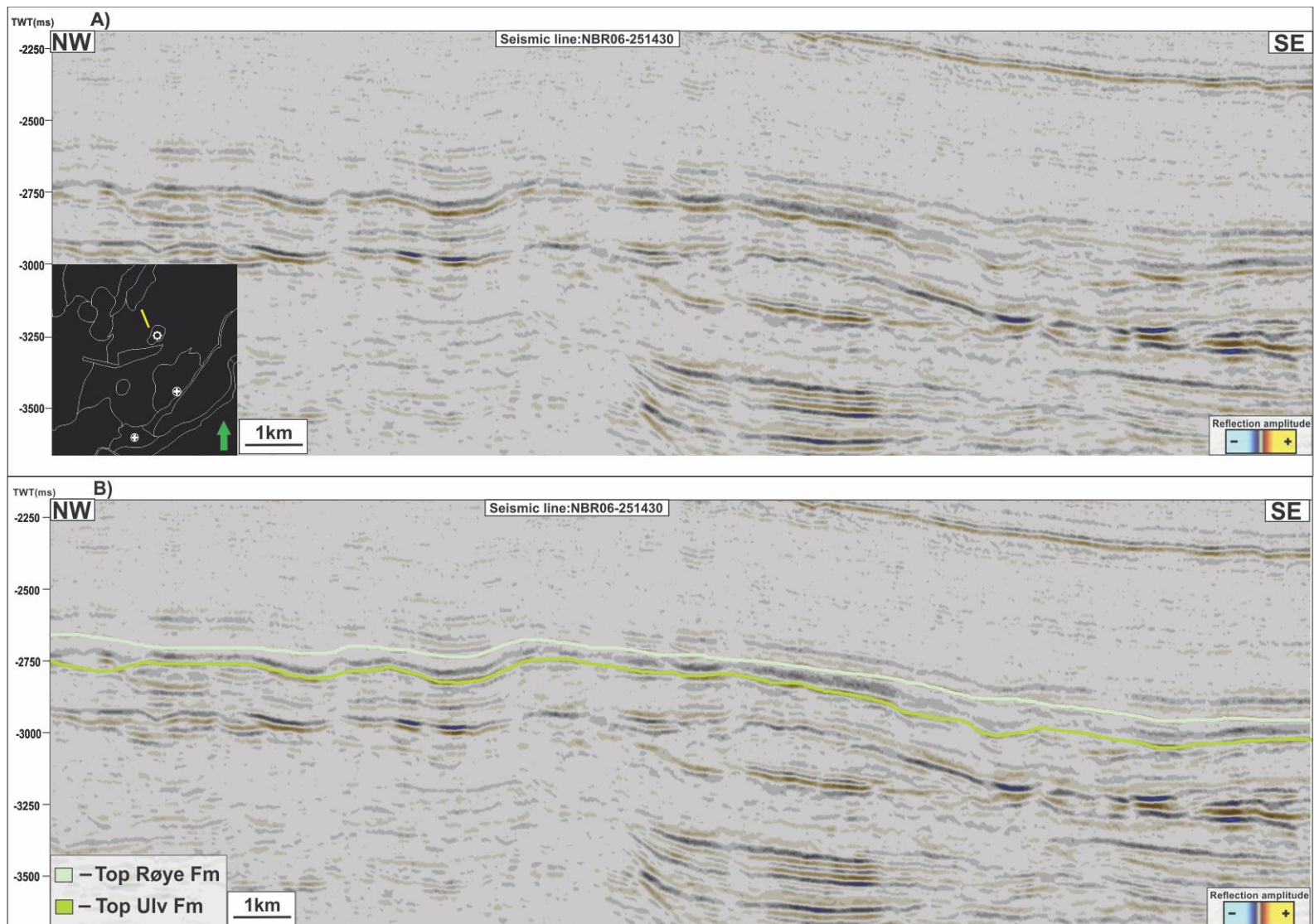


Figure 4.7 A) Seismic section displaying general characteristics for both the top Ulv Formation and the top Røye Formation. Inserted figure indicates position of seismic line. B) Seismic section with both of the horizons interpreted.

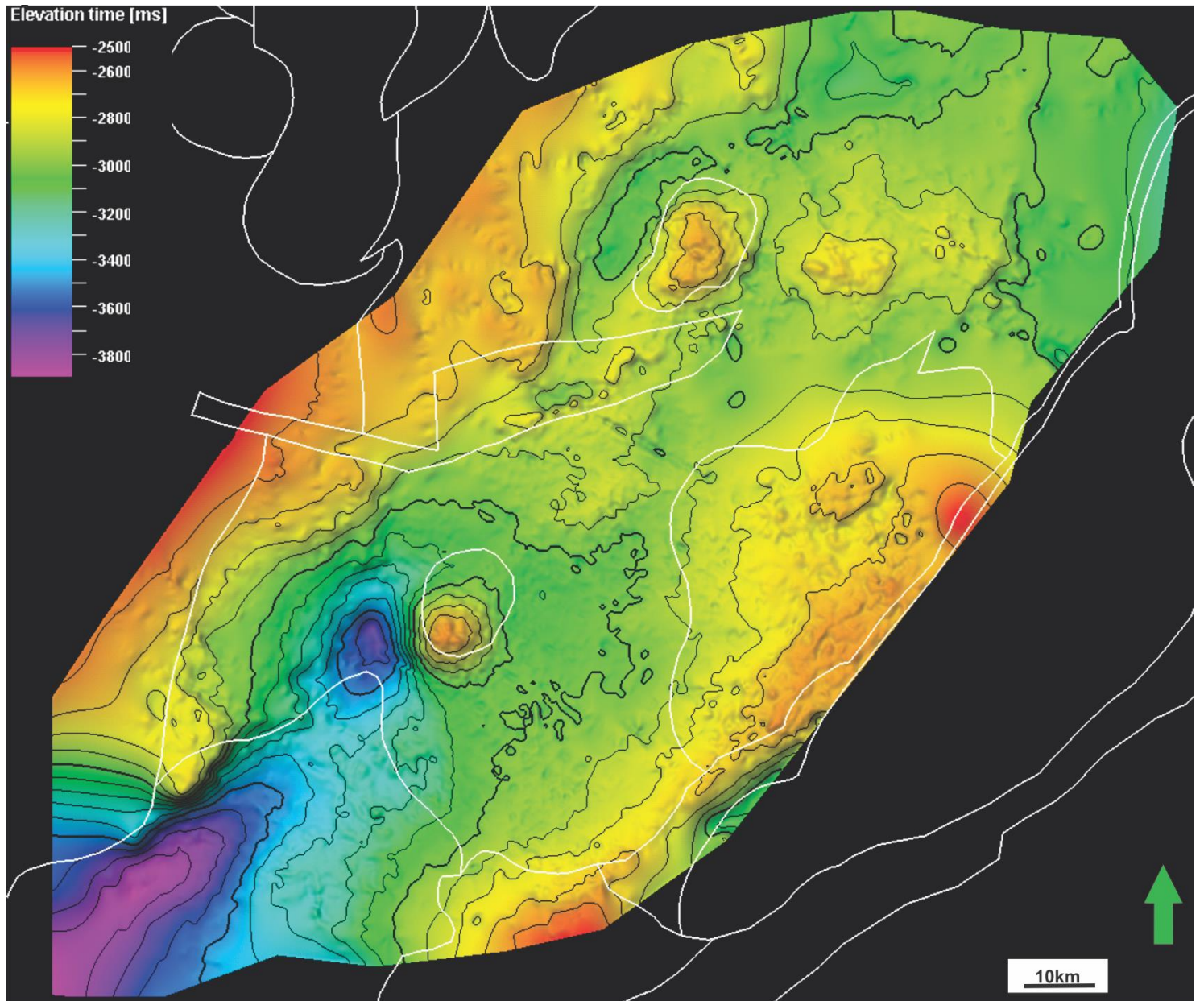


Figure 4.8 Surface map of the interpreted Top Ulv Formation - horizon. See Figure 4.4 for surrounding structural elements.

4.2.4 Top Røye horizon

The top Røye horizon have been mapped with the use of two well-ties (7226/11-1 and 7214/3-1) and is regarded as the top horizon of the Ottar basin.

Well 7226/11-1 penetrated the Røye Formation of mid Permian age at a depth of 3966m, consisting of silicified sediments with traces of organic material. In the seismic section it is located at 2534ms (TWT) (Figure 4.2). Above the Røye Formation, the Ørret Formation of the Tempelfjorden Group is situated, characterized by thin and organic-rich shales with rare interbedded sandstone and limestone at this location. The thickness of the Røye Formation is 137m, below this Formation, the Ulv Formation is found (NPD).

Well 7124/3-1 penetrated the Røye Formation at a depth of 3670m. The content resembles of what is found in well 7226/11-1, however a thicker section is found. In the seismic section it is located at 2446ms (TWT) (Figure 4.1). Above the Røye Formation, the Ørret Formation of the Bjarmeland Group is situated. The thickness of the Røye Formation is 230m, below this Formation, the Isbjørn Formation is found (NPD).

The top Røye horizon is characterized by low to medium amplitudes within the basin (Figure 4.8). On the highs, near the basin margins, the reflection amplitude is low, especially towards the east. The horizon is generally discontinuous, both within the basin and on the structural highs. The reflection coefficient is positive.

The top Røye horizon displays a shallower trend in the northeastern direction towards the Bjarmeland Platform, where the shallowest area is located at approximately 2800ms (TWT) (Figure 4.10). From the Samson Dome and to the southwest towards the Hammerfest Basin a deepening trend of the horizon is observed and is located at approximately 3700ms (TWT) at the deepest part of the study area. The top Røye horizon also marks the top boundary of the two domes within the Ottar basin which are prominent on the horizon.

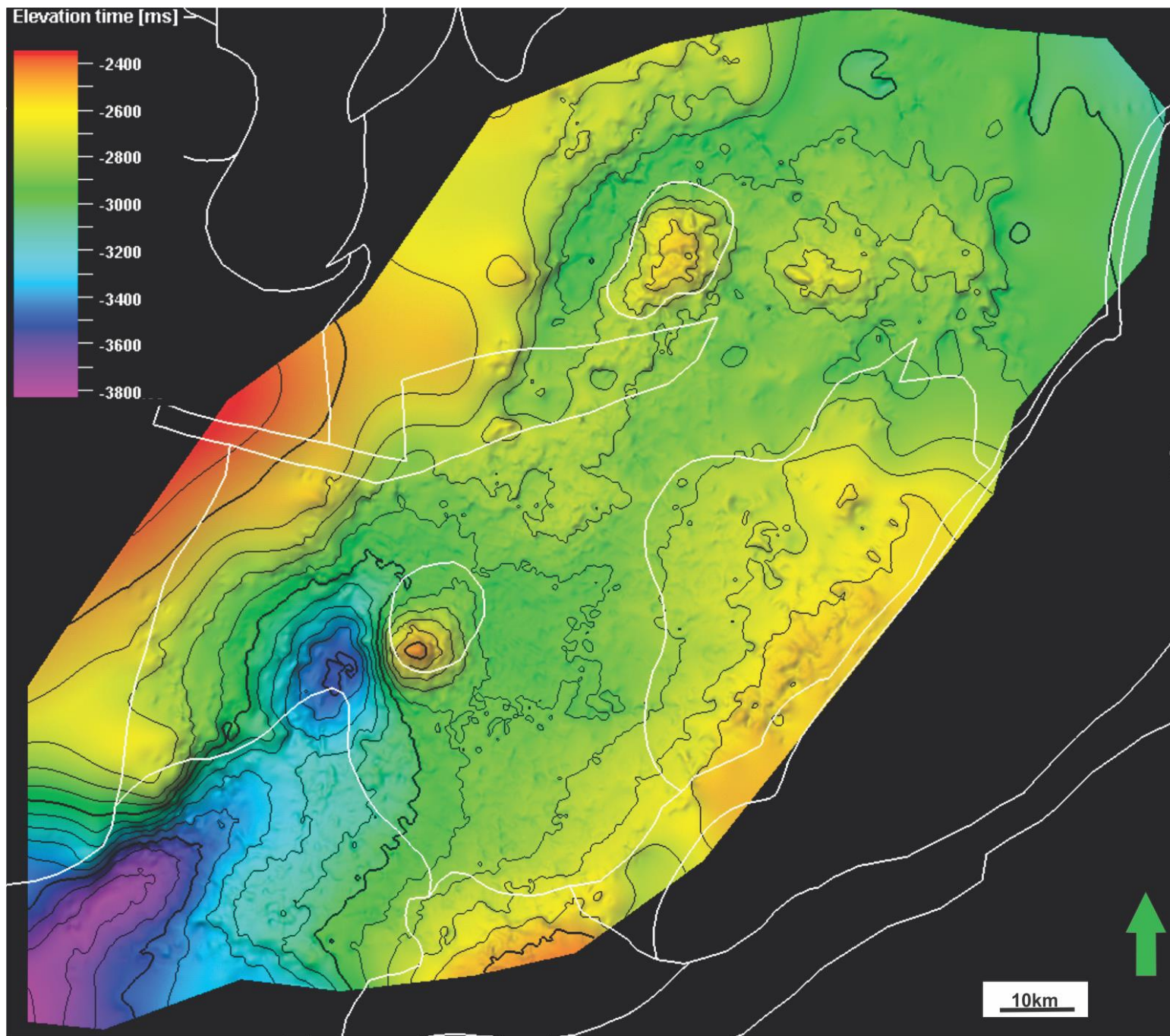


Figure 4.9 Surface map of the interpreted Top Røye Formation - horizon. See Figure 4.4 for surrounding structural elements.

4.3 Paleozoic units defined in the Ottar basin

The time-thickness of the four identified units in the Ottar basin will be presented. The defined units are S1 (top basement horizon- top Gipsdalen Group), S2 (top Gipsdalen Group- top Bjarmeland Group) and S3 (top Bjarmeland Group – top Tempelfjorden Group). A unit displaying the overall sediment distribution is also presented; T1 (top Basement horizon – top Tempelfjorden Group).

The internal units of the Ottar basin have been interpreted using well tops from wells 7226/11-1 and 7124/3-1 (NPD, 2017) (Figure 4.10). The time-thickness maps of the units will aid in understanding the geometry of the Ottar basin, resulting in a better delineation of the basin.

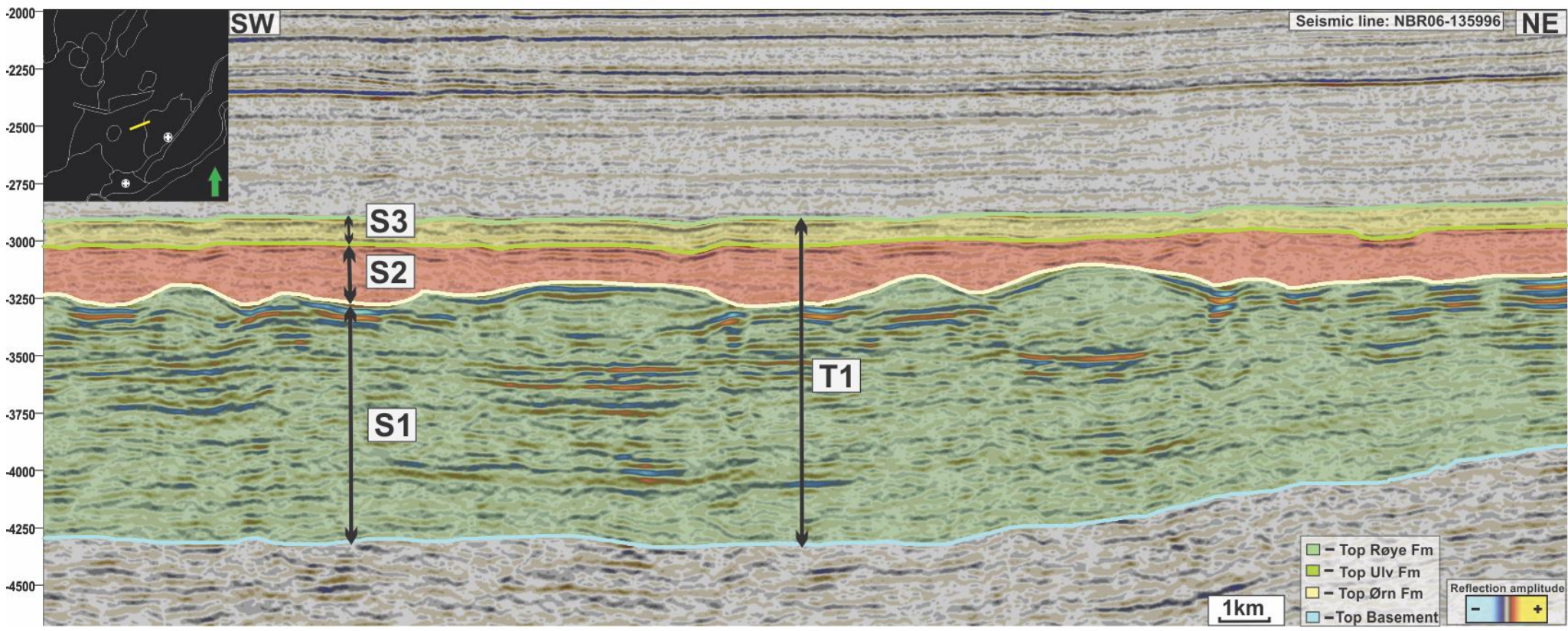


Figure 4.10: Seismic section illustrating the basin thickness with interpreted horizons and units of the study. Inserted figure indicates position of seismic line.

4.3.1 T1 – Total unit – total upper Paleozoic

The T1 unit is the total volume of the upper Paleozoic part of the Ottar basin, which is limited by the top basement- and the top Røye- horizon (Figure 4.10). The T1 unit represents sedimentary groups from the whole Paleozoic era (Figure 4.11). A thickening trend of the total unit is observed southwest, towards the Hammerfest Basin with an average thickness of approximately 1300ms (TWT). Towards the Bjarmeland Platform northeast, a thinning trend of the T1 unit is observed, with an average thickness of approximately 700ms (TWT). A thinning trend is observed towards both the Loppa High and the Norsel High. However the thinning in sediment distribution towards the Loppa High is observed as a more abrupt transition. The sediment distribution observed towards the Norsel High is more gradual (Figure 4.11).

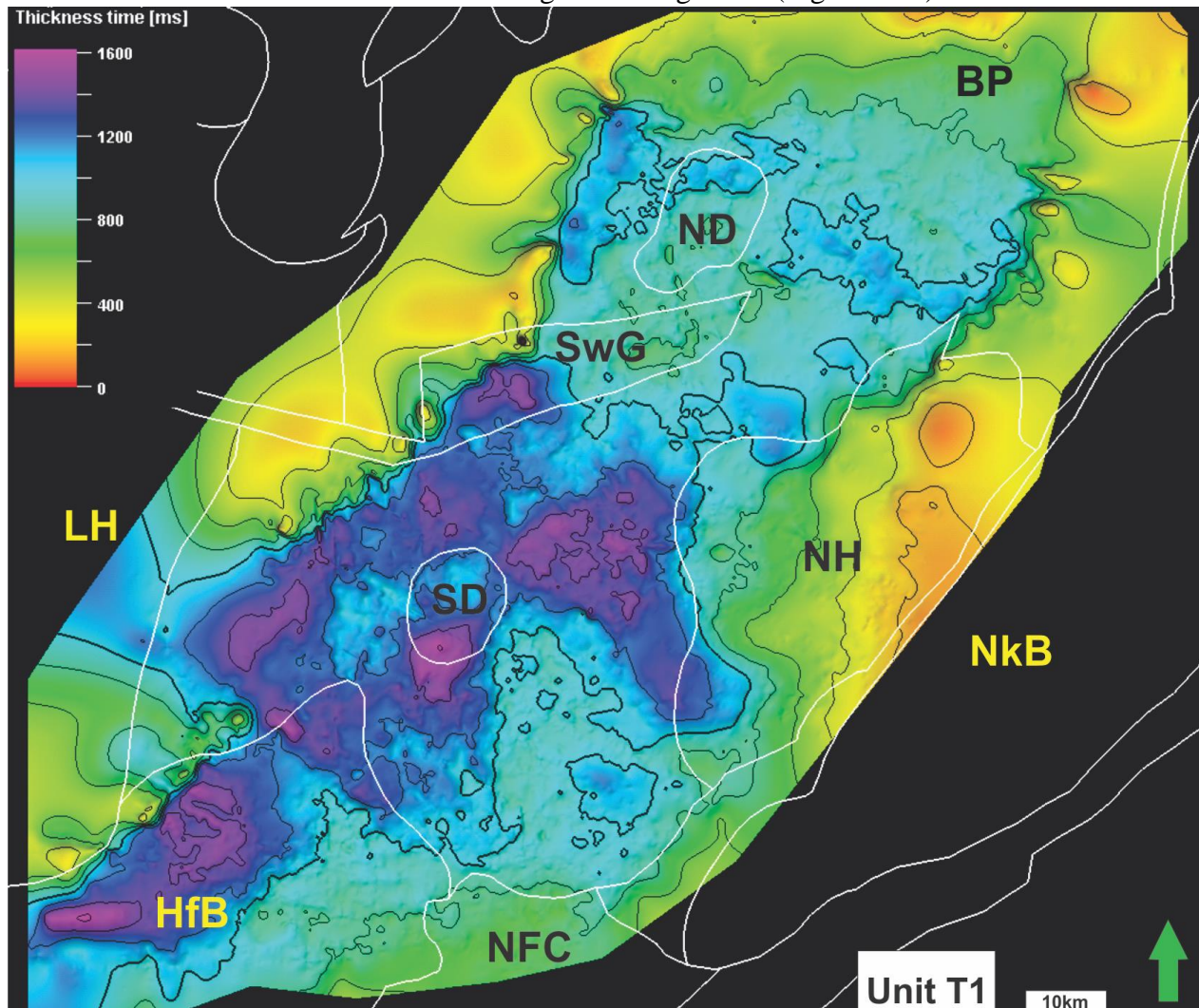


Figure 4.11 Isochron thickness map of seismic unit T1. Displaying total Paleozoic sediment distribution of the study area. Relevant structural elements are included; HfB- Hammerfest Basin, LH- Loppa High, SD- Samson Dome, SwG- Swaen Graben, ND- Nordvarg Dome, BP- Bjarmeland Platform, NH- Norsel High, NkB- Nordkapp Basin, NFC- Nysleppen Fault Complex.

4.3.2 S1- Unit 1 Billefjorden- and Gipsdalen Groups

The lowermost unit of the Ottar basin is seismic unit S1. The unit is suggested to represent sediments from both the Billefjorden Group and the Gipsdalen Group (Figure 4.12). The S1 unit is the volume limited by the above described horizons; top basement- and the top Ørn- horizon. The unit has a varying thickness, a thickening trend is observed from the central part of the Ottar basin towards the Hammerfest Basin with an average thickness of approximately 1000ms (TWT).

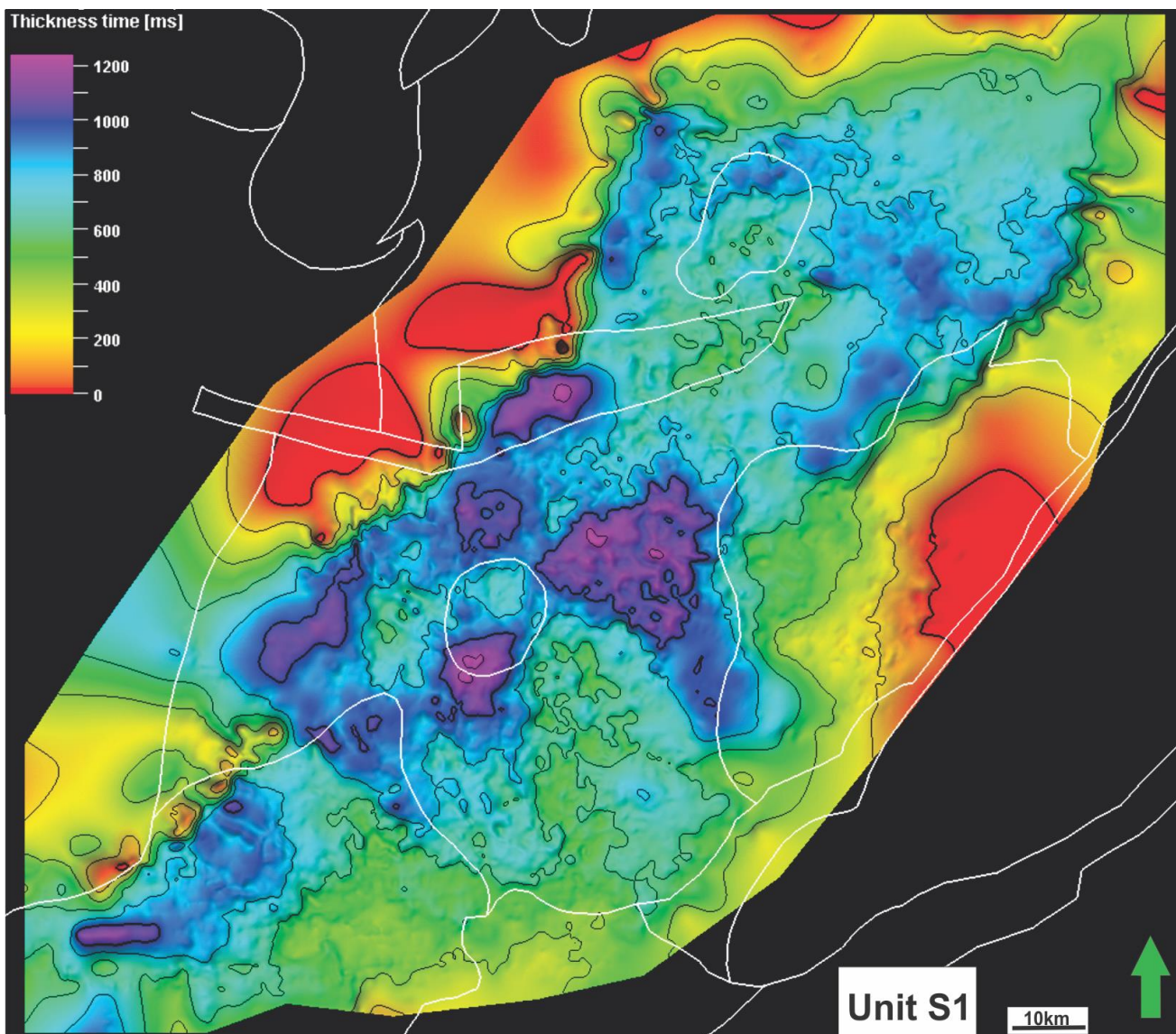


Figure 4.12 Isochron thickness map of seismic unit S1. Red features are incidents where the horizons crosses due to interpolation in Petrel. See Figure 4.11 for surrounding structural elements.

Towards the Bjarmeland Platform northeast, a thinner trend is observed, with an average thickness of approximately 500-600ms (TWT), being the thickest of the defined intervals herein. The S1 unit can in terms of internal seismic pattern be subdivided into two parts; an upper- and a lower- section.

The lower section of the S1 unit is characterized by medium to low amplitudes with a discontinuous pattern (Figure 4.10). The lower section of the S1 unit generally thins towards the basin margins with the thickest successions observed in the central part of the Ottar basin, on the Norsel High (east) and the Loppa High (west) the lower section is not observed. Towards the Hammerfest Basin (southwest) the lower section of the S1 unit has a relatively uniform thickness. Towards the Bjarmeland Platform (northeast) the succession of the lower section is observed as gradually thinning.

The upper section of the S1 unit is characterized by high amplitudes with a discontinuous pattern inside of the Ottar basin, this trend changes towards the basing margins e.g. Norsel High where the unit has low amplitudes and a continuous pattern (Figure 4.10).

There are small mound features located below the initial horizon of the S1 unit near the Samson Dome, the mounds are typically 50-100ms (TWT) with varying lateral extent, ranging from 1-3km. The internal reflection characteristics of the mounds are typically reflection free (Figure 4.5, Figure 4.10).

4.3.3 S2- Unit 2 Bjarmeland Group

The S2 unit is the volume limited by the top Ørn- and the top Ulv- horizon (Figure 4.13). This unit represents the sediments of the Bjarmeland Group. The thickness of the S2 unit is considerably thinner than the S1 unit (Figure 4.10, Figure 4.12, Figure 4.13). A thickening trend of the unit is observed southwest, towards the Hammerfest Basin with an average thickness of approximately 300ms (TWT). Towards the northeast near the Bjarmeland Platform, a thinning trend of the S2 unit is observed, with an average thickness of approximately 100ms (TWT).

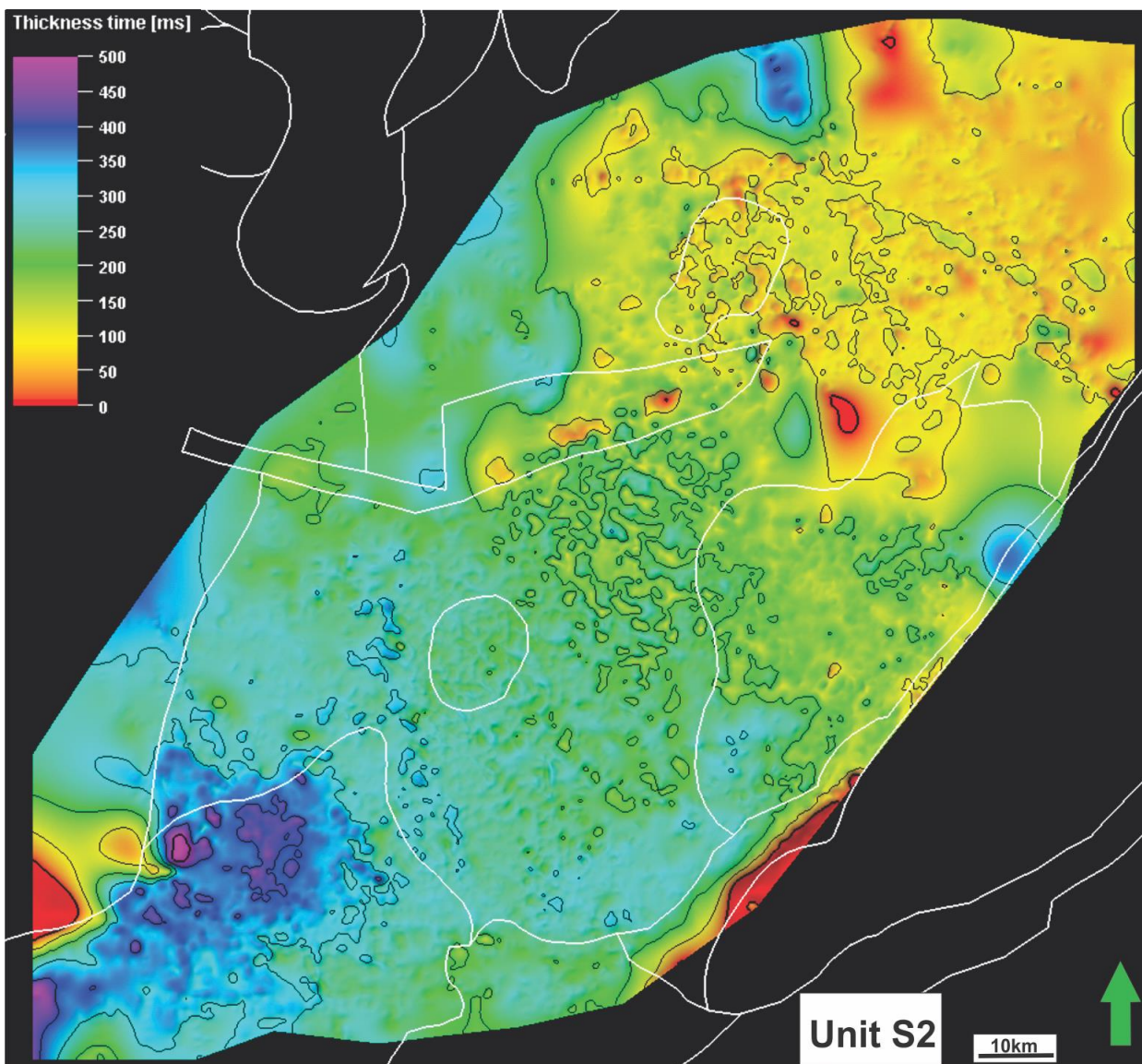


Figure 4.13 Isochron thickness map of seismic unit S2. Red features are incidents where the horizons crosses due to interpolation in Petrel. See Figure 4.11 for surrounding structural elements.

The internal seismic pattern in the S2 unit can be described as subparallel (Figure 4.10). Throughout most of the study area the internal reflections of the S2 unit are continuous, and with low to medium amplitudes.

Towards the basin flanks the internal seismic pattern is more mounded with a wavy reflection configuration (Figure 4.14). The reflections within the volume of the unit is characterized by low to medium amplitudes.

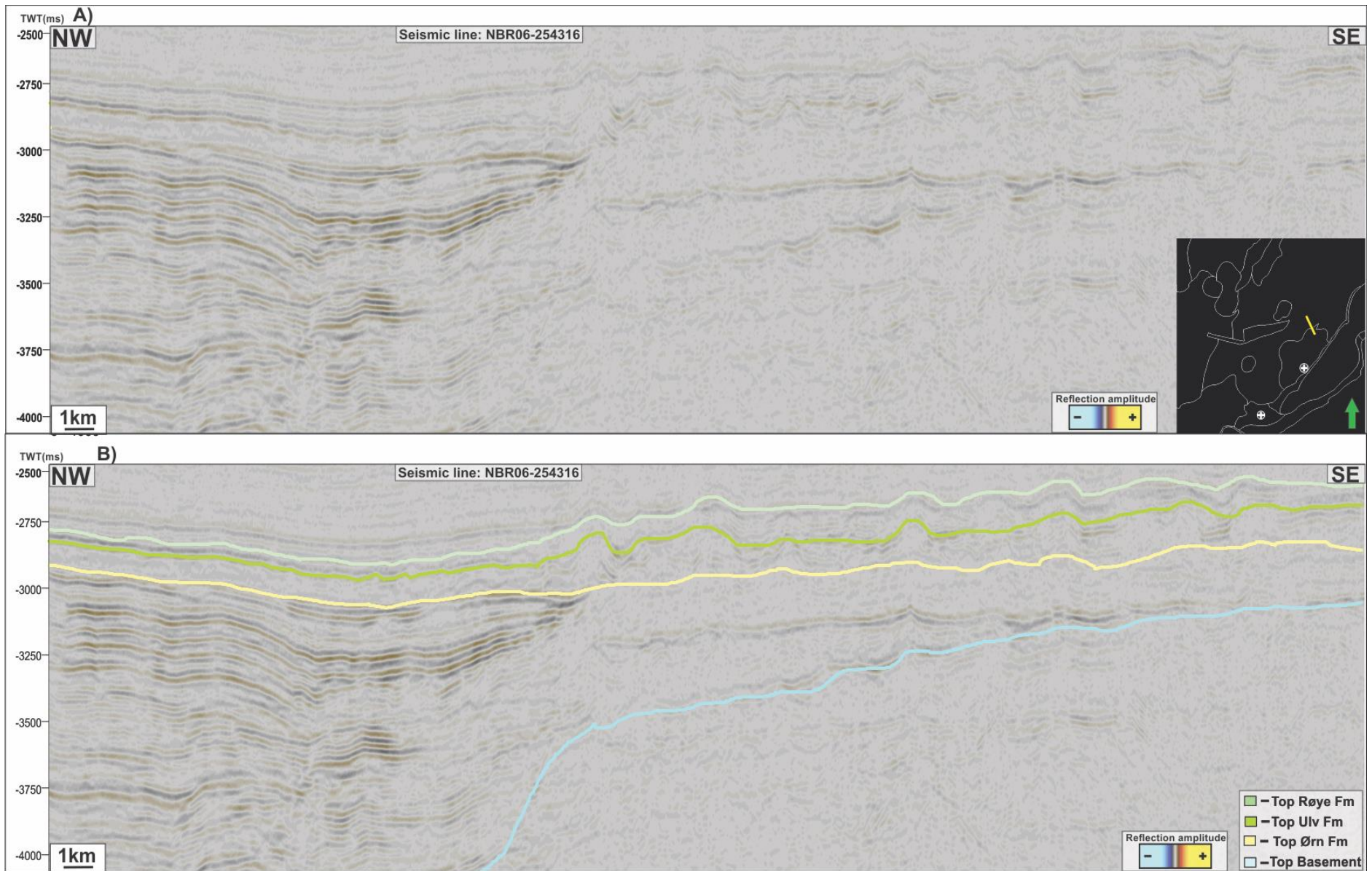


Figure 4.14 A) Seismic section without interpretation, inserted figure indicates position of seismic line. B) Seismic section including interpretation of the interpreted horizons.

4.3.4 S3- Unit 3 Tempelfjorden Group

The S3 unit is limited by the top Ulv- and the top Røye- horizon (Figure 4.15). This unit represents the sediments from the Tempelfjorden Group. A slight thickening trend of the unit is observed southwest, towards the Hammerfest Basin with an average thickness of approximately 100ms (TWT). Towards the northeast and the Bjarmeland Platform, a thinning trend of the S3 unit is observed, with an average thickness of approximately 50ms (TWT).

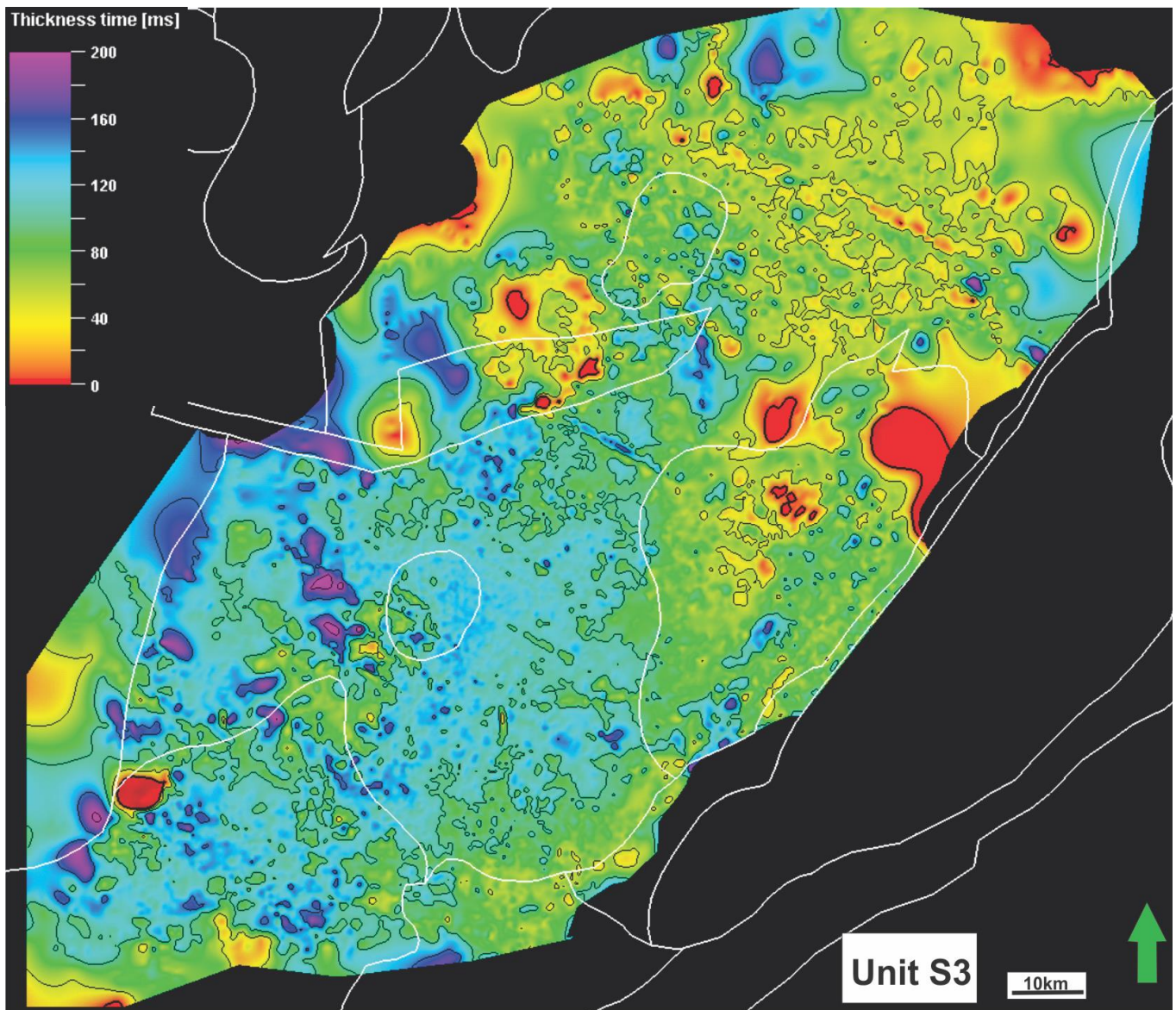


Figure 4.15 Isochron thickness map of seismic unit S3. Red features are incidents where the horizons crosses due to interpolation in Petrel. See Figure 4.11 for surrounding structural elements.

The general reflection configuration of the S3 unit is subparallel and continuous with low amplitudes (Figure 4.10).

The S3 unit has an average volume of approximately 100ms (TWT), which is the thinnest out of the 3 interpreted units. Within the basin area, the unit can be described as a thin uniform seismic section. Towards the basin's flanks, especially towards the Norsel High the internal seismic pattern is more mounded with a wavy reflection configuration (Figure 4.14).

5 Discussion

5.1 Paleozoic strata

The three major seismic units are defined from seismic observations and well data presented in the previous chapters, and includes the following lithostratigraphic units; the Billefjorden Group, the Gipsdalen Group (Unit S1), the Bjarmeland Group (Unit S2) and the Tempelfjorden Group (Unit S3). Documenting the lateral and vertical variations of thickness, the seismic stratigraphic expression and the regional setting of the area, have been crucial for delineating the Ottar basin.

The main previous work on the Ottar basin was presented by Breivik et al. (1995), which was based on gravimetric/magnetic and seismic data. The delineation results presented below, with better and denser data than used by Breivik et al. (1995) will naturally be compared to the work of Breivik et al. (1995).

5.1.1 The S1 unit -Billefjorden- and Gipsdalen Groups

Unit S1 is suggested to represent both the Billefjorden- and the Gipsdalen Groups (Chapter 4.3, Figure 4.10). Only the Gipsdalen Group of the S1 unit had well-ties (in wells 7226/11-1 and 7124/3-1), consequently the Billefjorden was incorporated in the S1 unit with the top basement horizon as the lower boundary. As described in Chapter 4.3.2, the seismic interpretation done in this work, suggest that the S1 unit should be subdivided into two parts based on the internal seismic pattern. The lower part is suggested to represent the Billefjorden Group with medium to low amplitudes with a discontinuous pattern. The upper part is suggested to represent the Gipsdalen Group with high amplitudes, discontinuous pattern and with several smaller mound features within the basin (Figure 4.10). According to Worsley (2008) the shift between the Billefjorden Group and the Gipsdalen Group is an unconformable contact, however this is not very prominent within the study area/Ottar basin.

The thickness of the S1 unit varies from 1200ms (TWT) in the basin to approximately 200ms (TWT) on surrounding highs. The time-thickness suggest that the Ottar basin had greater accommodation space than the surrounding highs, due to the widespread rifting in late Paleozoic, causing subsidence of the basins and uplift of adjacent structural highs in the southwestern Barents Sea (Faleide et al., 2015) (Figure 5.1, Figure 4.12).

The Billefjorden Group was deposited during the early phase of active rifting (Worsley, 2008). Two of the applied wells 7226/11-1 and 7124/3-1, are both located on the crests of structural highs, and confirm that the Billefjorden Group is absent (Larssen et al., 2005). The lowermost part of the Billefjorden Group includes reworked and weathered basement rocks, which typically causes chaotic reflection characteristics due to variations in amplitude and frequency (Larssen et al., 2005; Veeken, 2007). Lateral variations and extent of the Billefjorden Group is known due to several cases of infilling local half-grabens, this was as a result of rifting episodes in the Carboniferous (Visèan- Serpukhovian) (Larssen et al., 2005). Middle Carboniferous (Gipsdalen) carbonates (Bashkovarian) are known to rest directly on the basement in the well 7226/11-1 located on the Norsel High (Jensen & Sørensen, 1992; Larssen et al., 2005) (Figure 5.1). This supports the absence of the Billefjorden Group at this location.

The Gipsdalen Group is defined as the upper part of the S1 unit, characterized by high amplitude initial reflections, with discontinuous internal seismic pattern. Several small mounded features (50-100ms TWT thick, 1-3km lateral extent) are observed at the topmost part of the unit within the basin (excluding the prominent Samson- and Nordvarg – Domes), these mounded features are not seen towards basin margins (Figure 4.5, Figure 4.10, Figure 4.14).

On the crest of the Loppa High, the Gipsdalen Group is suggested by Larssen et al. (2002) to be absent due to erosion updip, however successive draping of the Loppa High by upper Paleozoic siliciclastic deposits, evaporites and carbonates are known (Larssen et al., 2005; Larssen et al., 2002). In well 7120/2-1, which is located near the crest of the Loppa High, a thickness of 79m of the Ørn Formation (top Gipsdalen) is preserved, while further south the Ørn formation is over 1000m thick, which supports the suggested erosion updip. Gradual thinning of the S1 unit is also observed at the eastern side of the Loppa High. As described in Chapter 4.3.2 and Figure 4.10, the seismic interpretation done in this work, suggest that the Gipsdalen Group is present on the

Norsel High, but have a thinner development here than in the Ottar basin.

The Gipsdalen Group was generally deposited as rhythmically bedded limestone and dolomite with several cases of algal-buildups, and only minor evaporite content in the platform areas (Larssen et al., 2005). In basinal areas the Gipsdalen Group is mainly dominated by evaporites, while in areas near basin margins the upper part of the Gipsdalen Group is deposited as anhydrite interbedded by carbonates (Henriksen et al., 2011; Jensen & Sørensen, 1992; Larssen et al., 2005) (Figure 5.1 ,Figure 4.14). Based on regional studies and well correlations, lateral lithology variations are assumed to take place in the Gipsdalen Group, especially from the center of the Ottar Basin and towards the basin margins (Figure 5.1).

Observations from seismic show an onlap development of the upper part of unit S1 towards local highs near basin margins e.g. Norsel- and Loppa- High (Figure 5.3, Figure 5.6). The onlap can be interpreted as an infill of the Ottar basin due to being a basin downflank of the Norsel- and Loppa- High. This corresponds to observations by Larssen et al. (2005) which described an onlapping development of the Gipsdalen Group towards the Norsel High, and suggesting that the highs surrounding the Ottar basin became part of the basin at a later stage..

The high amplitudes along the horizon defining the top of unit S1 (top Ørn Formation) (Figure 4.10), also corresponds with Larssen et al. (2005)'s findings: the topmost part of the Gipsdalen Group is mainly dominated by halite and anhydrite deposits in the southwestern part of the Ottar basin, which causes an increase in acoustic impedance from the overlying Bjarmeland Group. In the northeastern part of the Ottar basin, less amplitude variations are observed compared to areas further southwest and might be interpreted to represent less changes in lithology between the Gipsdalen- and the overlying Bjarmeland Group (Veeken, 2007). The presence of the two slightly mobilized salt domes; Nordvarg- and Samson – Domes have been documented by several authors, which supports the presence of evaporitic content in the upper part of the S1 unit within the central part of the Ottar basin (Breivik et al., 1995; Gudlaugsson et al., 1998; Jensen & Sørensen, 1992; Mattos et al., 2016).

The difference in lithology of the Gipsdalen Group within the basin compared to the highs gives an important understanding of the depositional environment and for the delineation process, and a summarized interpretation of the lateral lithology difference is given in Figure 5.1. An important

observation is the location of the buildups which usually forms at basin margins due to greater circulation of nutrition at these high points (Rafaelsen et al., 2008). From other areas in the southwestern Barents Sea such as; Loppa High and the Finnmark Platform a correlation between paleo-topographical highs and the location of carbonate buildups has been shown (Rafaelsen et al., 2008). A similar trend is also observed and suggested for the Ottar basin, which will be presented in the chapter discussing the delineation of the Ottar basin (Figure 5.1).

5.1.2 The S2 unit - Bjarmeland Group

Unit S2 represents the Bjarmeland Group with the horizon assumed to represent the top Ørn Formation as the lower boundary and the top Ulv Formation as the upper boundary (Figure 4.10). The top Ulv Formation was chosen as the upper boundary due to the Isbjørn Formation of the Bjarmeland Group being generally less visible in seismic sections and being absent in well 7226/11-1 (Larssen et al., 2002). As described in Chapter 4.3.3 and Figure 3.2, the seismic interpretation done in this work, suggest that the S2 unit displays smaller variations in amplitude and internal reflection pattern both vertically and laterally compared to the underlying S1 unit and this is interpreted to represent its depositional environment: according to Worsley (2008) the shift between the Gipsdalen Group and the Bjarmeland Group was caused by a major flooding event and was probably related to the final waning of the Gondwanan ice cap. This caused abrupt changes in climatic conditions; going from warm and arid climate to cool-water conditions (Worsley, 2008) (Figure 5.1). This change can in seismic data used here be observed by a shift from a high amplitude, discontinuous pattern in the uppermost part of the S1 unit to lower amplitudes, and more continuous seismic pattern in the S2 unit (Figure 4.10).

The Bjarmeland Group is dominated by cool-water carbonates including buildups (Worsley, 2008), and such depositional features can be represented by several mounds observed along the margins of the Ottar basin (Figure 4.14, Figure 4.15). However, the depositional environment of the Bjarmeland Group in the central part of the deep Paleozoic Ottar basin is poorly understood, and could be interpreted as fine grained carbonates or shale (Rafaelsen et al., 2008; Worsley, 2008).

On both the Norsel High and towards the Loppa High, the S2-, and also the S3- unit (discussed

below) has internal reflection pattern with higher amplitudes than the underlying S1 unit, this amplitude variation is reversed within the basin, where the S1 unit has internal reflection pattern with higher amplitudes than the S2-, and S3- units (Figure 4.14). The shift in reflection configuration is interpreted as a change in lithology, suggesting that the S2 unit could represent a different setting within the basin, compared to the edges of the basin, which might be expected at a shallower paleo-water depth.

5.1.3 The S3 unit - Tempelfjorden Group

Unit S3 represents the Tempelfjorden Group with the top Ulv Formation as the lower boundary and top Røye Formation as the upper boundary (Figure 4.15). The Røye Formation was chosen as the upper boundary due to the Ørret Formation of the Tempelfjorden Group being less visible in seismic sections and also that it passes into the Røye Formation at the Loppa High location (Larssen et al., 2002).

As described in Chapter 4.3.4 and Figure 4.15, the seismic interpretation done in this work, suggest that the S3 unit is the thinnest unit (approx. 100ms TWT) of the three defined units and shows minor lateral and vertical variations. The unit shows a minor thickening trend west towards the Loppa High of about 50ms (TWT) (Figure 4.15). This unit also shows mounds at the basin margins (Figure 4.14). The mounds are located above the previous described mounds in unit S2. The mounds from the S3 unit could thus interpreted as buildups or draping of previous buildups. The lithology of potential buildups might be changing from unit S2 to S3. Stemmerik and Worsley (2005) and Rafaelsen et al. (2008) all concludes that the Tempelfjorden Group (S3) marks a shift in depositional pattern, and was separated from underlying sediments by subaerial exposure, especially in the platform areas and local highs. This incident caused deposition to mainly be dominated by deeper water spiculitic chert and shales (Figure 5.1), and as such, it could be suggested that the mounds observed in S3 could be more silica rich (spiculites) than consisting of carbonates as suggested for older mounded features.

5.1.4 The T1 unit – total upper Paleozoic

The above described S1, S2 and S3 units can be combined to represent a –T1 unit, encompassing the upper Paleozoic sediment distribution of the study area (Figure 4.11).

Based on the total sediment distribution of the upper Paleozoic, an estimate length of the Ottar basin during this period was measured to be approximately 200km in the southwest-northeast direction. The width of the basin varies in the east-west direction between approximately. 90km at the widest parts to approximately 40km at the narrower parts. The dimensions of the Ottar basin is thus comparable in dimensions and depth with the Nordkapp Basin. The interpretation of the Ottar basin's dimensions corresponds well with previous studies, suggesting a length of at least 170km and a varying width of 50-80km (Gudlaugsson et al., 1998), (Breivik et al., 1995).

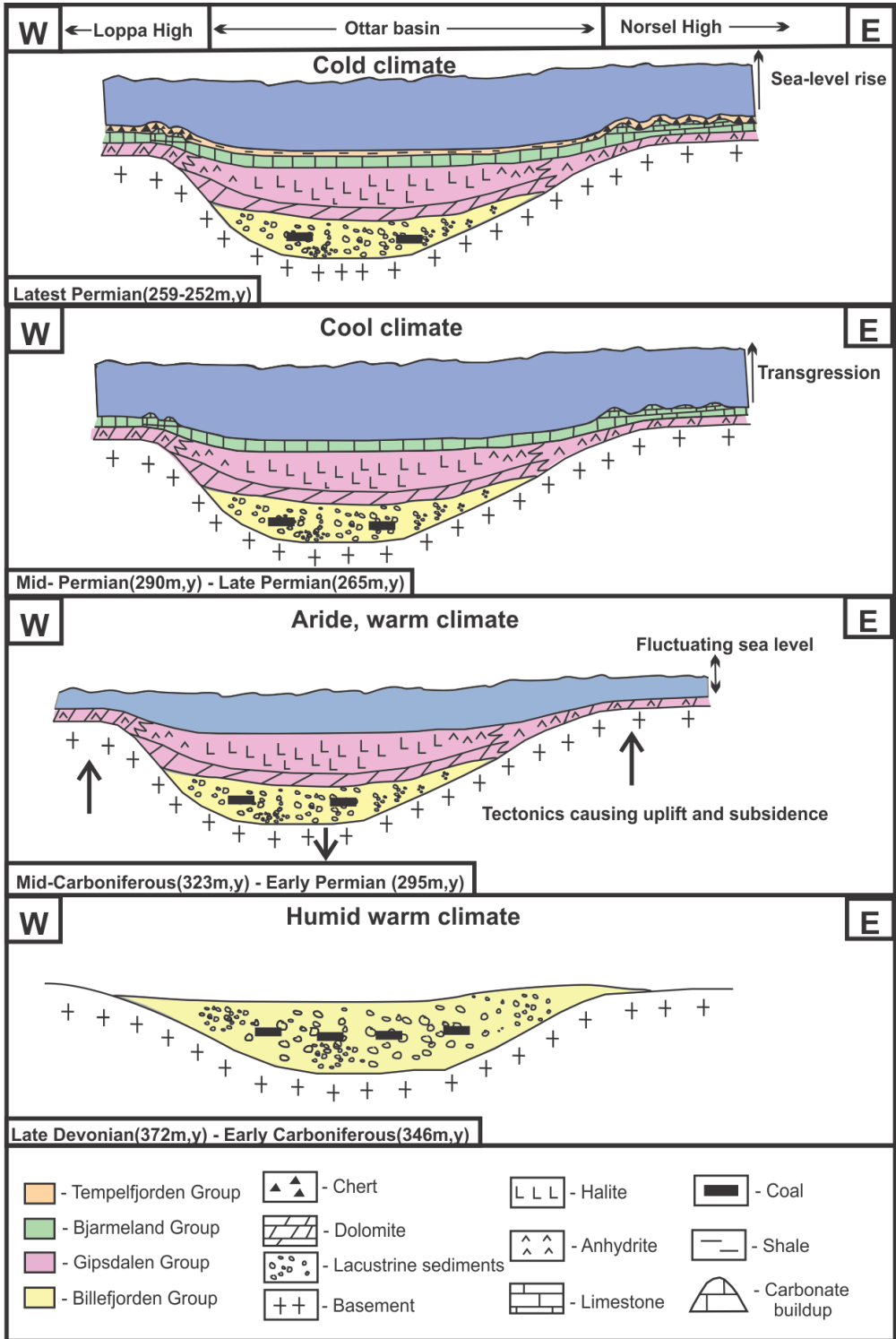


Figure 5.1 Proposed geological development 2D-model of the Ottar basin, illustrated by reconstruction of seismic line NBR06-251430. The highs in the figure represents Loppa High (W) and Norsel High (E). The proposed model is based on literature from (Faleide et al., 2015; Henriksen et al., 2011; Larssen et al., 2005; Larssen et al., 2002; Worsley, 2008)

5.2 Delineation of the Ottar Basin

In the following the delineation of the Ottar basin is discussed. The chapter will discuss profiles interpreted in this work and present them in a clockwise rotation starting at the western boundary (Figure 5.2).

5.2.1 Ottar basin

The Ottar basin is a structural element of the upper Paleozoic era (Breivik et al., 1995; Faleide et al., 2015). It is suggested located underneath the Permian succession on the southern part of the Bjarmeland Platform. Gernigon et al. (2014) suggests that the Ottar basin should be sub-divided into two parts, based on different magnetic lineament trends found in the two suggested parts; a southern Ottar basin located south of the Swaen Graben and an informally named Scott Hansen Complex located north of the Swaen-graben and includes the Nordvarg Dome (Figure 5.2).

Gernigon et al. (2014) studies are based on aeromagnetic data correlated with seismic.

Observations from seismic sections did not reveal any clear delineation pattern in close proximity to the Swaen-graben, which is possibly related to the slightly mobilized salt domes in the Ottar basin, and in this thesis the Ottar basin includes both of these proposed structural elements. Thus, the suggested sub-division of Gernigon et al. (2014) will not be applied in the following.

The definition of a basin is a circular downfolded structure (Lutgens et al., 2014). Tools that were used and combined for delineating the Ottar basin was seismic observations and geological interpretation.

Seismic observations examples; truncation of reflections, onlap of sediments, faults, time-thickness maps, etc.

Geological interpretation examples; lithology variations, diminishing basin fill etc.

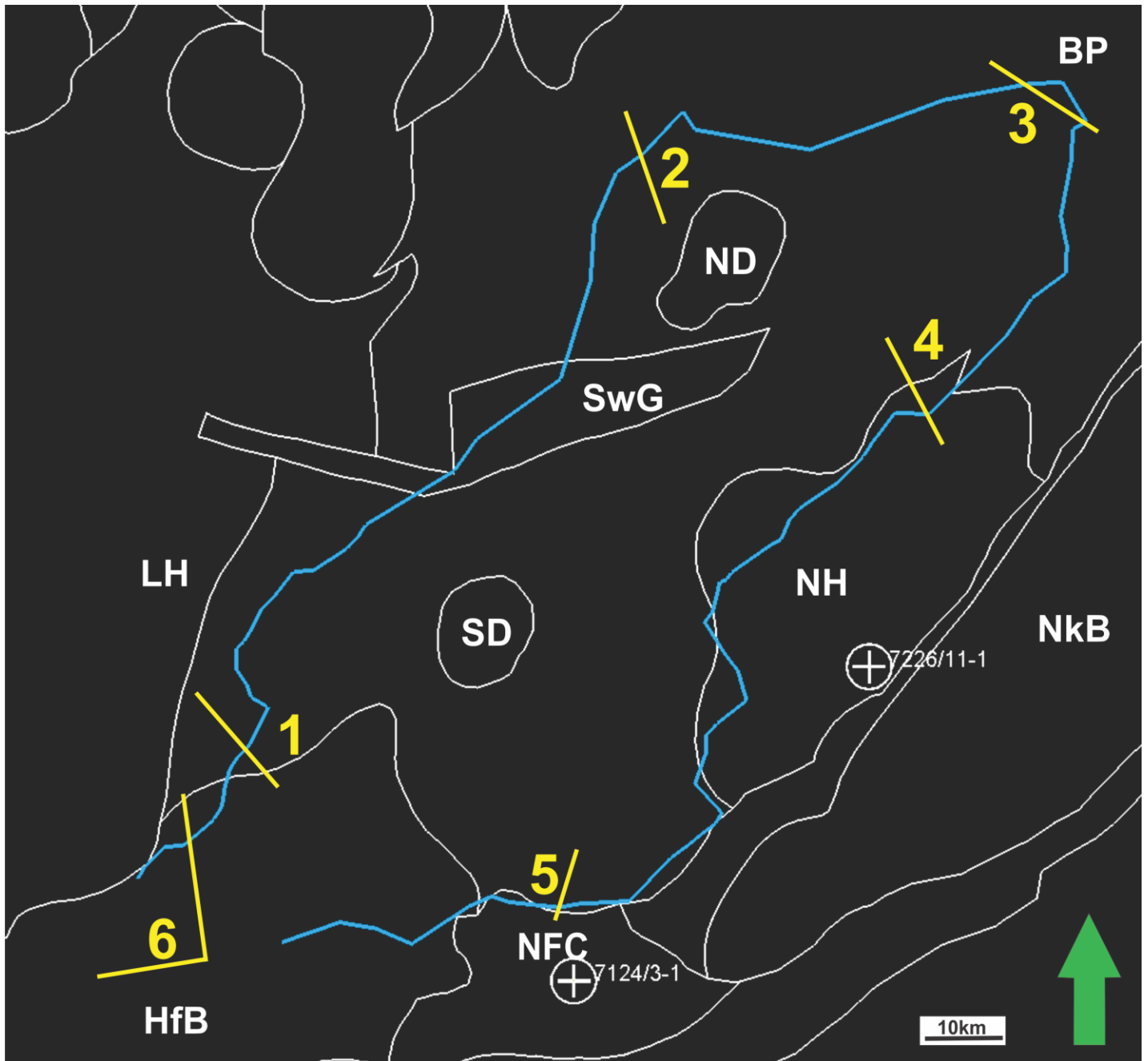


Figure 5.2 Overview of seismic line positions (yellow) used to determine the Otter basin boundary. Blue line represents the Otter basin delineation. Several important structural elements are included; BP – Bjarmeland Platform, HfB – Hammerfest Basin, LH – Loppa High, NkB – Nordkapp Basin, ND – Nordvarg Dome, NFC- Nysleppen Fault Complex, NH – Norsel High, SD – Samson Dome, SwG- Swaen-graben

The criteria for distinguishing the Ottar basin from the Loppa High to the southwest of the Swaen-graben, is based on onlap of reflections onto the adjacent Loppa High (Figure 5.2). The reflection configuration of the basin fill is interpreted as subparallel, and transitioning into a more parallel configuration towards the central parts of the basin. Chaotic reflection characteristics are displayed below the basin limit at approximately 3900ms (TWT) and is interpreted as the basement (Figure 5.3). At this location the basin has an average thickness of upper Paleozoic strata of approximately 1700ms (TWT).

By applying seismic attributes, the sediments in the basin show low structural variance (Figure 5.3B) and low chaos-characteristics (Figure 5.3C), while the basement underneath (5000ms TWT) and the adjacent high (3800ms TWT) show somewhat higher structural variance (Figure 5.3B) and higher chaos-characteristics (Figure 5.3C) (see section 3.5.1 Attributes).

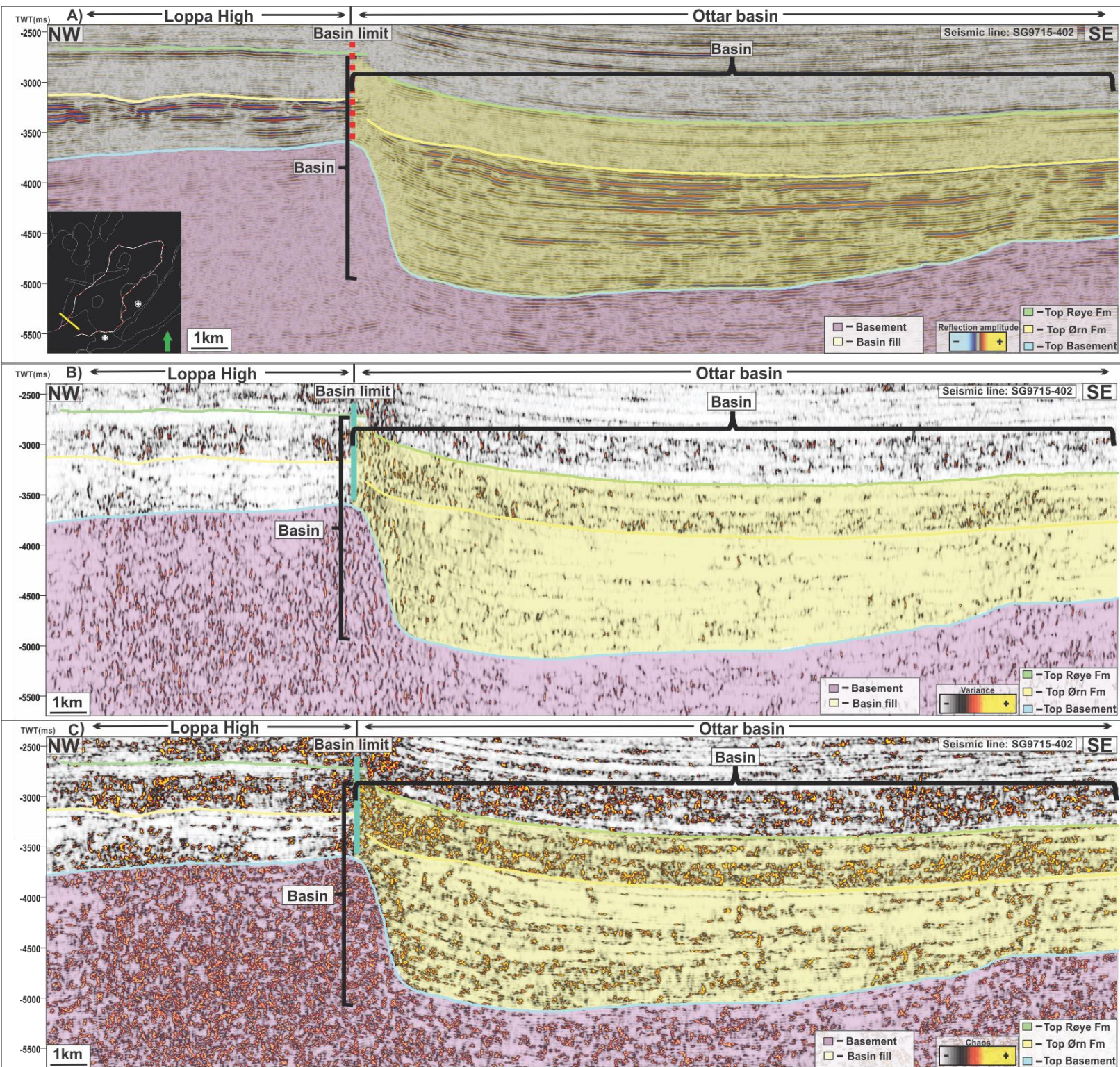


Figure 5.3 A) Seismic section displaying where the established delineation was set, inserted figure indicates position of seismic line. B) Variance-attribute applied to the seismic section A. C) Chaos-attribute applied to the seismic section A.

The criteria for distinguishing the Ottar basin from the Bjarmeland Platform, northwest of the Swaen-graben (Figure 5.2), is based on onlap of reflections onto the adjacent Bjarmeland Platform, a few buildups are also observed at this part of the Ottar basin, however they are not observed in this seismic line (Figure 5.4). The reflection configuration of the basin fill is defined as subparallel close to the basin margin. The observed updip towards the Nordvarg dome, is caused by the slight mobilization of the dome (Breivik et al., 1995). Chaotic reflection characteristics are displayed below the basin limit at approximately 3000ms (TWT) and is interpreted as the basement (Figure 5.4). The basin has an average thickness of upper Paleozoic strata of 1300ms (TWT) at this location and is considerably thinner than at the southwestern border.

By applying seismic attributes, the sediments in the basin show low structural variance (Figure 5.4B) and low chaos-characteristics (Figure 5.4C), the basement underneath (3700ms TWT) shows medium chaos-characteristic, possibly indicating a deeper top basement than what is interpreted here. The adjacent high (3800ms TWT) shows high structural variance (Figure 5.4B) and high chaos-characteristic (Figure 5.4C) (see section 3.5.1 Attributes).

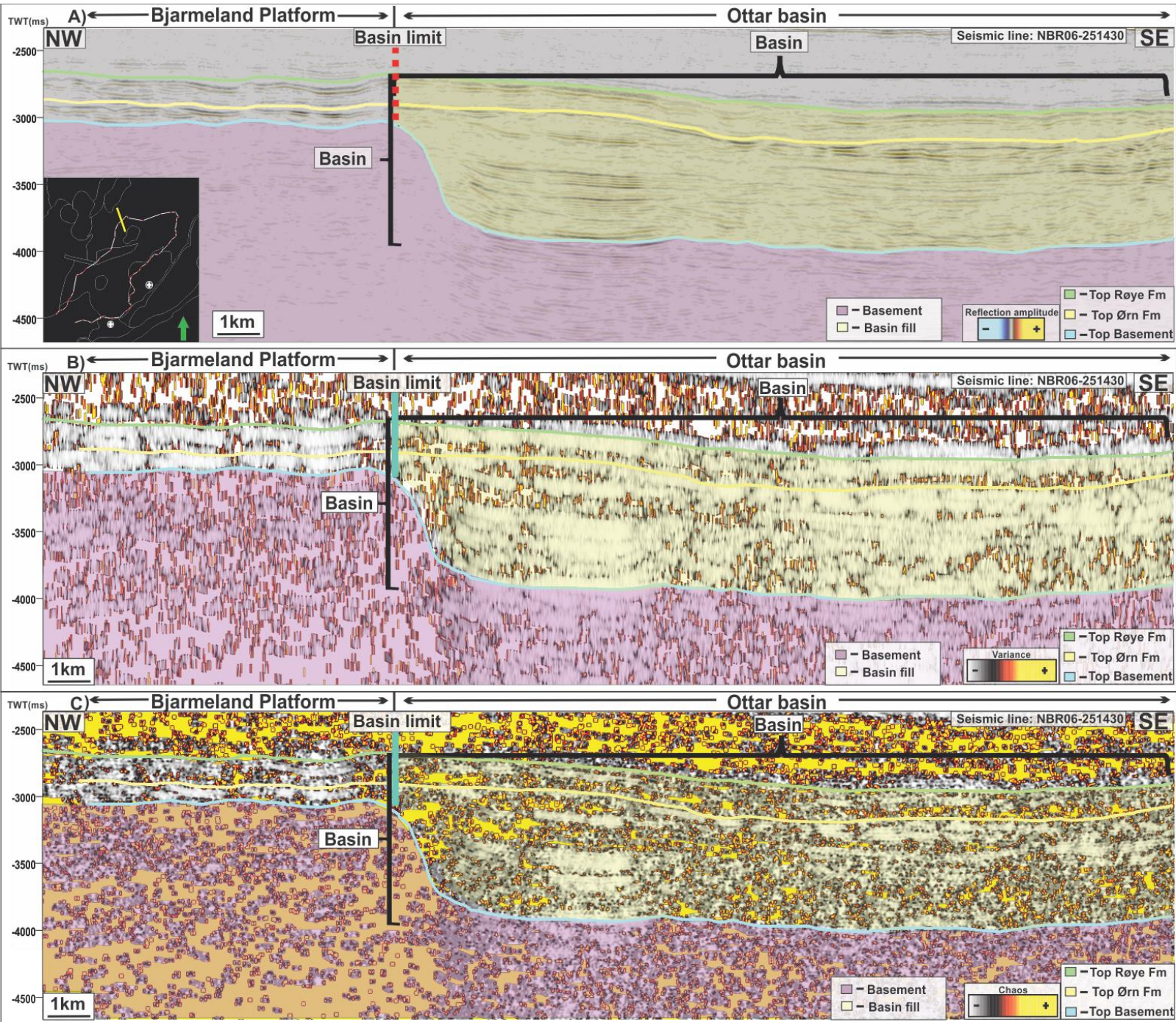


Figure 5.4 A) Seismic section displaying where the established delineation was set, inserted figure indicates position of seismic line. B) Variance-attribute applied to the seismic section A. C) Chaos-attribute applied to the seismic section A.

The criteria for distinguishing the Ottar basin from the Bjarmeland Platform, are based on several incidents of buildups on the adjacent basin margins (Figure 5.2). A few of the reflections located within the basin are observed to onlap the adjacent Bjarmeland Platform (Figure 5.5). The reflection configuration of the basin fill is defined as parallel at the central part of the Ottar basin. Chaotic reflection characteristics are located below the basin limits at approximately 3100ms (TWT) and is interpreted as the basement (Figure 5.5). The basin has an average thickness of upper Paleozoic strata of 500ms (TWT) at this location. Slightly further north towards the Bjarmeland Platform, the basin fill thins and diminishes at least below seismic resolution.

By applying seismic attributes, the sediments in the Ottar basin show low structural variance (Figure 5.5B) and low chaos-characteristics (Figure 5.5C). The basement underneath (3500ms, TWT) has a high structural variance (Figure 5.5B) and high chaos-characteristic (Figure 5.5C) characteristic. The buildups at the basin margins are observed with different variance- and chaos-characteristics compared to the adjacent sediments; the buildups show somewhat higher variance- and chaos-characteristics compared to the adjacent sediments (Figure 5.5B &C) (see section 3.5.1 Attributes).

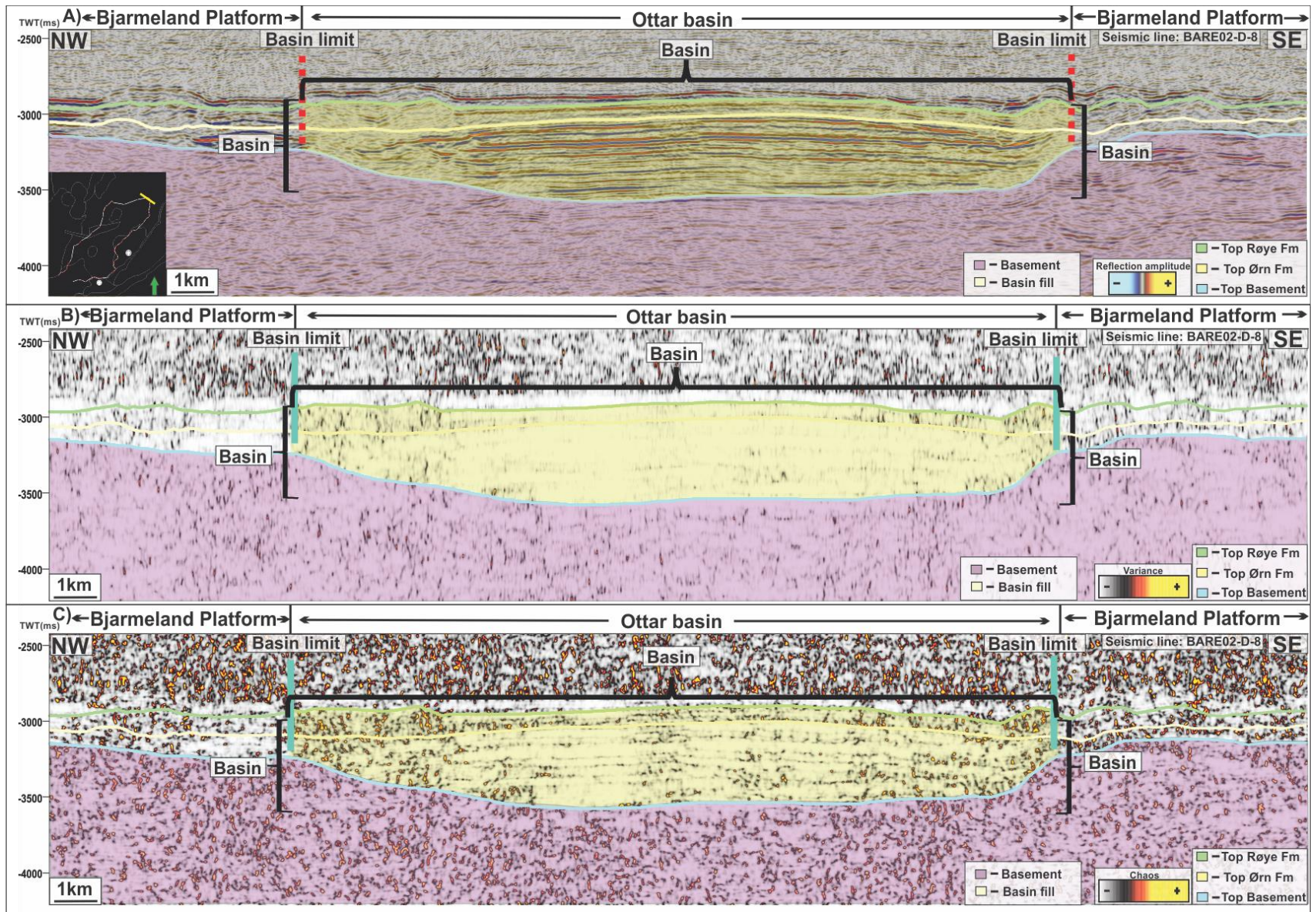


Figure 5.5 A) Seismic section displaying where the established delineation was set, inserted figure indicates position of seismic line. B) Variance-attribute applied to the seismic section A. C) Chaos-attribute applied to the seismic section A.

The criteria for delineating the basin towards the Norsel High (Figure 5.2), is based on onlap of reflections onto the adjacent Norsel High along with a few buildups located along the basin margin (Figure 5.6). The reflection configuration of the basin fill is defined as subparallel. Chaotic reflection characteristics are observed below the basin limit at approximately 3700ms (TWT) (Figure 5.6). A difference in reflection amplitude of the sediments within the basin compared to the ones on the adjacent high is observed. A few buildups are observed at approximately 2800ms (TWT), located towards the southeast of the seismic section. The basin fill has an average thickness of upper Paleozoic strata of approximately 1200ms (TWT) at this location.

By applying seismic attributes, the sediments in the basin show low structural variance (Figure 5.6B) and low chaos-characteristics (Figure 5.6C), with some layering of the strata. The basement underneath (3700ms TWT) shows a medium structural variance (Figure 5.6B), but high chaos-characteristic (Figure 5.6C). The suggested location for the Norsel High (4200ms TWT) shows a high structural variance and high chaos-characteristic (see section 3.5.1 Attributes).

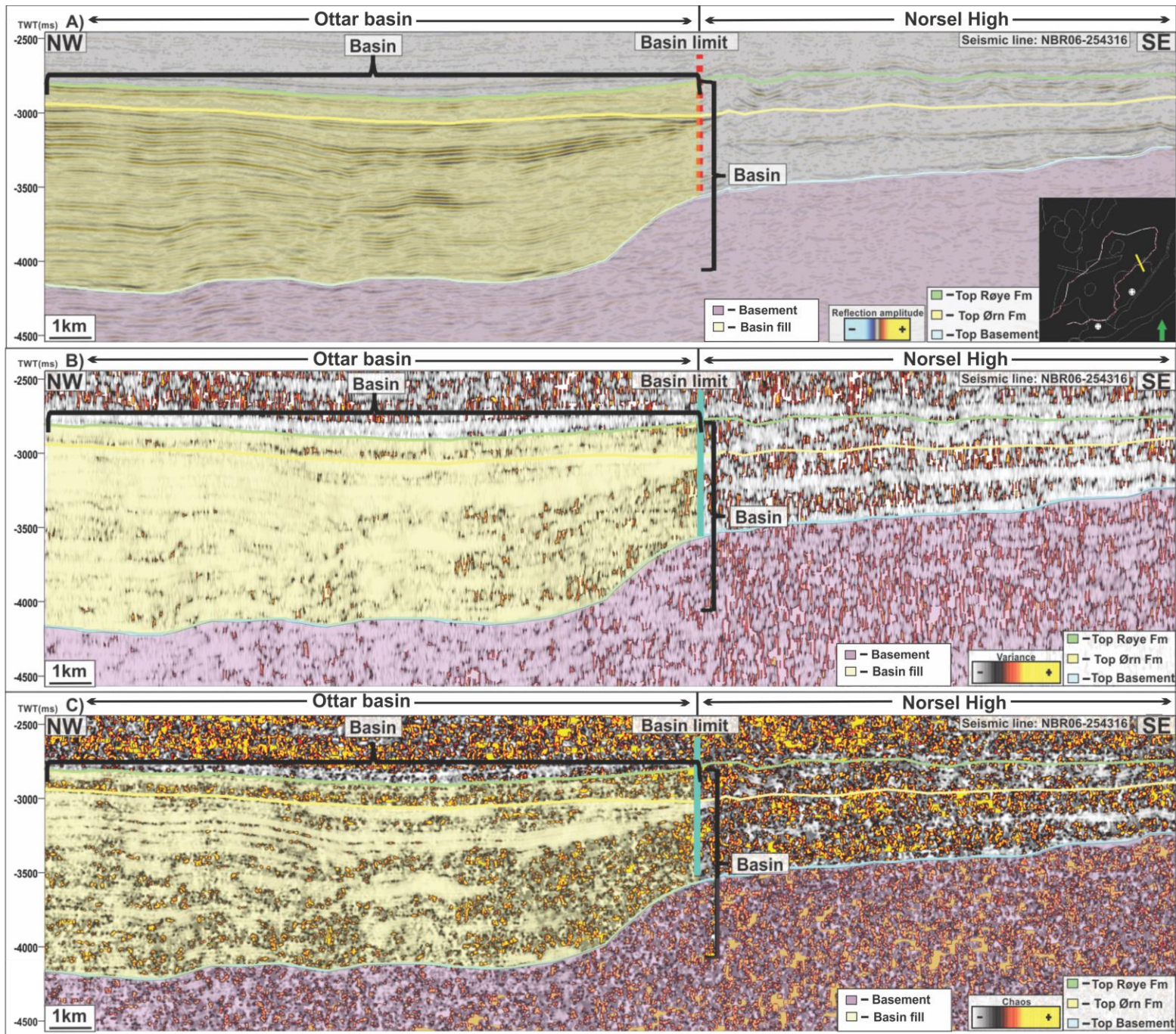


Figure 5.6 A) Seismic section displaying where the established delineation was set, inserted figure indicates position of seismic line. B) Variance-attribute applied to the seismic section A. C) Chaos-attribute applied to the seismic section A.

The criteria for delineating the basin towards the Nysleppen Fault Complex (Figure 5.2), is based on the diminishing basin fill along with onlap of reflections onto an adjacent local high (Figure 5.7). The reflection configuration of the basin fill is defined as parallel, with reflections showing a slight updip towards the local high. A few reflections at approximately 3700ms (TWT) is observed as truncated into the basement. Chaotic reflection characteristics are observed below the basin limit at approximately 3700ms (TWT) (Figure 5.7). A difference in reflection amplitude and frequency of the sediments within the basin compared to the ones on the adjacent local high is observed. The basin fill has an average thickness of upper Paleozoic strata of approximately 900ms (TWT) at this location.

By applying seismic attributes, the sediments in the basin show low structural variance (Figure 5.7B) and medium chaos-characteristics (Figure 5.7C), while the basement underneath (4000ms TWT) and the adjacent high (3500ms TWT) show medium structural variance (Figure 5.7B) and high chaos-characteristics (Figure 5.7C) (see section 3.5.1 Attributes).

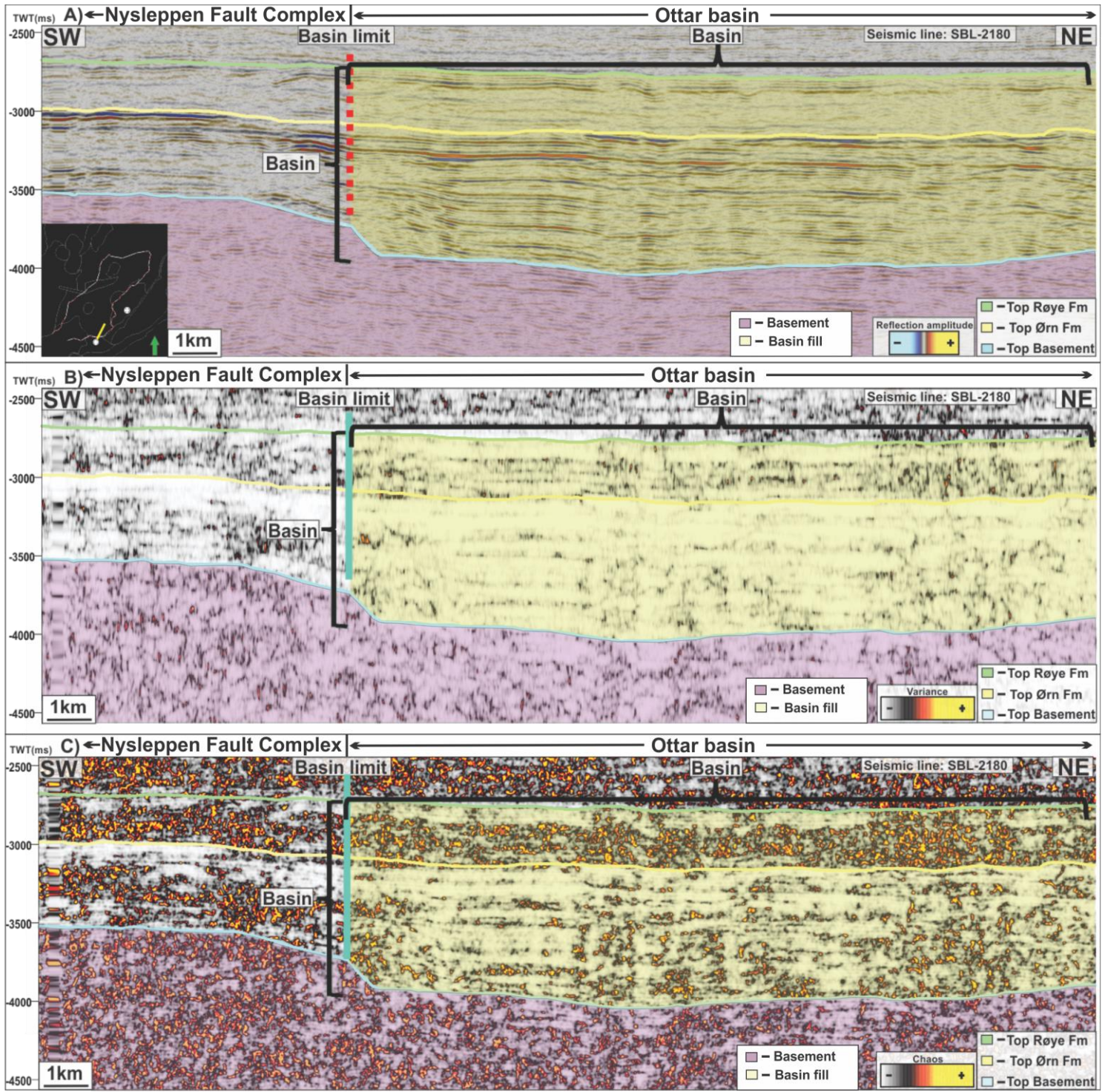


Figure 5.7 A) Seismic section displaying where the established delineation was set, inserted figure indicates position of seismic line. B) Variance-attribute applied to the seismic section A. C) Chaos-attribute applied to the seismic section A.

A composite line consisting of more than one seismic line was used to interpret the delineation towards the Hammerfest Basin (Figure 5.2), due to lack of seismic line coverage in the southwestern part of the study area (Figure 5.8). Many of the seismic lines had severe cases of disturbance (artefacts) in this part of the study area, this is one of the few composite lines that were possible to generate.

The delineation of the Ottar basin towards the Hammerfest Basin is difficult to establish. The paleo-Hammerfest Basin might have been connected to the Ottar basin at Paleozoic level as there is no abrupt termination of the Ottar basin at this location. Suggested by Dengo and Røssland (1992) the Hammerfest Basin in Late Devonian-Early Carboniferous time was originally a northeast trending half-graben, which coincides with the structural trend of the Ottar basin (Figure 2.1, Figure 2.2). However major salt structures like the Samson- and Nordvarg Dome have not been reported from the Hammerfest Basin, but there might be deep seated salt deposits that have escaped reactivation like the Ottar basin, although gravity surveys do not indicate the presence of major salt deposits. The complex structuring of the Hammerfest Basin from Late Jurassic to Early Cretaceous distorts the underlying seismic sections, preventing to follow Paleozoic-reflections further into the Hammerfest Basin. Further studies are needed to determine the proper delineation towards the Hammerfest Basin, with new seismic data consistently being released this should be achievable (Breivik et al., 1995).

A deepening trend of the Paleozoic section is observed further southwest, into the Hammerfest Basin. It seems like the Ottar basin transitions into the Hammerfest Basin by diminishing basin fill at a saddle point (Figure 5.8). This saddle point is suggested to mark the end of the Ottar basin towards the southwestern part of the study area (Figure 5.8). However, there are no clear delineation pattern towards this part of the study area. The total upper Paleozoic strata unit (T1) indicates a thickening sediment distribution towards the Hammerfest Basin (Figure 4.11), which supports the interpretation of a paleo-connection between the paleo-Hammerfest Basin and the Ottar basin.

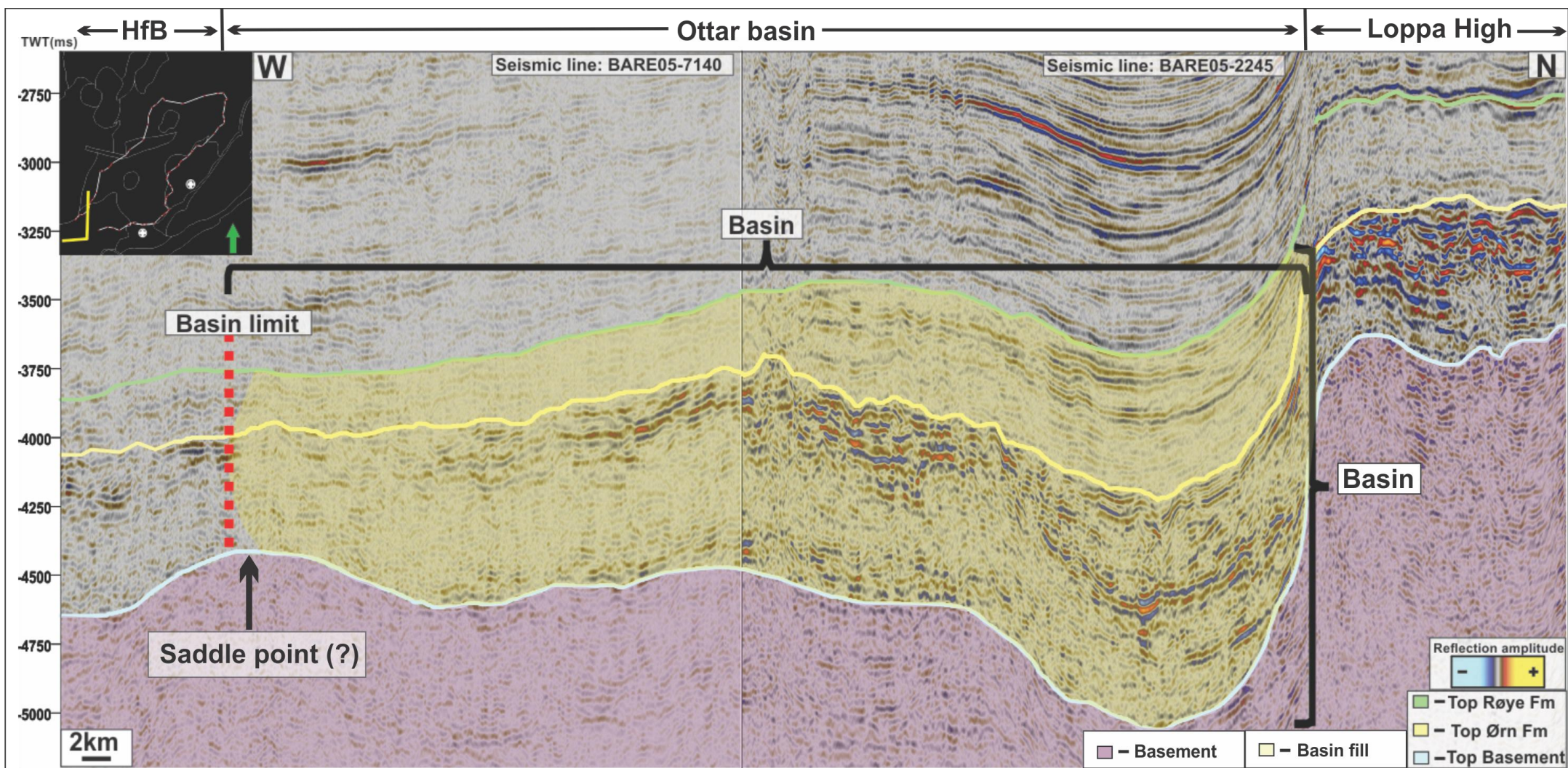


Figure 5.8 Seismic section displaying where the established delineation was set, inserted figure indicates position of the composite seismic line. A suggested saddle point between the Otter basin and the Hammerfest Basin is indicated in the figure. HfB-Hammerfest Basin

The newest seismic survey utilized in this study is from 2006, which is relatively old. With new, improved seismic data in terms of resolution constantly being released publicly, observations of Paleozoic structures and reflections might be easier. Newer and better seismic would especially be helpful towards the southwestern part of the study area, near the Hammerfest Basin.

The final proposed delineation of the Ottar basin is displayed in Figure 5.9.

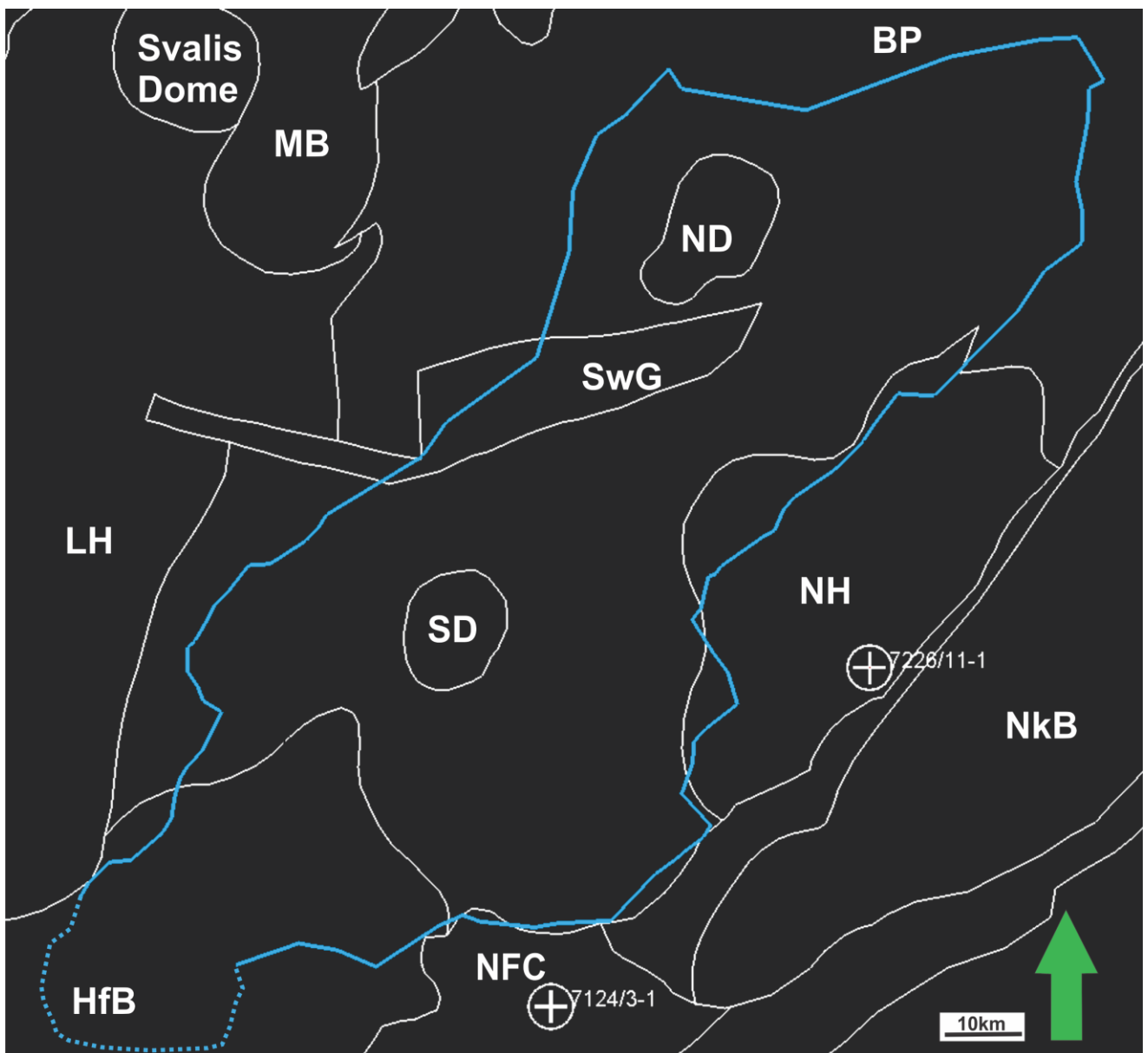


Figure 5.9 Proposed delineation of the Ottar basin (blue line), the dotted line towards southwest indicates uncertainty of the boundary. Structural elements: HfB- Hammerfest Basin, LH- Loppa High, SD- Samson Dome, SwG- Swaen Graben, ND- Nordvarg Dome, BP- Bjarmeland Platform, MB- Maud Basin, NH- Norsel High, NkB- Nordkapp Basin, NFC- Nysleppen Fault Complex.

6 Summary & Conclusion

- Three seismic units encompassing four different lithostratigraphic units of the upper Paleozoic succession have been interpreted (Billefjorden-, Gipsdalen-, Bjarmeland- and Tempelfjorden- Groups) and a geological development model of the Ottar basin and the adjacent areas have been proposed.
- The proposed delineation of the Ottar basin towards the Loppa High (west) is based on steep faults, which follows older tectonic lineaments along with onlap of the sediments situated in the Ottar basin onto the Loppa High.
- The proposed delineation towards the Bjarmeland Platform (north) is based on diminishing basin fill, buildups along basin margins and onlap of the basin fill onto the Bjarmeland Platform.
- The proposed delineation towards the Norsel High (east) is based on buildups along the basin margin along with onlap of the sediments situated in the Ottar basin onto the Norsel High.
- The delineation process towards the Hammerfest Basin (southwest) revealed no clear delineation patterns, however a thickening of the upper Paleozoic strata was observed, implicating that there might be a potential link between the paleo-Hammerfest Basin and the Ottar basin. The two basins might have been connected before the substantial tectonic events that occurred to the Hammerfest Basin during the Mesozoic era.
- Further research is required to establish a boundary of the Ottar basin towards the Hammerfest Basin, possibly further investigating the tectonic setting with focus on how the Ottar basin and Hammerfest Basin were initially formed.

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