NTNU – Trondheim
Norwegian University of
Science and Technology

Regional geological seismic interpretation of Triassic infill in the southwestern Barents Sea

Stian Bessesen Ekerheim

Petroleum Geoscience and Engineering
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Supervisor: Ståle Emil Johansen, IPT

Norwegian University of Science and Technology
Department of Petroleum Engineering and Applied Geophysics

Abstract

The Barents Sea has been subject to increasing focus through the years due to the discoveries of e.g. Havis, Skrugard and Nordvarg, which show some of the potential of the area. Despite 30 years of exploration large parts of the Barents Sea are still considered as relatively new frontiers, and the geological history is still open to new or more thorough theories. In 2011 MultiClient Geophysical (MCG) shot a 2D seismic survey in the southwestern Barents Sea with the aim of creating a solid frame for tying future surveys. This study uses the data acquired by MCG to map the Triassic infill in the southwestern Barents Sea. The Triassic period has been described as a relatively calm period of regional subsidence, and this study aims on explaining the factors responsible for the Triassic infill.

Through interpretation of the seismic lines and well tying, the Triassic deposits are divided in three; Sassendalen Group of Early to Mid Triassic age, Snadd Formation of Mid to Late Triassic age and Fruholmen Formation of Late Triassic age. The basinal development of the area is described through construction and interpretation of seismic profiles and time-thickness maps.

In Early Triassic time the southwestern Barents Sea received large amounts of sediments from the Ural Mountains in the east. Uplift of a NNE-SSW trending ridge from the Gardarbanken to western Loppa High in Permian–Early Triassic time divided the region in two subsiding areas. While the western basinal area was quite sheltered by the ridge, the eastern area received large amounts of sediments. In the upper part of Sassendalen Group seismic clinoforms show westward progradation onto the ridge. Snadd Formation represents a shift in Mid Triassic time. The ridge was inverted, and the area turned into a large, subsiding basin with the Loppa High area as depocentre. And in addition to the Baltic provenance area, general eastward thinning suggests a provenance area west of the southwestern Barents Sea. In the Nordkapp and Maud Basins as well as locally on the Bjarmeland Platform salt tectonics played an important role in altering accommodation space throughout the Triassic period. Fruholmen Formation is a very thin unit, but it is very similar to Snadd Formation. The uplift of the ridge that divided the region in Early to Mid Triassic times is related to Late Permian extension from

the North Atlantic rifting system, and the inversion of the ridge resulted from a Triassic renewal of the rifting.

Sammendrag

Barentshavet har de senere årene fått stadig mer oppmerksomhet som følge av oppdagelsene av bl.a. Havis, Skrugard og Nordvarg som viser noe av områdets potensiale. På tross av utforskning de siste 30 årene regnes fremdeles store deler av Barentshavet for å være relativt ukjent territorium, og den geologiske historien er åpen for nye eller mer utdypende teorier. I 2011 skjøt derfor MultiClient Geophysical (MCG) en 2D-seismisk undersøkelse i det sørvestre Barentshavet. Tanken var å lage et sikkert rammeverk man kan knytte annen seismikk til, og dermed gjøre det lettere å kombinere ulike undersøkelser i fremtiden. Denne studien benytter dataene fra MCG til å kartlegge den triassiske innfyllingen i det sørvestre Barentshavet. Trias har blitt beskrevet som en relativt rolig periode med regional innsynkning i Barentshavet, og denne studien tar sikte på å forklare hvilke faktorer som spilte inn under den triassiske innfyllingen.

Gjennom å tolke de seismiske linjene og knytte dem til letebrønner, deles de triassiske avsetningene i tre deler; Sassendalengruppen fra tidlig til midtre trias, Snaddformasjonen fra midtre til sen trias og Fruholmenformasjonen fra sen trias. Ved å konstruere og tolke seismiske profiler og tids-tykkelseskart beskriver denne studien bassengutviklingen i området.

I tidlig trias mottok det sørvestre Barentshavet store mengder sedimenter fra Uralfjellene i sørøst. Heving av en NNØ-SSV-orientert rygg i perm–tidlig trias fra Gardarbanken til Loppa delte regionen i to innsynkningsbasseng. Ryggen skjermet det vestre bassenget for mye av sedimenttilførselen. I den østre delen var tilførselen av sedimenter så stor at seismiske klinoformer viser prograderende avsetning vestover i øvre Sassendalen. Snadd representerer et skifte i midtre trias til et stort, regionalt basseng med Loppa som deposenter, samt sedimenttilførsel fra vest over Loppa i tillegg til baltisk tilførsel fra øst. I Nordkappbassenget, ved Maudbassenget og lokalt på Bjarmelandsplatformen førte salttektonikk til lokal bassengutvikling

gjennom hele trias. Fruholmen er en veldig tynn avsetning, men den viser mye av den samme utviklingen som Snadd. Hevingen av ryggen som delte det sørvestre Barentshavet i tidlig trias, er mest sannsynlig et resultat av ekstensjonspåvirkning fra riftingen i den nord-atlantiske midthavsryggen i perm, mens den regionale innsynkningen fra midtre trias representerer en fornyelse av riftingen.

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1 Introduction

The Barents Sea is part of the Arctic Ocean. It is located as shown in Figure 1 between Norway, Svalbard, Franz Josef Land and Novaya Zemlya. In this study I will focus on the southwestern part indicated by the black square. Exploration of the Barents Sea has been going on for the last 30 years, and the geological evolution of the area has been subject to investigation in several studies (e.g., Faleide et al. (1984); Glørstad-Clark et al. (2010); Gernigon and Brönner (2012)). However, the lack of good seismic data from the northwestern Barents Sea (Riis et al., 2008) and the lack of high quality deep seismic data point to the importance of further studies to improve our understanding of this relatively new frontier. Especially considering that recent hydrocarbon discoveries in the southwestern Barents Sea (e.g. Skrugard, Havis and Nordvarg) have increased the economic potential and interest for the area (Abrahamson, 2013).

In short terms the evolution of the region is explained as the result of Caledonian Orogeny, Devonian compressional and extensional tectonics, Carboniferous rifting, Permian and Triassic subsidence, Jurassic and Cretaceous extensional tectonics and Cenozoic uplift and erosion. In Ekerheim (2012) I looked into these events by studying literature (e.g. Faleide et al. (1984); Gernigon and Brönner (2012); Gudlaugsson et al. (1998); Glørstad-Clark et al. (2010)) and by interpreting one seismic line from MCG's 2011 supertie survey (seismic line 05, Figures 2, 7 and 35).

Figure 1: Geographical location of the study area (Ekerheim, 2012).

In this study I focus on interpreting the Triassic depositional unit throughout the study area. The Triassic deposits constitute a substantial part of the stratigraphy of the southwestern Barents Sea (lithostratigraphic column, Figure 3) and indicate a large-scale subsidence. Through this study I will describe the Triassic basinal history in the southwestern Barents Sea to find out which factors are controlling

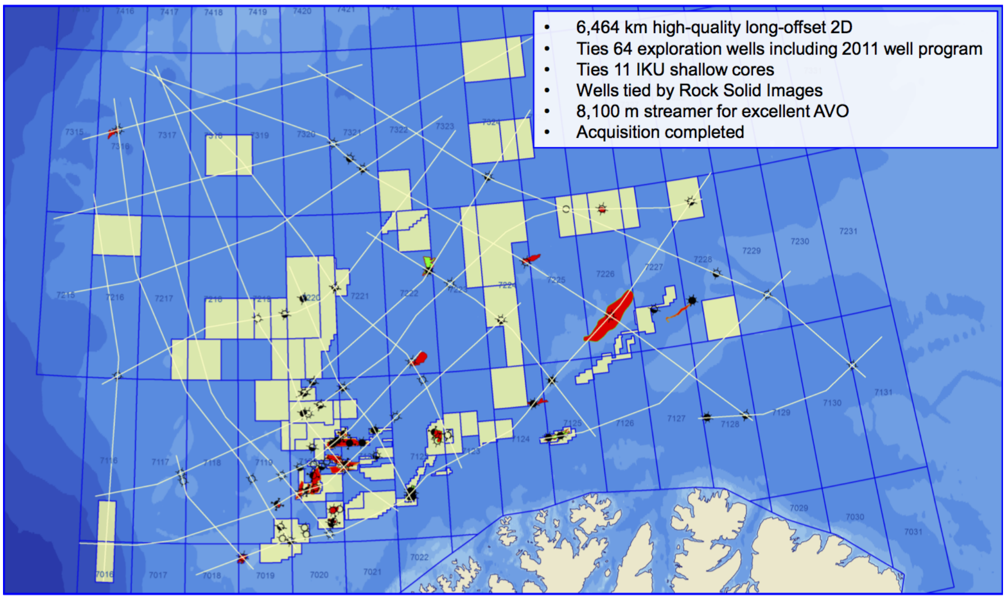


Figure 2: MCG's 2011 Barents Sea Supertie (MCG, 2011). The seismic 2D lines 00-09 are shot approximately SE-NW, and the lines 20-30 are shot approximately SW-NE.

the Triassic infill.

I have interpreted all the seismic lines from the MCG-survey and done well correlation with 24 well logs from NPD. The wells are located at points where the seismic lines intersect each other. From the seismic lines including Triassic interpretation I have constructed seismic profiles. The Triassic part of the Mesozoic supersequence is subdivided into three subsequences; Sassendalen Group, Snadd Formation and Fruholmen Formation. From the seismic profiles I have created time-thickness maps for each of the three Triassic subsequences.

Observed seismic clinoforms in the Sassendalen Group tell us that the Early to Mid Triassic was a time of massive sediment supply from east-southeast. Large rivers transported huge amounts of sediments from the Ural Mountains (Jacobsen and van Veen, 1984; Johansen et al., 1993; Riis et al., 2008; Skjold et al., 1998; Smelror et al., 2009; van Veen et al., 1993; Glørstad-Clark et al., 2010; Ramberg et al., 2007). The sediments were deposited as prograding deltas since the supply was greater than the subsidence. For the northern Barents Sea there has been suggested a northeastern source area (Mørk et al., 1989; Mørk and Worsley, 1982; Nøttvedt et al., 1993; Rønnevik et al., 1982; Skjold et al., 1998; van Veen et al., 1993), but the evidences are scarce. Glørstad-Clark et al. (2010) suggest Greenland or the Stappen High as the source area for Late Triassic sedimentation. For the southwestern Barents Sea a western source is indicated by Glørstad-Clark et al. (2010) in Late Triassic time by clinoforms at the southwestern edge of the Loppa High, showing sediment transportation eastwards. At the Finnmark Platform and in the Nordkapp Basin coastal and channel sands indicate an eastern or south-eastern provenance area (Worsley, 2008). This sediment supply from both east and west indicates that the southwestern Barents Sea was gradually being filled through Triassic time.

The seismic profiles and the time-thickness maps show how Early to Mid Triassic times were subject to great sediment supply into the eastern part of the study area. Seismic clinoforms show westward progradation and onlapping onto the paleo-Loppa High that was part of a SSW-NNE trending ridge dividing the southwestern Barents Sea in two. Permian–Early Triassic uplift of the paleo-high along with reactivation of the Troms-Finnmark Fault Complex created accommodation space south and east of the high. In the Nordkapp and Maud Basins salt movement from Early Triassic time locally altered accommodation space.

Through Mid and Late Triassic times extensional influence from the North Atlantic rifting inverted the paleo-Loppa High and turned it into the depocentre for a large subsiding area. Locally salt altered accommodation space, being most prominent in the Nordkapp Basin. Local subsidence in the Hammerfest, Bjørnøya and Tromsø Basins is also observed. This subsidence is related to fault movement in normal faults that were active during Late Triassic–Jurassic times.

2 Geological evolution of the southwestern Barents Sea

In Early Carboniferous time the Barents Sea was part of the Laurentian continent located at the equator (Ramberg et al., 2007). Today the area is located in the Arctic, and the different climate zones in-between the equator and the Arctic have left their marks in the stratigraphy (Ramberg et al., 2007). The typical stratigraphy of the western Barents Sea is shown in Figure 3. The structural elements in the southwestern Barents Sea (Figure 6) bear witness of the tectonic history, mainly three post Caledonian phases (Faleide et al., 1984). These are the Svalbardian phase, the Mid and Late Kimmerian phase and the Laramidian phase (Faleide et al., 1984).

2.1 Late Paleozoic

The Caledonian Orogeny resulted from the collision of Baltica and Laurentia. It influenced the Barents Sea area by compression during Silurian and Early Devonian times (Figure 4a) (Gernigon and Brönner, 2012). The basement in the area is of Caledonian origin and was most likely the northern flank of the Caledonides (Gernigon and Brönner, 2012). On top of the basement there are Caledonian sediments as a result of uplift and erosion by the compressional regime at the time (Faleide et al., 1984).

From Late Devonian to Mid Carboniferous times the tectonic regime was dominated by extension (Figure 4b), leading to the development of rift basins in the southwestern Barents Sea (Lippard and Roberts, 1987; Gabrielsen et al., 1990; Dengo and Røssland, 1992; Jensen and Sørensen, 1992; Nøttvedt et al., 1993). This process is referred to as the Svalbardian phase by Faleide et al. (1984). The alignment of horst and graben structures sugests that the Svalbardian phase reactivated faults in Caledonian zones of weakness (Faleide et al., 1984; Gudlaugsson et al., 1998; Glørstad-Clark et al., 2010).

As the Barents Sea area moved further north, the climate changed. By Mid Car-

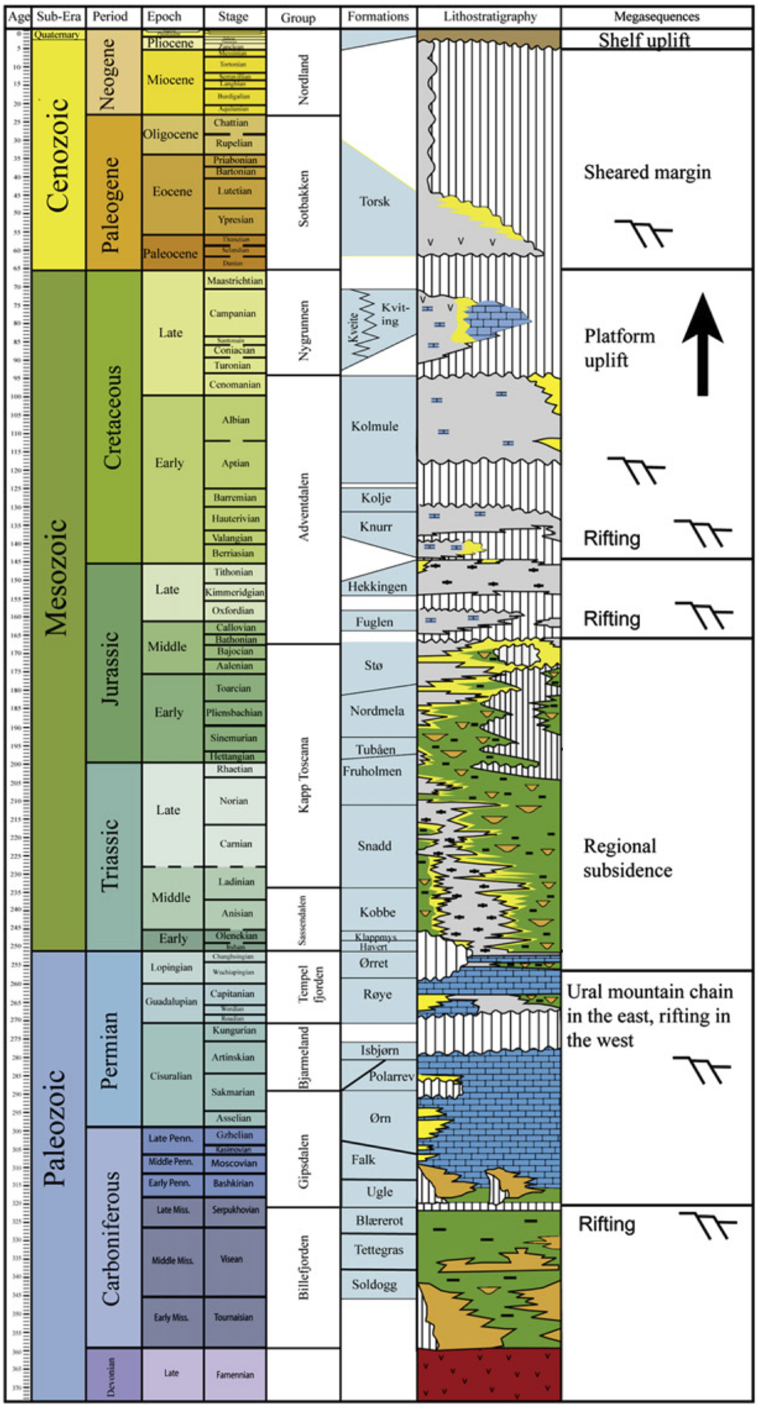
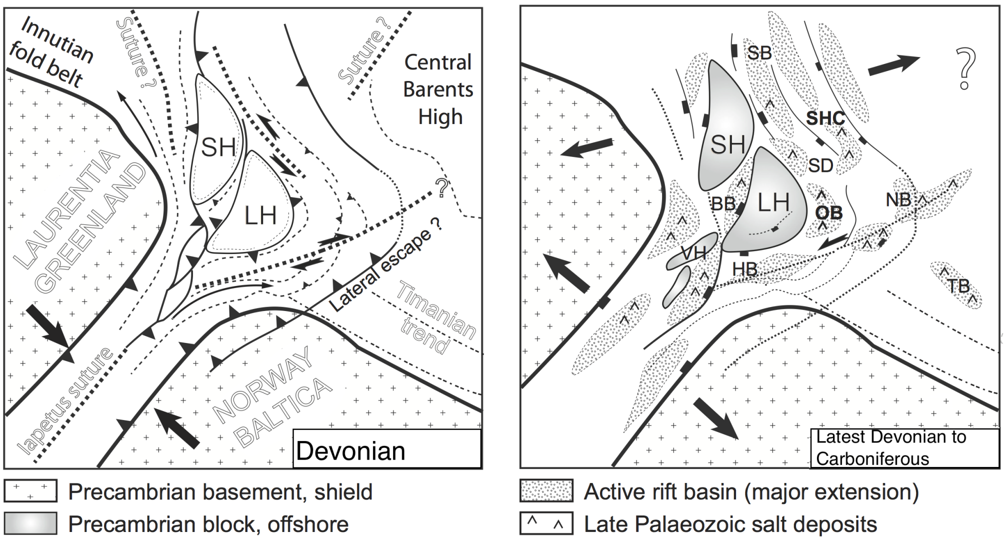


Figure 3: Litostratigraphy from the western Barents Sea. Modified from Nøttvedt et al. (1993); Larssen et al. (2002) by Glørstad-Clark et al. (2010). Red, basement; green, fluvial shale; brown, fluvial sand; black, coal; white, hiatus; blue, carbonate; yellow, marine sand; grey, marine shale.



(a) Sketch showing lateral escape caused by the collision of the two continents (Gernigon and Brönner, 2012).

(b) Sketch showing Late Paleozoic graben development by reactivation of faults in the basement (Gernigon and Brönner, 2012).

Figure 4: Devonian and Carboniferous structural sketches made by Gernigon and Brönner (2012). BB, Bjørnøya Basin; HB, Hammerfest Basin; LH, Loppa High; NB, Nordkapp Basin; OB, Ottar Basin (south); SB, Sørkapp Basin; SD, Svalis Dome; SH, Stappen High; SHC, Palaeozoic Scott Hansen complex (informal); TB, Tiddlybanken Basin; VH, Veslemøy High.

boniferous time there was an arid climate and deposition of carbonates and evaporites. This created a carbonate platform extending from the Pechora Basin in today's Russia to the Sverdrup Basin in today's Canada (Ramberg et al., 2007; Faleide et al., 1984; Gudlaugsson et al., 1998).

From Late Carboniferous to Permian time the tectonic activity quieted. Late Permian subsidence, along with the influence of compressional events east of the area and extensional events west of the area, gave rise to the paleo-Loppa High (Gabrielsen et al., 1990; Gudlaugsson et al., 1998; Ziegler, 1988, 1989). By Late Permian time the rift system between Norway and Greenland led to the opening of a seaway connecting the European basins and the Arctic, but during Triassic time the southern opening of this seaway was closed (Faleide et al., 1984; Müller et al., 2005; Nødttvedt et al., 2008).

2.2 Mesozoic

In the Mesozoic era the Barents Sea was part of the Boreal Sea at the northern border of Pangaea (Ramberg et al., 2007; Glørstad-Clark et al., 2010). As the climate got more humid, great rivers moved large amounts of sediments to the epicontinental seaway at the Barents Sea (Glørstad-Clark et al., 2010; Ramberg et al., 2007). The rivers deposited thick sands in the eastern Barents Sea and silts in the western Barents Sea. The deposition was strongly influenced by transgression and regression (Glørstad-Clark et al., 2010; Ramberg et al., 2007).

Erosion of the Ural Mountains southeast of the Barents Sea is assumed to be the most important source for sediments deposited in the Barents Sea during the Triassic period (Jacobsen and van Veen, 1984; Johansen et al., 1993; Riis et al., 2008; Skjold et al., 1998; Smelror et al., 2009; van Veen et al., 1993; Glørstad-Clark et al., 2010). For the northern Barents Sea and Svalbard a northeastern source area has been suggested by Mørk et al. (1989); Mørk and Worsley (1982); Nøttvedt et al. (1993); Rønnevik et al. (1982); Skjold et al. (1998); van Veen et al. (1993) based on quite scarce seismic data and outcrop studies.

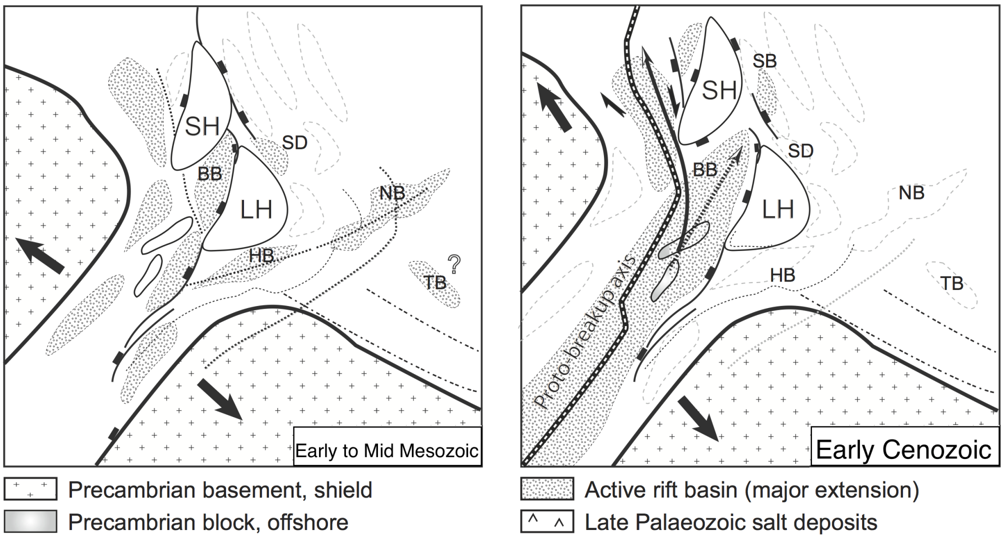
The tectonic activity during Triassic time was relatively low, but tectonic subsidence, fault reactivations and changes in sediment supply all together affected accommodation space and infill of the western Barents Sea (Glørstad-Clark et al., 2010). Several phases of minor uplift during Early Triassic time created islands that influenced the development of local accommodation space in Mid Triassic time (Glørstad-Clark et al., 2010). The stress regime shifted to extensional in Late Triassic time (Faleide et al., 1984; Glørstad-Clark et al., 2010).

In Early Jurassic time most of the dominant Hammerfest Basin was covered by a coastal plain as subsidence balanced the sediment supply (Ramberg et al., 2007). At the end of the Early Jurassic epoch, however, the Hammerfest Basin was flooded due to increased subsidence (Ramberg et al., 2007). The Mid Kimmerian phase in Mid to Late Jurassic time is seen in Figure 5a. This phase was a reactivation of rifting in the Norwegian-Greenland Sea (Glørstad-Clark et al., 2010; Faleide et al., 1984; Ramberg et al., 2007). The extension led to subsidence along normal faults in the Bjørnøya, Tromsø and Harstad Basins (Faleide et al., 1993a,b). At the transition from Jurassic to Cretaceous time the Late Kimmerian phase resulted in rotated fault blocks and the rise of the Loppa, Sentralbanken and Stappen Highs (Ramberg et al., 2007; Faleide et al., 1984).

The rifting between Norway and Greenland went along the edge of the Barents Shelf, and its influence on the Barents Sea became less prominent (Ramberg et al., 2007). Subsidence in Early Cretaceous time created accommodation space in the western basins in the southwestern Barents Sea while the eastern part remained quite stable (Faleide et al., 1993b). In the Late Cretaceous–Early Cenozoic transition the influence of the rifting in the North Atlantic increased again (Faleide et al., 1993b). Activation of normal faults gave subsidence near the margin in the west, local deformation caused by compression along some faults, and uplift of the Svalbardian Platform (Faleide et al., 1993b; Gabrielsen et al., 1990; Faleide et al., 1984).

2.3 Cenozoic

In Early Cenozoic time a continental break-up reactivated the Kimmerian system (Figure 5b), turning the Barents Sea into a sheared margin (Dimakis et al., 1998;



(a) Structural sketch showing the rifting responsible for the main stage of graben development (Gernigon and Brönner, 2012).

(b) Structural sketch showing the final continental breakup between Laurentia and Baltica (Gernigon and Brönner, 2012).

Figure 5: Structural sketches made by Gernigon and Brönner (2012). BB, Bjørnøya Basin; HB, Hammerfest Basin; LH, Loppa High; NB, Nordkapp Basin; SB, Sørkapp Basin; SD, Svalis Dome; SH, Stappen High; TB, Tiddlybanken Basin.

Faleide et al., 1991, 1993b). This phase is called the Laramide phase, and it resulted in block faulting, subsidence and westward tilting close to the margin (Faleide et al., 1984). The Nordkapp and the Hammerfest Basins were uplifted and the the Upper Cretaceous rocks eroded (Rønnevik et al., 1982; Faleide et al., 1984; Ramberg et al., 2007). In Mid Cenozoic time the Barents Shelf became a source area as the margin was uplifted. The sediments were deposited in Mid and Late Cenozoic time as a subsiding wedge west of the margin (Faleide et al., 1984, 1993b).

2.4 Structural elements

In Figure 6 we see the main structural features in the southwestern Barents Sea. Gabrielsen et al. (1990) have made a detailed overview of these structures. This

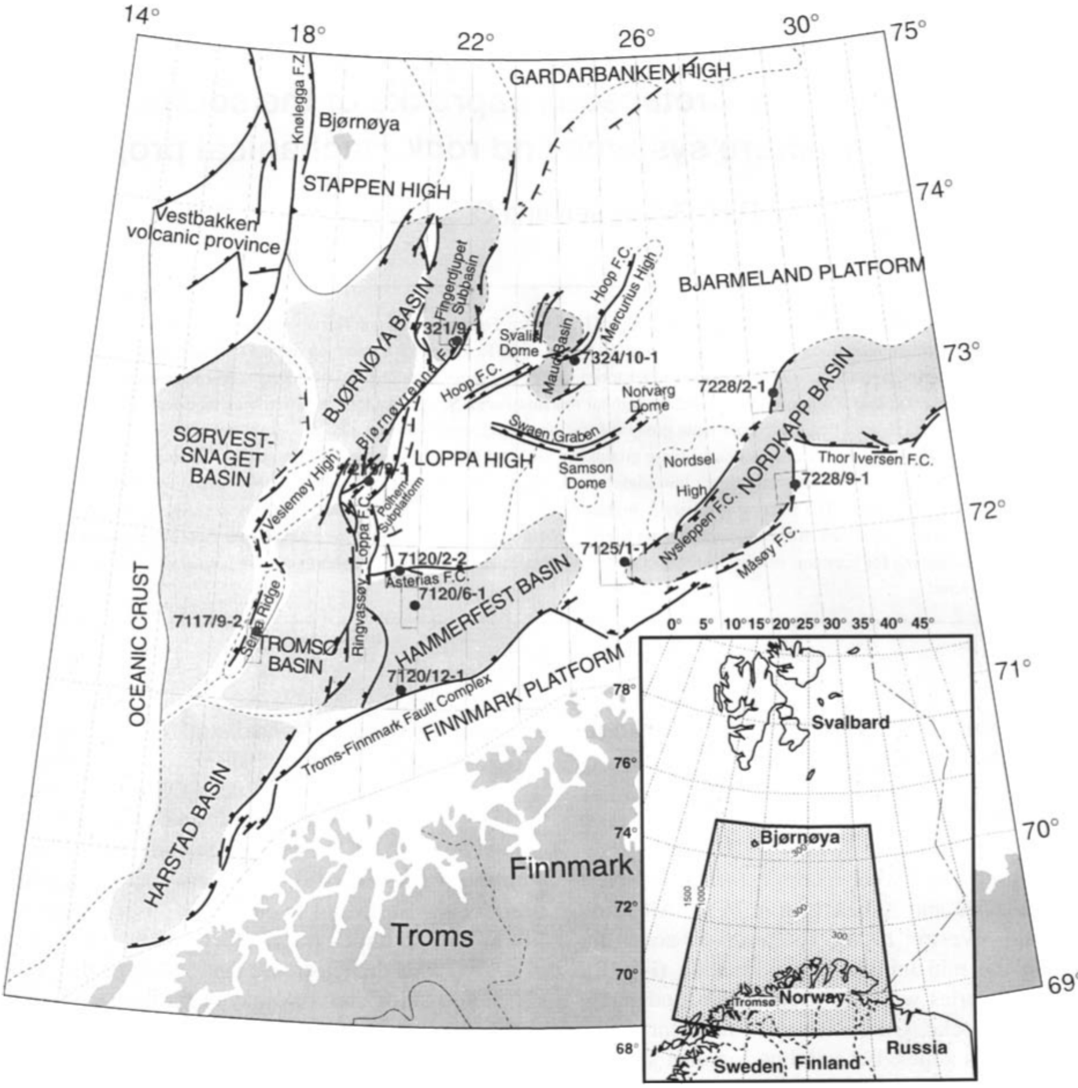


Figure 6: Map of the structural elements in the southwestern Barents Sea (Gabrielsen and Kløvjan, 1997).

section summarizes the most important information of the structural features of interest when having Triassic interpretation in mind.

2.4.1 Asterias Fault Complex

The Asterias Fault Complex separates the Loppa High and the Hammerfest Basin (Figure 6). The fault complex may have been an active inverse structure during Late Triassic time when the Loppa High area acted as a depocentre. The implication of this is that the fault complex was hinge to a northerly basin in earlier times, and that later subsidence to the south reactivated the hinge zone. In the transition from Jurassic to Cretaceous time inversion was renewed, and a great uplift along the fault complex took place in Early Cretaceous time (Gabrielsen et al., 1990).

2.4.2 Bjarmeland Platform

The Bjarmeland Platform (Figure 6) is a stable area south of Gardarbanken High, east of the Fingerdjupet Subbasin and the Loppa High and north of the Hammerfest and Nordkapp Basins. The Mercurius and Norsel Highs, the Swaen Graben, the Maud Basin, the Svalis, Nordvarg and Samson Domes and partly the Hoop Fault Complex are part of the platform. In Late Carboniferous time the Bjarmeland Platform started developing into a stable platform. A north-south oriented fault zone terminated the platform to the west in Late Permian to Early Triassic times. Throughout this time there was a structural high east of this fault zone. However, this uplifted area turned into a basin during Late Triassic time. Present day Loppa High and Fingerdjupet Subbasin resulted from Late Mesozoic and Cenozoic tectonism and therefor did not influence this development of the Bjarmeland Platform. The structures within the platform are mainly resulting from weak extension and salt tectonics (Gabrielsen et al., 1990).

2.4.3 Bjørnøya Basin

The Bjørnøya Basin (Figure 6) is divided into the shallow Fingerdjupet Subbasin and a deeper westerly part by the Leirdjupet Fault Complex. The basin has the characteristics of a half graben as it is bounded by the Bjørnøyrenna Fault Complex in southeast and a faulted slope from the Stappen High in northwest (Gabrielsen, 1984; Gabrielsen et al., 1990).

The basin is mostly filled with Early Cretaceous sediments, and the upper part of the fill has been eroded. Faleide et al. (1984) interpreted dome structures in the basin as salt diapirs while Rønnevik and Jacobsen (1984) found no salt diapirs.

Prior to Early Cretaceous time the knowledge of the basin history is scarce. Gravimetric measurements have indicated a paleo-basin which, according to Ziegler (1988), was an active basin in Late Carboniferous to Permian times. Based on fault analysis by Moretti et al. (1988) and the profiles of Rønnevik et al. (1982); Rønnevik and Jacobsen (1984) the Bjørnøya Basin has been interpreted as a half-graben created by faulting and local invertion in Late Cretaceous and Cenozoic times (Gabrielsen et al., 1990).

2.4.4 Bjørnøyrenna Fault Complex

The Bjørnøyrenna Fault Complex separates the Bjørnøya Basin (Fingerdjupet Subbasin and the deeper part) and the Loppa High (Figure 6). The fault complex consists in general of normal faults with great throws. Common features are deformed fault planes, highly deformed footwall blocks and reverse faults. The Bjørnøyrenna Fault Complex was active during Late Jurassic and Early Cretaceous times, and in Late Cretaceous and Cenozoic times it was reactivated (Gabrielsen et al., 1990).

2.4.5 Fingerdjupet Subbasin

The Fingerdjupet Subbasin is bounded by the Leirdjupet Fault Complex, the Bjarmeland Platform and the Loppa High (Figure 6). Within the subbasin a horst and graben pattern is defined by fault blocks trending SSW-NNE. The subbasin is presumed to have a similar pre-Ladinian history as the Stappen and Loppa Highs. In Ladinian to Callovian times it was part the regional platform, but in Late Jurassic time extensional tectonic activity created the dominating faults that allowed for Early Cretaceous subsidence. In Cretaceous and perhaps Cenozoic times some of these faults were reactivated.

2.4.6 Finnmark Platform

The Finnmark Platform (Figure 6) is bounded by the Troms-Finnmark Fault Complex, the Nordkapp Basin and the Norwegian Calledonian outcrops. The platform developed as a stable platform in Late Carboniferous time (Gabrielsen et al., 1990).

2.4.7 Hammerfest Basin

The Hammerfest Basin is bounded by the Troms-Finnmark, Asterias and the Ringvassøy-Loppa Fault Complexes and the Bjarmeland Platform (Figure 6). The basin is relatively shallow, and the western part is dipping towards the Tromsø Basin. It includes both listric normal faults and deep, high angle faults. The eastern part is less affected by faulting (Gabrielsen et al., 1990).

Talleraas (1979) interpreted the the basin as a failed rift in a junction, and Hanisch (1984b,a) interpreted it as a riftsystem overprinting an older one. Rønnevik and Jacobsen (1984) have traced the structural predecessors of the SW-NE trending basins in the area back to Late Devonian–Early Carboniferous times. During Triassic time both the Tromsø and the Hammerfest Basins were part of a larger regional depositional system, but already in Early Triassic time the Hammerfest Basin had a separate depocentre (Berglund et al., 1986; Gabrielsen et al., 1990). The basin as it is now, developed from Mid Jurassic time with the dome in the middle of the basin and subsidence culminating in Early Cretaceous time (Gabrielsen et al., 1990).

2.4.8 Hoop Fault Complex

The Hoop Fault Complex is a SW-NE trending lineament cutting across the Bjarmeland Platform and the Loppa High (Figure 6). The southern part of the fault complex is a narrow graben, and the northern part is a multitude of normal faults. The central part is influenced by subsidence of the Maud Basin in Late Carboniferous to Permian times. Later, salt movements resulted in listric fault movements (Gabrielsen et al., 1990).

2.4.9 Loppa High

The Loppa High is diamond-shaped high located southeast of the Bjørnøya Basin and north of the Hammerfest Basin (Figure 6). The eastern part of the high is comprised of a platform, and the western and northwestern part is a crestal margin. Bjørnøyrenna and Ringvassøy-Loppa Fault Complexes separate the high from the Bjørnøya and Tromsø Basins, and the Asterias Fault Complex separates it from the Hammerfest Basin. The northern boundary is the Svalis Dome, the northeastern boundary is the Maud Basin, and in east and southeast a monocline is the boundary towards the Bjarmeland Platform and the Hammerfest Basin (Gabrielsen et al., 1990).

Since Devonian time the western margin of the Loppa High has been uplifted for a minimum of four times. In Section 2.4.2 the uplift in Late Permian to Early Triassic time is explained. This early uplift affected the paleo-Loppa High. From Mid Triassic to Mid Jurassic times (Ladinian to Callovian) the Loppa High was part of great platform spanning over the Bjarmeland Platform and the Hammerfest Basin. The Loppa High of today was crated by Late Jurassic–Early Cretaceous and Late Cretaceous–Cenozoic tectonism. In Cretaceous time the high was uplifted to the extent of an island, and erosion cut deep into the Triassic sediments (Gabrielsen et al., 1990).

2.4.10 Maud Basin

The Maud Basin (Figure 6) is located east of the Svalis Dome. One interpretation of the basin is as a rim syncline of the dome. The Hoop Fault Complex cuts the basin into a southern and northern part, the northern part being deeper than the southern. The basin started developing in Early to Mid Triassic times due to growth faulting along the Hoop Fault Complex and salt movement towards the rising Svalis Dome (Baglo, 1989; Gabrielsen et al., 1990).

2.4.11 Måsøy Fault Complex

The Måsøy Fault Complex separates the Finnmark Platform and the western part of the Nordkapp Basin. The faults are dominantly SW-NE trending, and it is easiest to identify them in Late Paleozoic to Mesozoic sequences. The fault zone is extensional in general, and asymmetric subsidence in the western part of the Nordkapp Basin has led to prominent flexuring (Gabrielsen et al., 1990).

2.4.12 Nordkapp Basin

The Nordkapp Basin is located south and southeast of the Bjarmeland Platform and north of the Finnmark Platform (Figure 6). The margins of the basin are defined by the Måsøy, Nysleppen and Thor Iversen Fault Complexes. The basin is thought of as a Late Paleozoic rift basin rich in salt. The pre-Permian basin is divided into a southwestern part shaped as a half graben, and a central and northern part with a more symmetrical shape. The evaporites are most likely of Carboniferous age. In Early to Mid Triassic times salt diapirism and subsequent subsidence were at their greatest. The subsidence in Late Triassic time decreased, but in Late Jurassic to Early Cretaceous times the basinal subsidence was reactivated. There was a new reactivation in Cenozoic time as well (Gabrielsen et al., 1990).

The general model used in explaining salt related structural evolution (Trusheim, 1959) cannot be applied because of the lack of evidence for a pillow stage in the

Nordkapp Basin. Normally a phase of salt pillow and primary rim synclines is followed by a phase of diapirism and secondary rim synclines. The Nordkapp Basin however, evolved as an enormous secondary rim syncline around closely spaced salt diapirs, probably due to the confinement of large amounts of salt in a narrow basin. (Jensen and Sørensen, 1988; Gabrielsen et al., 1990).

2.4.13 Nordvarg Dome

The Nordvarg Dome is a circular to elliptical structure located on the Bjarmeland Platform (Figure 6). Carboniferous evaporites were covered by carbonates in Late Carboniferous to Permian times. The Mesozoic sequence show doming, but the lack of primary rim synclines raises the question of whether the doming was caused by the salt or by compressional stresses (Gabrielsen et al., 1990).

2.4.14 Nysleppen Fault Complex

The Nysleppen Fault Complex separates the Nordkapp Basin from the Bjarmeland Platform (Figure 6). Fault movements from Early Carboniferous time have been documented, but the fault complex may actually represent a basement lineament. In Mesozoic and Cenozoic times the faults were activated again, giving the fault complex a greater complexity in the younger sequences (Gabrielsen et al., 1990).

2.4.15 Polheim Subplatform

The Polheim Subplatform constitute a block-faulted western area on the Loppa High (Figure 6). It is situated between the Ringvassøy-Loppa Fault Complex, the Bjørnøyrenna Fault Complex and the stabil eastern part of the high. In Late Paleozoic time the subplatform was subject to uplift and formed a positive structural element. But in Early to Mid Triassic times the subplatform was downfaulted. In Jurassic–Cretaceous times listric faults were formed as well (Gabrielsen et al., 1990).

2.4.16 Ringvassøy-Loppa Fault Complex

The Ringvassøy-Loppa Fault Complex separates the Loppa High and the Hammerfest Basin from the Tromsø Basin (Figure 6). Most of the subsidence related to the Ringvassøy-Loppa Fault Complex has its origin in Mid Jurassic time with its peak in Early Cretaceous time. There may have been movements in the fault complex prior to this, but the Tromsø Basin has proven too deep for reflection seismic to give the answer (Gabrielsen et al., 1990).

2.4.17 Samson Dome

The Samson Dome (Figure 6) is smaller, but practically identical to the Nordvarg Dome in Section 2.4.13 when it comes to shape and history (Gabrielsen et al., 1990).

2.4.18 Senja Ridge

The Senja Ridge defines the western boundary of the Tromsø Basin (Figure 6). From Mid Cretaceous time to Late Pliocene the ridge was a positive feature, but it may have developed earlier. The structure is complex and may contain intrusions and lie ontop of a basement high (Gabrielsen et al., 1990).

2.4.19 Svalis Dome

The Svalis Dome (Figure 6) lies on the northern border to the Loppa High. The salt dome is a pillow, and its crest contains collapsed grabens. The salt is probably Late Carboniferous, and salt movements here may have induced the Early Triassic faulting of the Hoop Fault Complex (Baglo, 1989; Gabrielsen et al., 1990). The saltmovement may in turn have resulted from the uplift of the paleo-Loppa High. Most of the doming occured due to a regional tectonic event in Early Tertiary time (Gabrielsen et al., 1990).

2.4.20 Swaen Graben

The Swaen Graben (Figure 6) may be related to a significant tectonic incidence in Late Jurassic time. It is an extensional feature, but the fault plane geometries suggest strike-slip movements too (Gabrielsen et al., 1990).

2.4.21 Sørvestnaget Basin

The Sørvestnaget Basin (Figure 6) is a deep basin with thick deposits of Cretaceous and Cenozoic sediments. The basin is bounded by lavas from the Vestbakken Volcanic Province in the north and oceanic crust in the west. To the southeast the Veslemøy High and the Senja Ridge bound the basin. At the Jurassic level the Sørvestnaget Basin is separated from the Bjørnøya Basin by a high, but at Cretaceous levels the two basins seem to be one and the same. At Tertiary level a hinge system separates the two basins. Faulting and subsidence have at least occured from Early Cretaceous time. Any older deposits are buried too deep to reveil anything on reflection seismic (Gabrielsen et al., 1990).

2.4.22 Thor Iversen Fault Complex

The Thor Iversen Fault Complex separates the eastern part of the Nordkapp Basin from the Finnmark Platform (Figure 6). The fault zone was most active in Permian and Triassic times. The fault complex is thought to be an old zone of weakness. Late Paleozoic and Mesozoic extensional events and retraction of salt in the Nordkapp Basin is believed to have played an important role in influencing the fault movements (Gabrielsen et al., 1990).

2.4.23 Troms-Finnmark Fault Complex

The Troms-Finnmark Fault Complex (Figure 6) represents a division between the Finnmark Platform and the Hammerfest, Tromsø and Harstad Basins. Listric normal faults along with roll-over anticlines are typical for the fault complex (Fønstelien and Horvei, 1979; Gabrielsen, 1984; Faleide et al., 1984; Berglund et al., 1986; Gabrielsen et al., 1990). The fault complex is thought to be an old zone of weakness, and reactivation of the fault zone has taken place on ceveral occasions up to Eocene time.

2.4.24 Tromsø Basin

The Tromsø Basin is bounded by the Senja Ridge, the Veslemøy High, the Ringvassøy-Loppa Fault Complex and the Troms-Finnmark Fault Complex (Figure 6). The depth of the basin has made it difficult to interpret its old history. It has been suggested that the basin did not exist prior to Late Paleozoic time, and that the Tromsø Basin along with the Hammerfest and Bjørnøya Basins comprised one basinal area until Late Triassic–Early Jurassic times (Gudlaugsson et al., 1987; Rønnevik et al., 1982; Gabrielsen et al., 1990). In Mid Jurassic time faulting may have started, and in Early Cretaceous time the Hammerfest and Tromsø Basins were separated (Gabrielsen et al., 1990).

3 Data and methods

3.1 Seismic data

In this study I have used 2D seismic data shot by MCG in 2011. The location of the seismic lines is shown in Figure 7. The survey was shot to construct a grid that ties all exploration wells in the southwestern Barents Sea, thereby constituting a solid reference for other surveys. The distance covered by the seismic lines vary from about 100 kilometers to about 485 kilometers. Alltogether the survey covers 6,507 kilometers and ties 11 IKU shallow wells and 64 exploration wells (Abrahamson, 2013).

The data is pre-stack time migrated to ensure the best time-position for reflectors in areas with steep dips. Also, the data is zero-phased in order to place the peak of the wavelet on the accoustic impedance contrast. The quality in the seismic survey is mostly good, but in the most western part of the region the data deteriorates due to processing errors. Beneath the base of Triassic the quality deteriorates too, and in large parts of the Tromsø, Bjørnøya and Sørvestnaget Basins the Triassic depositional unit is buried too deep as well.

There are a lot of factors influencing the amplitude of a recorded seismic event, thus influencing the penetration depth of the seismic data. Normally divergens plays the major role in causing time dependent changes in amplitude. As the wavefield increases in size the total energy stays constant, resulting in a weaker wavefront. And as velocity generally increases with depth, the raypath curves and spreads. This decreases the energy density further, and thus it also decreases the amplitude of the wavefront. Other factors for amplitude decrease are absorption converting energy to heat through friction, scattering and interference. In general the amplitude will decrease exponentially with time. This means the penetration depht is frequency dependent in a manner that high frequencies give shallow penetration and low frequencies give deep penetration (Sheriff and Geldart, 1995; Boggs, 2010)

The resolution of seismic data tells us the level of details visible on the seismic

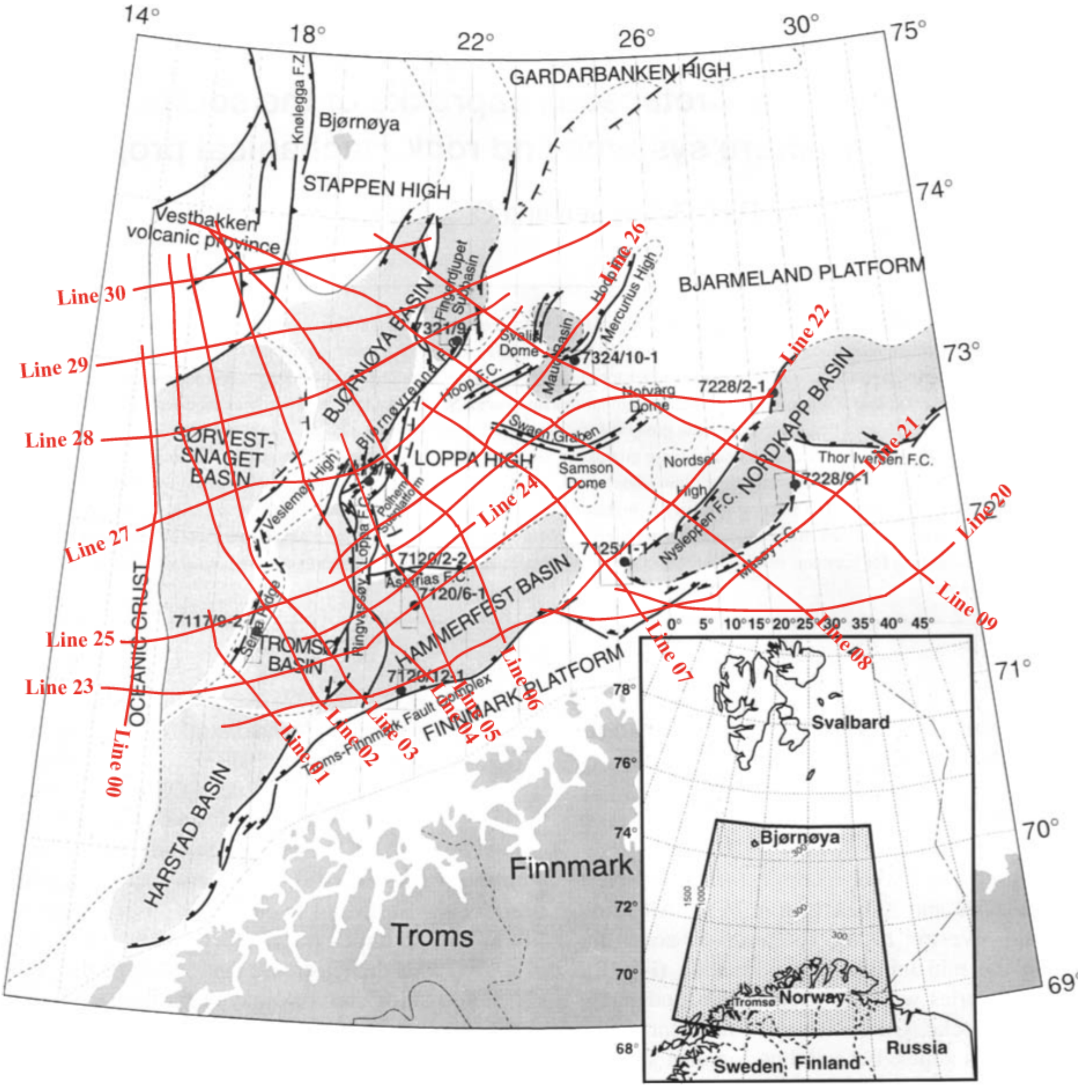


Figure 7: Map of seismic lines from MCG on top of structural elements in the southwestern Barents Sea. Modified from Gabrielsen and Kløvjan (1997) and MCG (2011).

records. Resolution is normally divided in two; the vertical resolution and the horizontal resolution.

In the vertical direction the seismic resolution is limited to $\lambda/4$ where λ is wavelength (Sheriff and Geldart, 1995). This limit was defined by Rayleigh (Jenkins and White, 1957) as minimized interference effect at half-cycle separation between reflectors. This means that if a bed within a medium of different properties has a thickness of $\lambda/4$, there will be constructive interference from the top and base of the bed, and the two boundaries will be tuned into one strong reflection. Beds of greater thickness will show the top and base as two reflectors. $\lambda = v/f$ where v is velocity and f is frequency, gives the vertical resolution:

$$\Delta z = \frac{v}{4f} \tag{1}$$

which is frequency dependent in the way that high frequencies give high resolution and low frequencies give low resolution (Sheriff and Geldart, 1995; Boggs, 2010).

The horizontal resolution is often given by the first Fresnel zone. Sheriff and Geldart (1995) defines a Fresnel zone as:

> "an area from which reflected energy arriving at a detector has phases differing by no more than a half-cycle".

This gives a relatively constructive interference, showing all the reflectors within the Fresnel zone as one reflection point. The radius of the first Fresnel zone is given by

$$R_1 = \sqrt{\frac{\lambda h_0}{2}} = \frac{v}{2}\sqrt{\frac{t}{f}} \tag{2}$$

where h_0 is the depth, v is average velocity, t is two-way travel time and f is frequency. This frequency dependency gives the same relation as for vertical resolution; high frequencies – high resolution and vice versa (Sheriff and Geldart, 1995; Boggs, 2010).

On unmigrated data the Fresnel zone is often considered to be the main reason for horisontal limitation, but other effects like trace spacing and signal/noise ratio also affects what can be distinguished. When working with migrated 2D data the

Fresnel zone cannot be used to give the horizontal resolution. This is because migration doesn't collapse the Fresnel zone in the direction perpendicular to the seismic line. Hence, reflectors outside the seismic line will influence the recorded seismic signals (Sheriff and Geldart, 1995).

3.2 Study method

Seismic reflections are generated as a response to density-velocity changes in the sub-surface. These changes occur at unconformities or bedding surfaces that separate rocks of different physical properties, lithology, textures and structural behavior. Weathering of the lower layer at an unconformity may further enhance the contrast (Boggs, 2010).

While unconformities separate rock bodies, bedding surfaces are sedimentary boundaries within a rock body. Hence, the difference in acoustic impedance along with the thickness of the beds will prevent some bedding surfaces from showing on seismic. The recorded seismic event might in fact represent the average of several thin bedding surfaces phased together (Boggs, 2010). A bed thickness less than the seismic wavelength means that the top and base reflections can be phased together and result in very large amplitudes. Thick beds can have small amplitudes due to complete separation of top and base reflections (Sheriff, 1980; Boggs, 2010).

In this study I have mapped stratigraphic seismic sequences and created a framework from 2D seismic data from MCG and well data from NPD. The interpretation is done on a regional scale with emphasis on basin interpretation of the Triassic deposits. As Glørstad-Clark et al. (2010) explanes; seismic stratigraphy allows you to interpret stratal information and reconstruct paleogeography from seismic data (Mitchum et al., 1977b,a; Vail et al., 1977a,b).

3.2.1 Reflection Configuration

To relate the seismic reflections to stratigraphy one should pay attention to the continuity and configuration of the reflections. By configuration Boggs (2010)

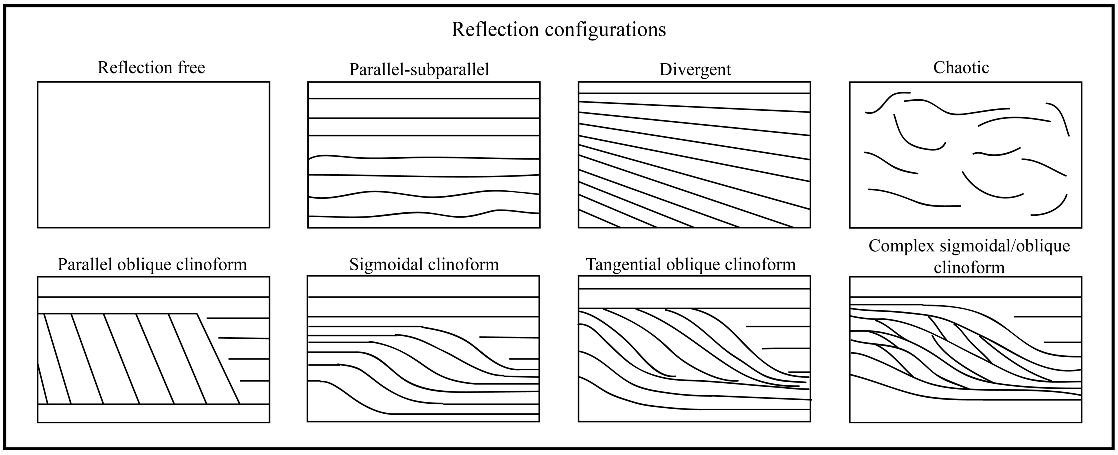


Figure 8: Seismic reflection configurations.

refers to

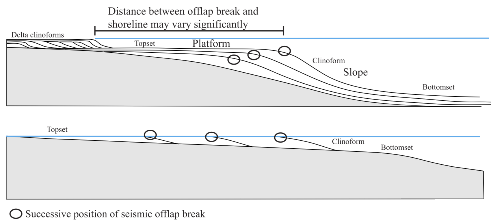
> "the gross stratification patterns identified on seismic records".

From the reflection configuration one can interpret bedding patterns, fluid contacts, paleotopography and erosion and depositional processes.

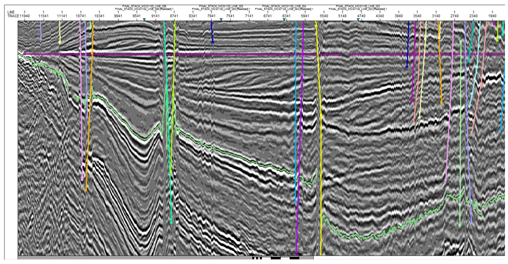
Different reflection configuration patterns are shown in Figure 8. Reflection free configuration is often interpreted as thick salt, igneous rocks or strata with high dipping angle. Parallel configuration is interpreted as deposits with a uniform rate of deposition, and divergent configuration as deposits with a laterally varying deposition rate or surface tilting during deposition. Clinoforms are interpreted as deposition during progradation. This gives a lateral build-out. The term clinoform was introduced by Rich (1951) along with the terms undaform and fondaform. Undaform refers to the relatively flat surface above wave base while fondaform is the relatively flat and undisturbed ocean floor. The sloping surface in-between is the clinoform (Boggs, 2010). Figure 9b shows sigmoidal clinoforms in Sassendalen Group southeast of the paleo-Loppa High.

3.2.2 Reflection Continuity

The reflection continuity is depending on the continuity of the acoustic impedance contrast along the respective boundary. Continuity can be used for interpreting



(a) Scetch showing the different scale in clinoforms from a shelf and a prograding delta. Glørstad-Clark et al. (2010) modiefied the figure from Emery and Myers (1996); Bullimore et al. (2004).



(b) Seismic clinoforms from line 06 in Figure 7. The clinoforms are onlapping the paleo-Loppa High from southeast. Flattened at Top Sassensdalen Group.

Figure 9: Clinoforms

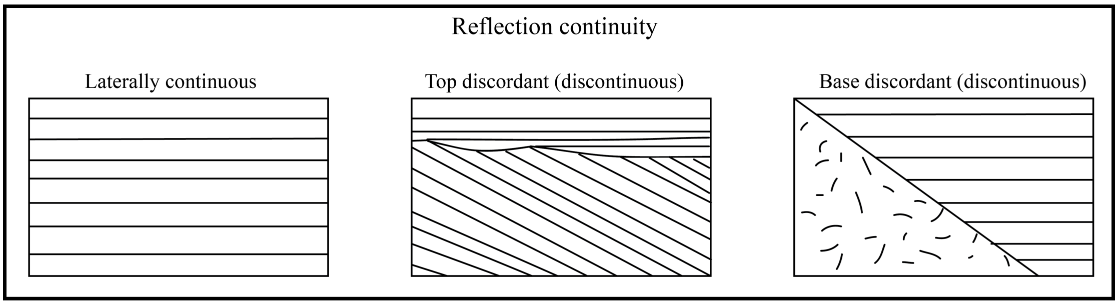


Figure 10: Seismic reflection continuity. Modified from Boggs (2010).

bedding continuity, velocity-density contrast, depositional processes and environment. Figure 10 shows some examples of reflection continuity (Boggs, 2010).

By interpreting stratigraphic geometry from seismic reflections one can identify seismic facies. Seismic facies are equivalent to the depositional environments of lithology. Seismic facies analysis provides information about geological setting and sediment source (Boggs, 2010).

3.2.3 Seismic Sequence Analysis

Seismic sequence analysis is a term for indentifying stratigraphic units bounded by unconformities (Boggs, 2010). Sequences were considered by Sloss (1963) to be units of interregional scale separated by interregional unconformities, and in 1977

Mitchum et al. (1977b) extended the consept by defining the depositional sequence as

> "a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities".

This means that sequences can be as small as a few tens of meters (Boggs, 2010). Distinctive groups of depositional sequences constitute supersequences which are of the same magnitude as the sequences of Sloss (1963).

Since this study is focusing on Triassic basin development, the interpretation is focused on the Triassic depositional unit. I started by interpreting Cenozoic, Cretaceous and Lower to Mid Mesozoic supersequences. The Mesozoic supersequence is divided further into a Jurassic and a Triassic units, and the Triassic unit is divided into 3 subsequences. These subsequences are Sassendalen Group, Snadd Formation and Fruholmen Formation.

This division was done by mapping unconformities and their correlative conformities and by well correlation. The Base Triassic unconformity is a relatively strong, positive reflector. The Base Cretaceous and the Base Cenozoic unconformities are top discordant, showing erosion down in the sequences underneath. Sassendalen Group subsequence is dominated by fine grained non-siliceous clastics (Worsley, 2008). The base is a marine shale deposited on top of a hard carbonate platform (Figure 3), resulting in a strong reflector. The Top Sassendalen Group marks the change from an eastward thickening system with clinoforms to a westward thickening system with a more parallel configuration. Carnian sandstones in the Snadd Formation on the Finnmark Platform and in the Nordkapp Basin are deposited as coastal sands and channels coming from the Baltic Shield (Worsley, 2008). In Early Norian time the "Rhaetian" transgression gave a relative sea-level rise which opened up the seaway south to the European basins (Worsley, 2008). On the Barents Shelf this incidence is marked by a decrease in subsidence and depositional rate. Without the Uralian depositional dominance, the result was a shallow marine and coastal environment and deposition of the Fruholmen Formation (Figure 3) (Worsley, 2008).

4 Regional Triassic seismic interpretation

4.1 Well data and profiles

The seismic sequences in this 2D seismic interpretation is described in Section 3.2.3. The interpretation was done by mapping faults and horizons, and by tying the horizons to the wellbores in Figures 14, 17, 19, 21, 24 and 27. I also compared with earlier work (e.g. Faleide et al. (1984); Glørstad-Clark et al. (2010); Gabrielsen et al. (1990); Abrahamson (2013); Ekerheim (2012)) when doing the interpretation.

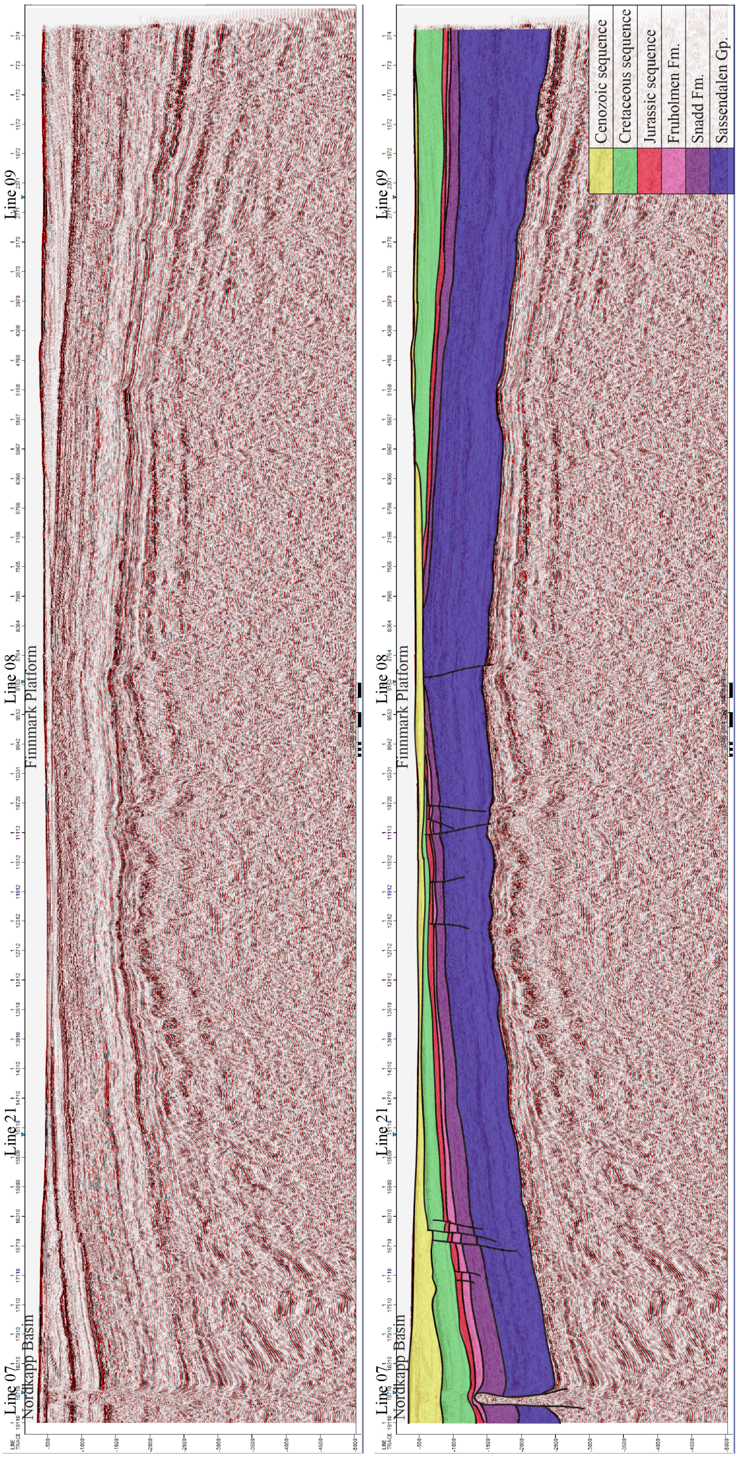
The final interpretation resulted in Figures 11, 12, 15, 18, 20, 22, 25 and 28 to 30, going approximately from west to east, and Figures 31 to 38 and 40, going approximately from north to south.

From Figure 11 it is clear that Sassendalen Group is thinning from the Finnmark Platform in the east towards the Nordkapp Basin in the west, indicating a depocentre in the east in Early to Mid Triassic times. The lower half of the subsequence consists of weak reflectors diverging towards east. The upper half has stronger reflectors with a parallel to divergent configuration. A divergent configuration indicates laterally varying deposition of sediments. By the Nordkapp Basin rising salt has altered the accommodation space. The subsequence is thickest at the eastern side where the influence was greatest.

Snadd Formation is at its thickest in the west and thinning towards east and northeast. East of the intersection with seismic line 08 Cretaceous or Cenozoic erosion has removed the entire Snadd subsequence. Snadd is thinning towards this area from both east and west, indicating two depocentres in Mid to Late Triassic times. The influence of the rising salt is still evident, but for this subsequence there is more accommodation space on the western side of the salt.

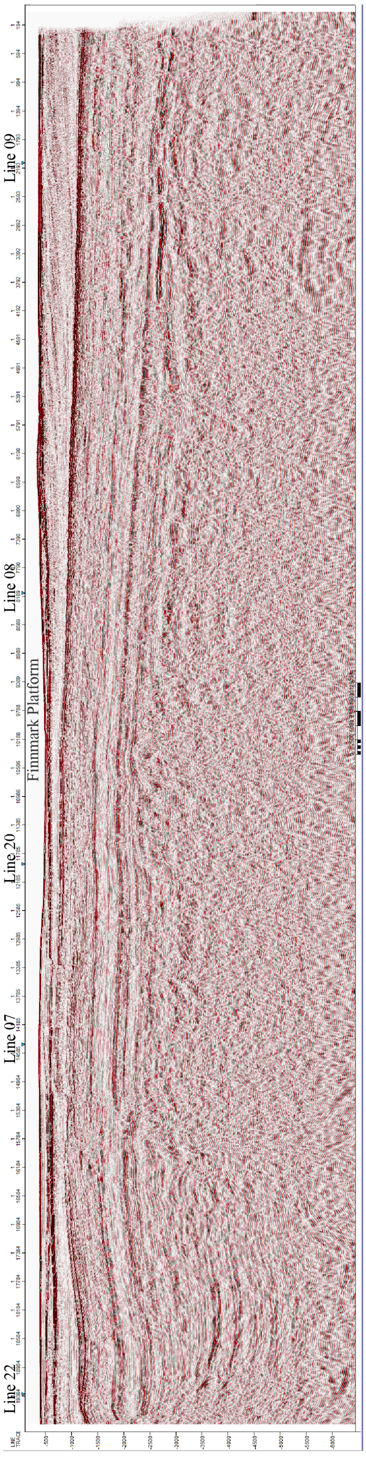
Fruholmen Formation shows much of the same trend as Snadd Formation, mainly one depocentre in the eastern end of the profile and one in the western side in Late Triassic time. In this subsequence the subsidence is greatest at the eastern side of the salt.

In Figure 12 there is a graben structure. The graben itself is part of the Bjarme-

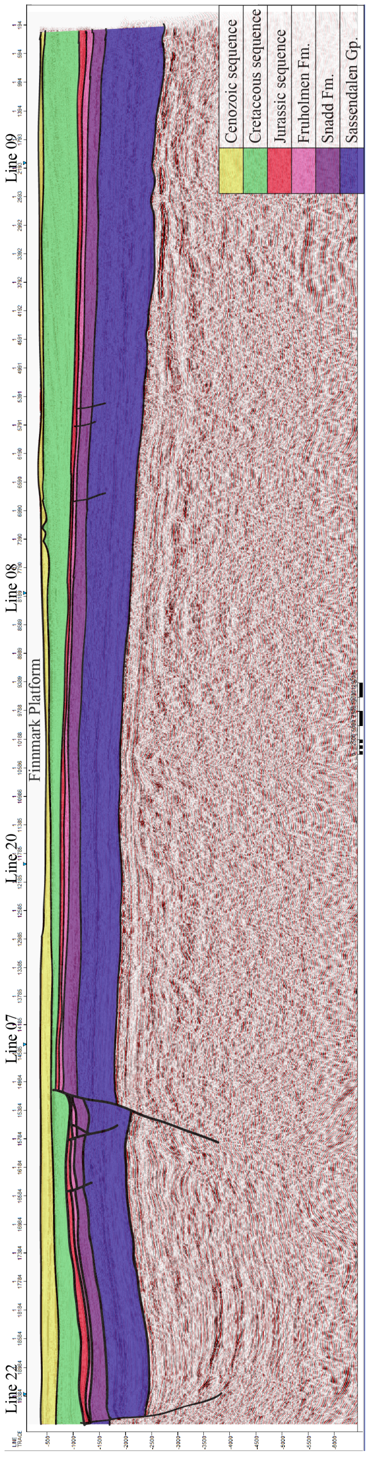


(a) Seismic line 20 (b) Seismic profile, line 20

Figure 11: Seismic 2D line 20 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 21



(b) Seismic profile, line 21

Figure 12: Seismic 2D line 21 and a profile showing the seismic interpretation. The location is shown in Figure 7.

land Platform, and the faults belonging to the Troms-Finnmark Fault Complex, separate it from the Finnmark Platform. In this profile Sassendalen Group is thinning from northeast towards the graben, but in the graben the subsequence is thicker. Thus the faults were active in Early to Mid Triassic times. The reflectors are subparallel to parallel, indicating a quite uniform deposition.

Inside the graben Snadd Formation is thinning towards the east. East of the graben the subsequence has a quite uniform thickness. This indicates a stable platform in the east and some subsidence in the west where the profile borders to the Hammerfest Basin in Mid to Late Triassic times.

Fruholmen Formation is thinning from the eastern edge of the profile to the intersection with seismic line 08. West of this point the subsequence has a quite uniform thickness, indicating stable conditions in Late Triassic time.

Figure 14 shows seven well logs from seismic line 22. These wells are located at intersections to seven other seismic lines. Hence, correlation to these wells builds a strong foundation for further interpretation. Wellbore 7120/12-2, 7122/7-3 and 7226/11-1 are penetrating throuhg the Triassic unit, providing thicknesses for all the units present. The final interpretation is presented in the profile in Figure 15.

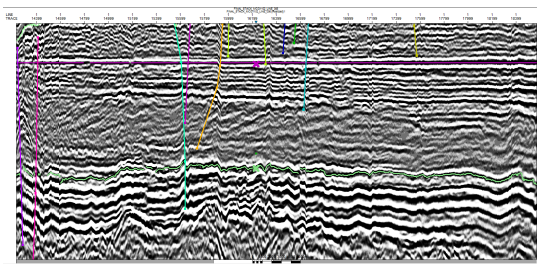


Figure 13: Seismic clinoforms from seismic line 22 showing southwestern progradation. Flattened at Top Sassendalen Group.

In the northeast at the border to the Nordkapp Basin we see evidence of salt pushing up at the Mesozoic supersequence. The layering within the Cretaceous supersequence show the shape of a dome, meaning that the salt rose until Cretaceous time or later. Sassendalen Group is thinner on the Nordkapp Basin side than the Norsel High side of the salt, indicating more subsidence southwest of the salt in Early to Mid Triassic times. At the intersection with seismic line 21 the thickness of Sassendalen Group shows that the Troms-Finnmark Fault Complex was active at the time, giving subsidence at this southern part of the Bjarmeland

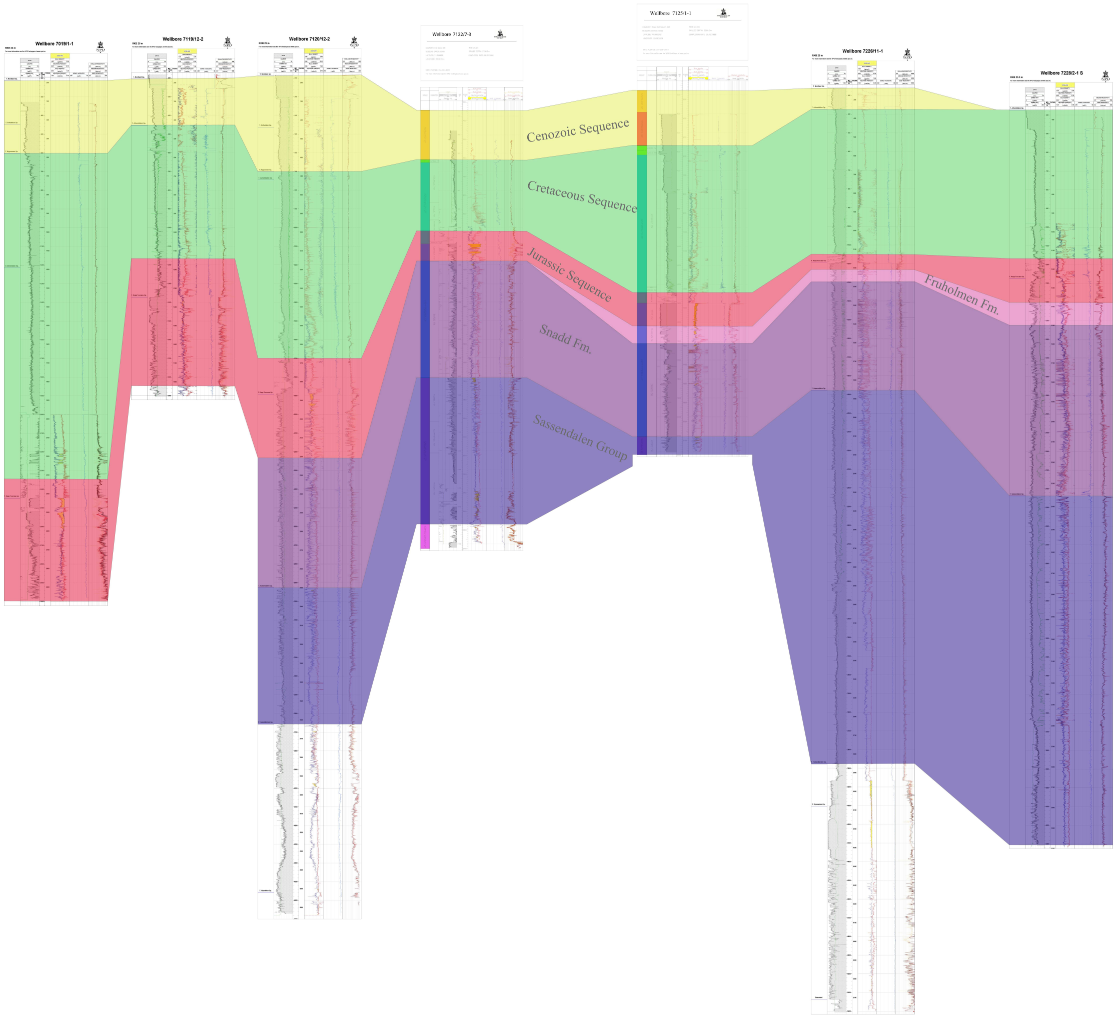
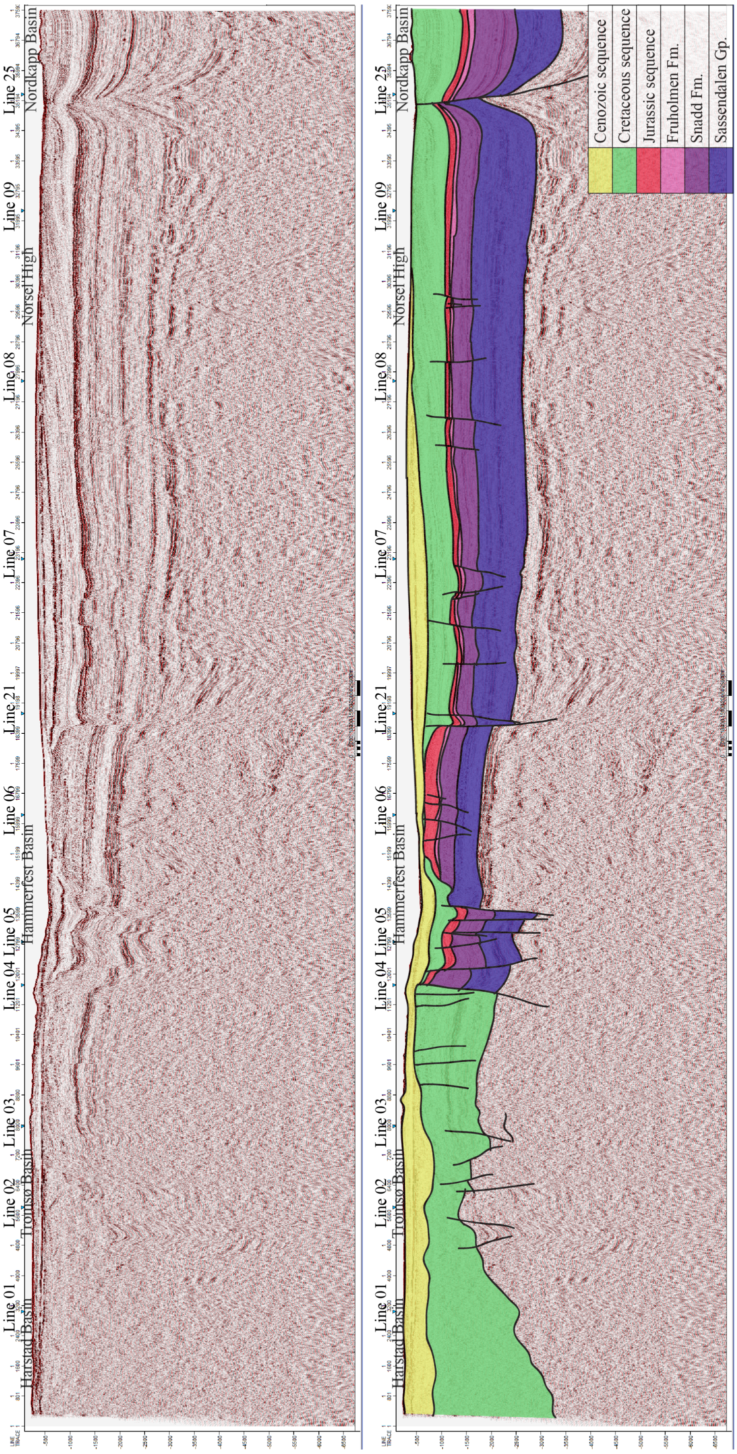


Figure 14: Wells from seismic line 22. Wellbore 7019/1-1 is located at the intersection of seismic line 22 and 01, wellbore 7119/12-2 at the intersection of seismic line 22 and 02, wellbore 7120/12-2 at the intersecion of seismic line 22 and 03, wellbore 7122/7-3 at the intersection of seismic line 22 and 05, wellbore 7125/1-1 at the intersection of seismic line 22 and 07, wellbore 7226/11-1 at the intersection of seismic line 22 and 08 and wellbore 7228/2-1S at the intersection of seismic line 22 and 25. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 22 (b) Seismic profile, line 22

Figure 15: Seismic 2D line 22 and a profile showing the seismic interpretation. The location is shown in Figure 7.

Platform. In the Hammerfest Basin at about the intersecting seismic line 05 there is subsidence as well. Between seismic lines 05 and 06 there are seismic clinoforms showing sediment transport towards southwest (Figure 13).

Snadd Formation, on the other hand, is thicker by far in the Nordkapp Basin, indicating subsidence of the Nordkapp Basin in Mid to Late Triassic times. The salt was still rising, and accommodation space was created on the hanging wall of the listric Nysleppen fault. In general the subsequence is getting thicker towards northeast, but subsidence in the Hammerfest Basin has given a thickening trend towards southwest in the area west of the Troms-Finnmark Fault Complex.

Fruholmen Formation is thickest in the Nordkapp Basin, supporting subsidence of the basin in Late Triassic time. For the rest of the area the thickness of Fruholmen Formation is generally thinning towards southwest.

The difference in steepness for the boundaries between the layers and the thicknesses suggest that the salt was rising during deposition of the whole Mesozoic supersequence, and that the depocentre shifted from souhtwest to northeast of the rising salt in Mid Triassic (Early Ladinian) time. The main events of faulting and subsidence happened in Createaceous time as the Cretaceous supersequence shows the most alteration.

Figure 17 shows the correlation of five wells at the intersection of seismic line 23 and five other seismic lines. The resulting interpretation is shown in Figure 18. Here, none of the wells penetrate the whole Triassic unit. Hence, the importance of correlation with the interpretation from the intersecting seismic lines is far greater than for instance seismic line 22.

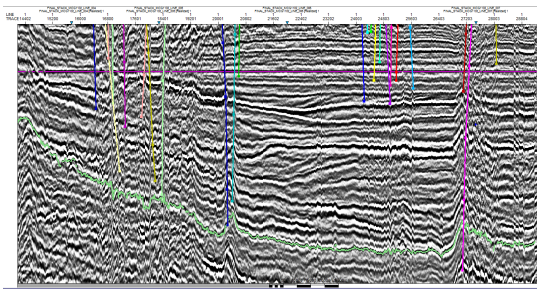


Figure 16: Seismic clinoforms from seismic line 23 showing southwestern progradation. Flattened at Top Sassendalen.

The profile shows Sassendalen Group getting thinner from the Samson Dome towards the Ringvassøy-Loppa Fault Complex. The thickness at the dome suggests that the salt rose at a slow rate during

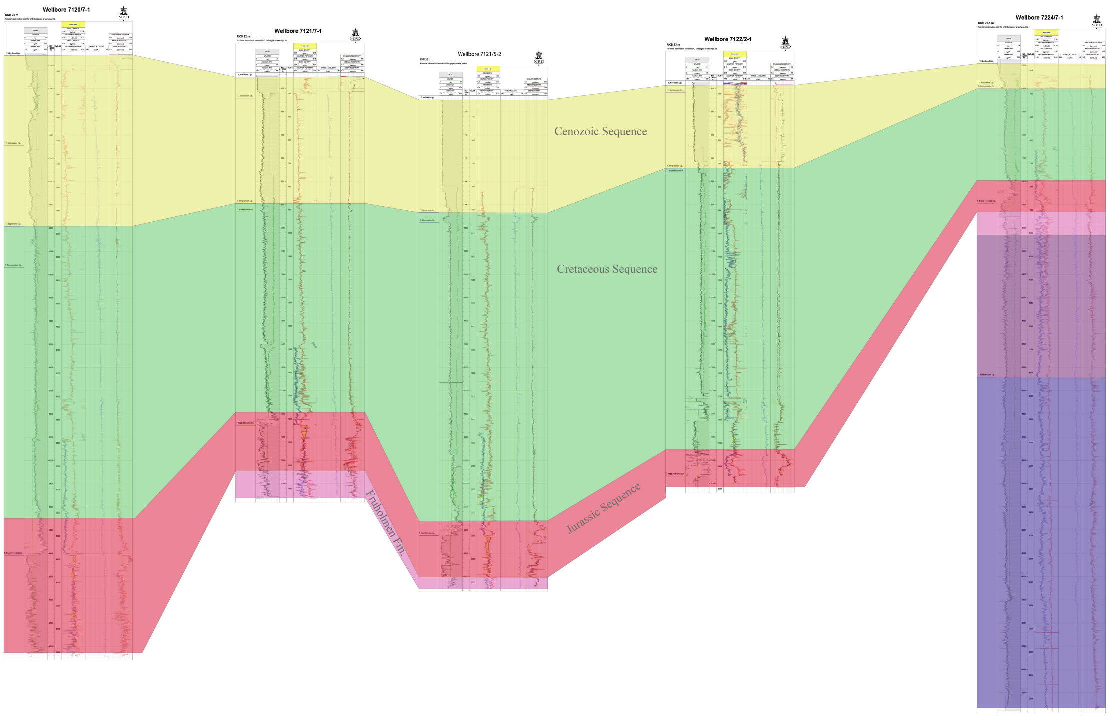
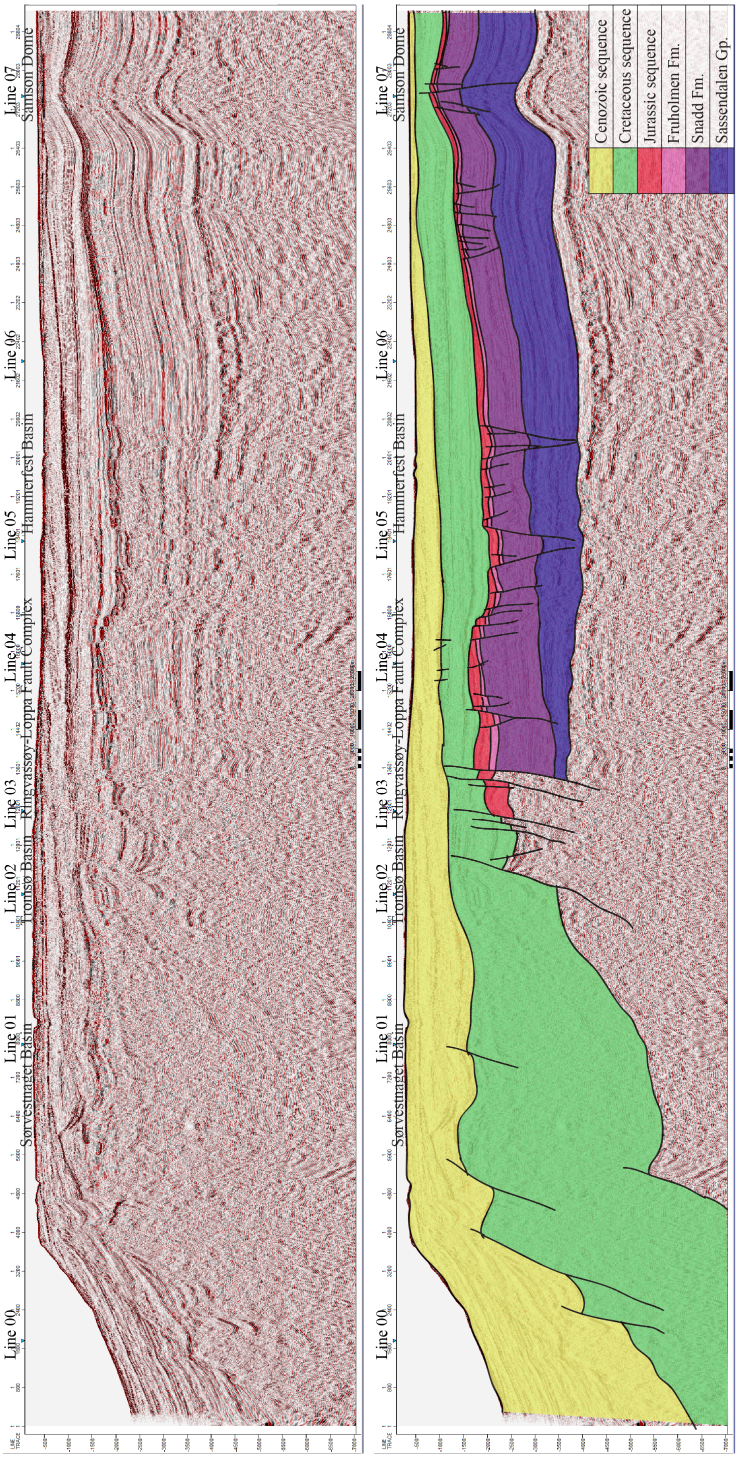


Figure 17: Wells from seismic line 23. Wellbore 7120/7-1 is located at the intersection of seismic line 23 and 03, wellbore 7121/7-1 at the intersection of seismic line 23 and 04, wellbore 7121/5-2 at the intersecion of seismic line 23 and 05, wellbore 7122/2-1 at the intersection of seismic line 23 and 06 and wellbore 7224/7-1 at the intersection of seismic line 23 and 07. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 23 (b) Seismic profile, line 23

Figure 18: Seismic 2D line 23 and a profile showing the seismic interpretation. The location is shown in Figure 7.

deposition of Sassendalen Group, creating accommodation space southwest of the dome. Within Sassendalen Group seismic clinoforms indicate sediment transportation to the southwest and onto the paleo-Loppa High (Figure 16).

Snadd Formation is at its thickest at the most southwestern part of my Snadd interpretation and thinning to the northeast. This indicates a change in subsidence of the Tromsø Basin in Mid Triassic time. At the Samson Dome the subsequence is thinner, indicating that the dome was still rising. The same trend is valid for Fruholmen Formation.

From Figure 19 we see the that the Triassic unit at the intersection between seismic line 03 and 24 is buried much deeper than at the intersection between seismic line 06 and 24. The full interpretation of seismic line 24 is shown in Figure 20.

The normal faults at the Asterias Fault Complex and the Ringvassøy-Loppa Fault Complex divides the profile in three main parts; the Loppa High area in northeast, the Hammerfest Basin in the middle and the Tromsø Basin in southwest. In the area northeast of seismic line 04 Sassendalen Group is thinning towards southwest. At the hanging wall that constitute the Hammerfest Basin Sassendalen Group is much thicker than at the footwall of Loppa High. This indicates subsidence of the Hammerfest Basin in Early to Mid Triassic times. Southwest of seismic line 04 Sassendalen Group is getting thicker, and the dip suggests more accommodation space in the southwest. At the Loppa High seismic clinoforms show sediment transport towards southwest.

The same trend occurs for Snadd Formation, but the thinning is at a smaller scale. The smaller faults constituting horst and graben structures in the Hammerfest and Tromsø Basins indicate an extensional tectonic regime from Mid Triassic to Jurassic times. At the Loppa High there are fewer and thicker reflectors than in the Hammerfest Basin, indicating different conditions on the two sides of the Asterias Fault Complex. In the Tromsø Basin the thickness of Snadd Formation suggests subsidence relative to the Hammerfest Basin in Mid to Late Triassic time.

Fruholmen is thickest in the Hammerfest Basin and thinning to both sides, indicating a depocentre in the Hammerfest Basin in Late Triassic times.

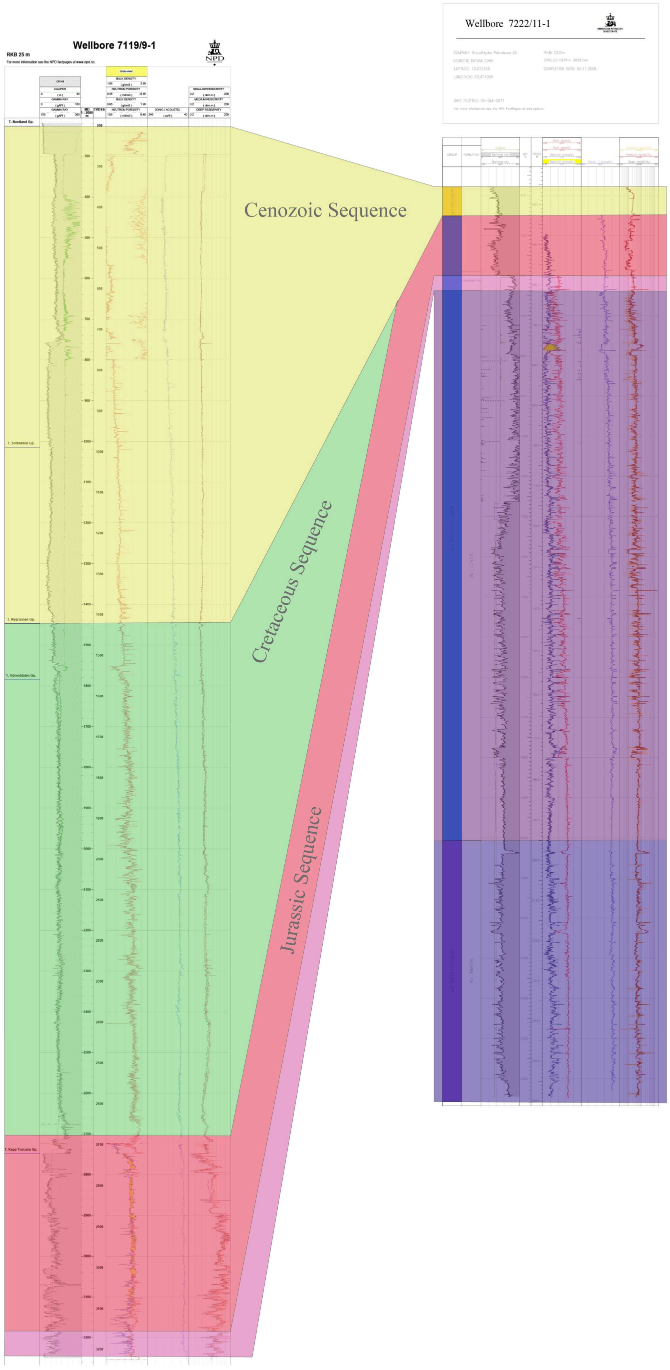
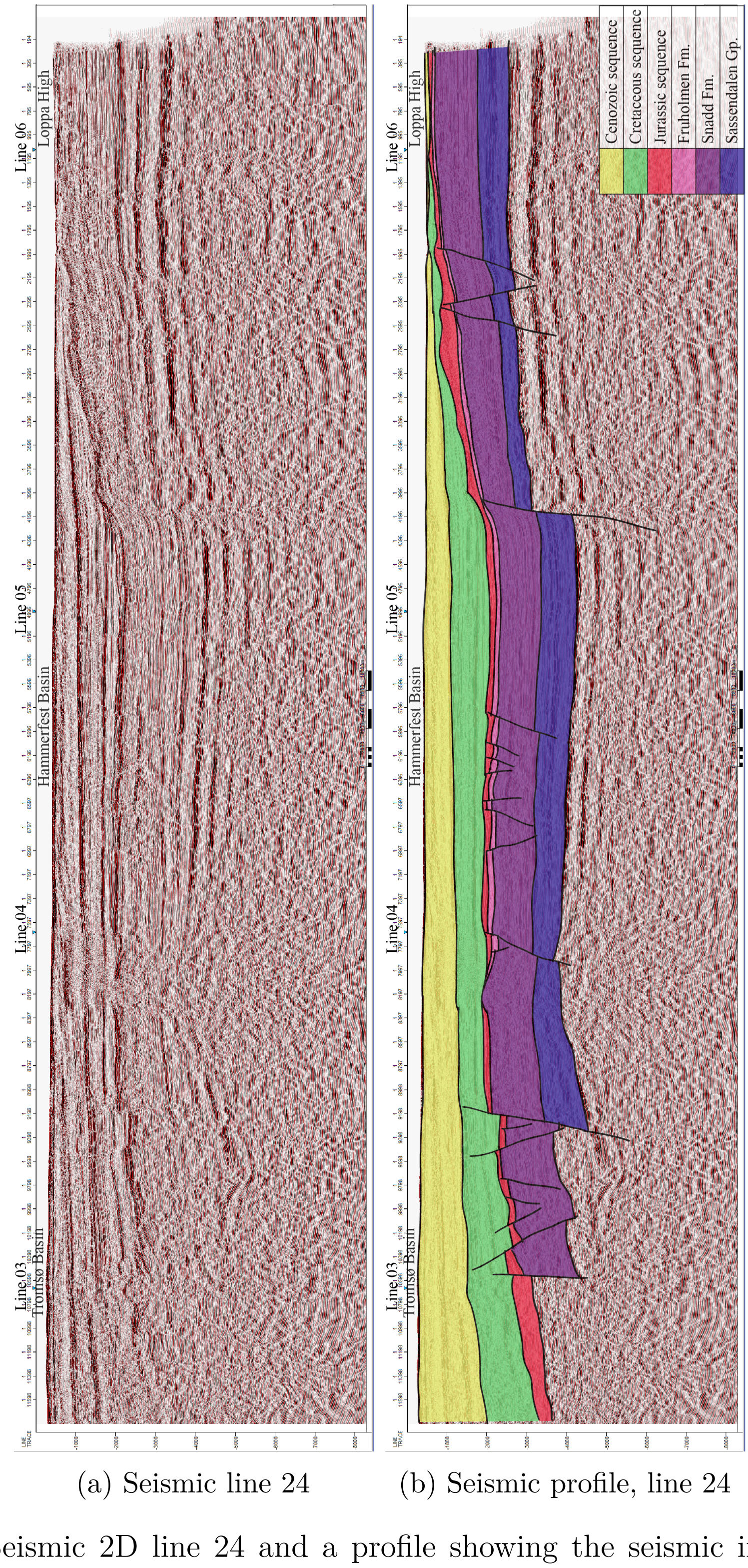


Figure 19: Wells from seismic line 24. Wellbore 7119/9-1 is located at the intersection of seismic line 24 and 03 and wellbore 7222/11-1 is located at the intersection of seismic line 24 and 06. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 24 (b) Seismic profile, line 24

Figure 20: Seismic 2D line 24 and a profile showing the seismic interpretation. The location is shown in Figure 7.

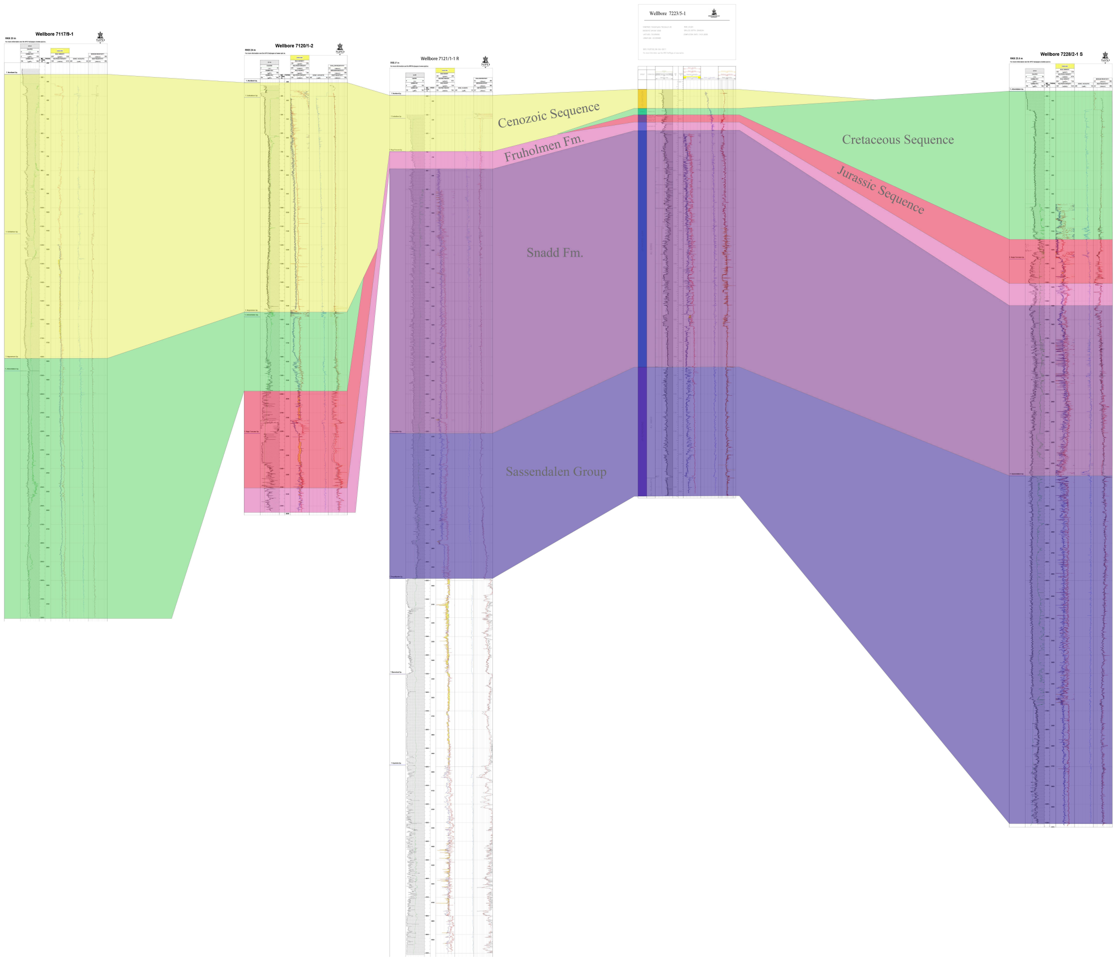
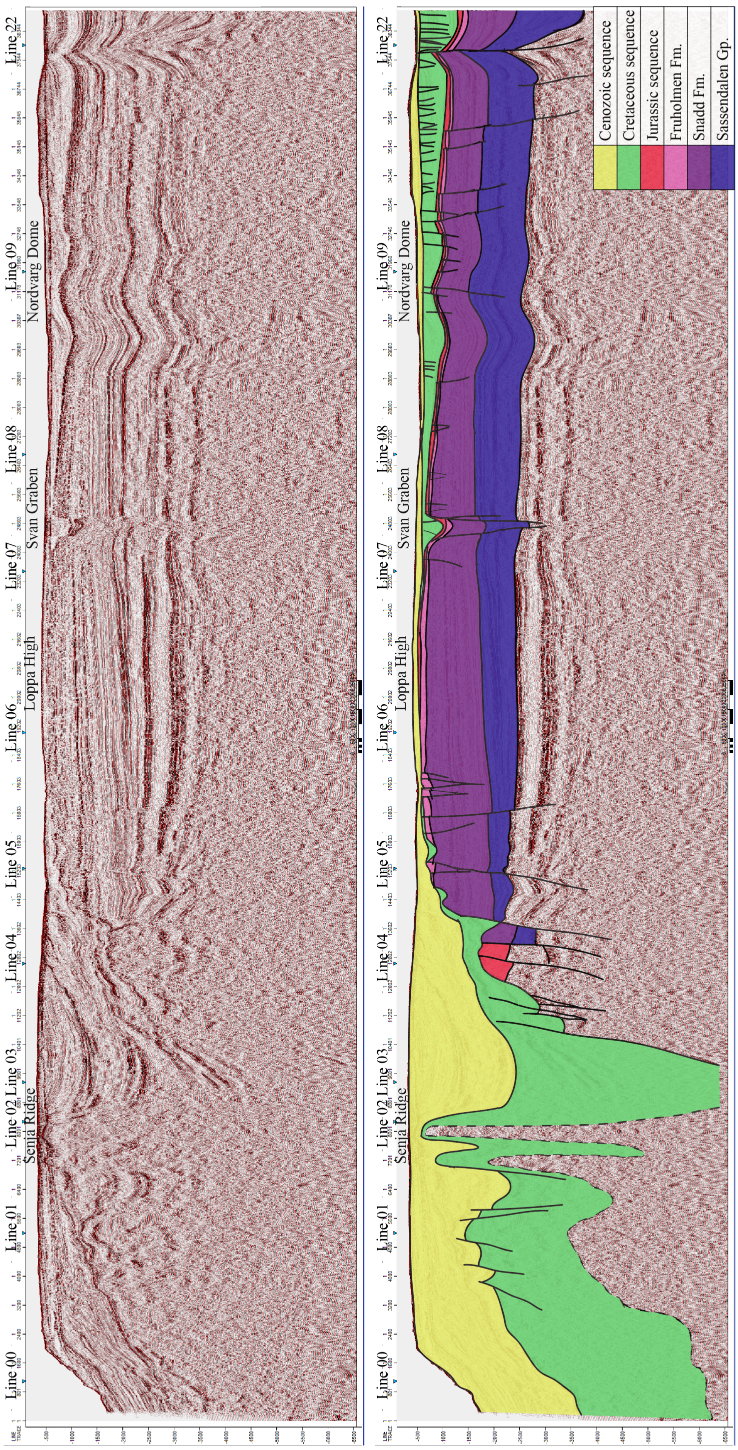


Figure 21: Wells from seismic line 25. Wellbore 7117/9-1 is located at the intersection of seismic line 25 and 01, wellbore 7120/1-2 at the intersection of seismic line 25 and 04, wellbore 7121/1-1R at the intersecion of seismic line 25 and 05, wellbore 7223/5-1 at the intersection of seismic line 25 and 07 and wellbore 7228/2-1S at the intersection of seismic line 25 and 22. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 25 (b) Seismic profile, line 25

Figure 22: Seismic 2D line 25 and a profile showing the seismic interpretation. The location is shown in Figure 7.

In Figure 21 five wells are tying seismic line 25 with five crossing seismic lines. Only one of the wells penetrates all the way through the Triassic depositional unit. The related interpretation of seismic line 25 is shown in Figure 22.

The profile shows Sassendalen Group thinning westwards from the salt at the border to the Nordkapp Basin onto the paleo-Loppa High. The rising salt has created accommodation space on both sides, but the thickness of Sassendalen Group shows greatest subsidence in the Nordkapp Basin. Uplift of the paleo-Loppa High has influenced the accommodation space northeast of the high. The depocentre in this profile is located at about the Nordvarg Dome at the Bjarmeland Platform. Seismic clinoforms within the subsequence indicate southwestward sediment transportation onlapping the paleo-Loppa High in Early to Mid Triassic times (Figure 23). At the Ringvassøy-Loppa Fault Complex Sassendalen Group appears to get thicker again in southwest, indicating subsidence of the Tromsø Basin as well.

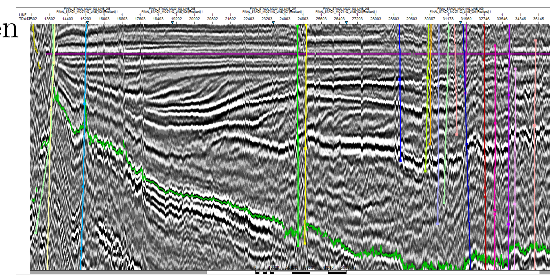


Figure 23: Seismic clinoforms from seismic line 25 showing southwestern progradation. Flattened at Top Sassendalen.

The thicknesses of Snadd and Fruholmen Formations are oposite of Sassendalen Group, thinning to the northeast and east. This indicates a change in depocentre and possibly sediment source. The salt was still rising, and a listric fault belonging to the Nysleppen Fault Complex created more accommodation space in the Nordkapp Basin in Mid and Late Triassic times. The Snadd and Fruholmen subsequences are thickest at the Loppa High, indicating a depocentre in this area.

Figure 24 shows three wells at the intersection of seismic line 26 and three other seismic lines. Only one of the wells penetrates throughout the Triassic depositional unit. The wells clearly show that Sassendalen Group is thinning in the southwestern direction while Snadd Formation is getting thicker. Fruholmen Formation on the other hand is only present in one of the wellbores and may have been removed

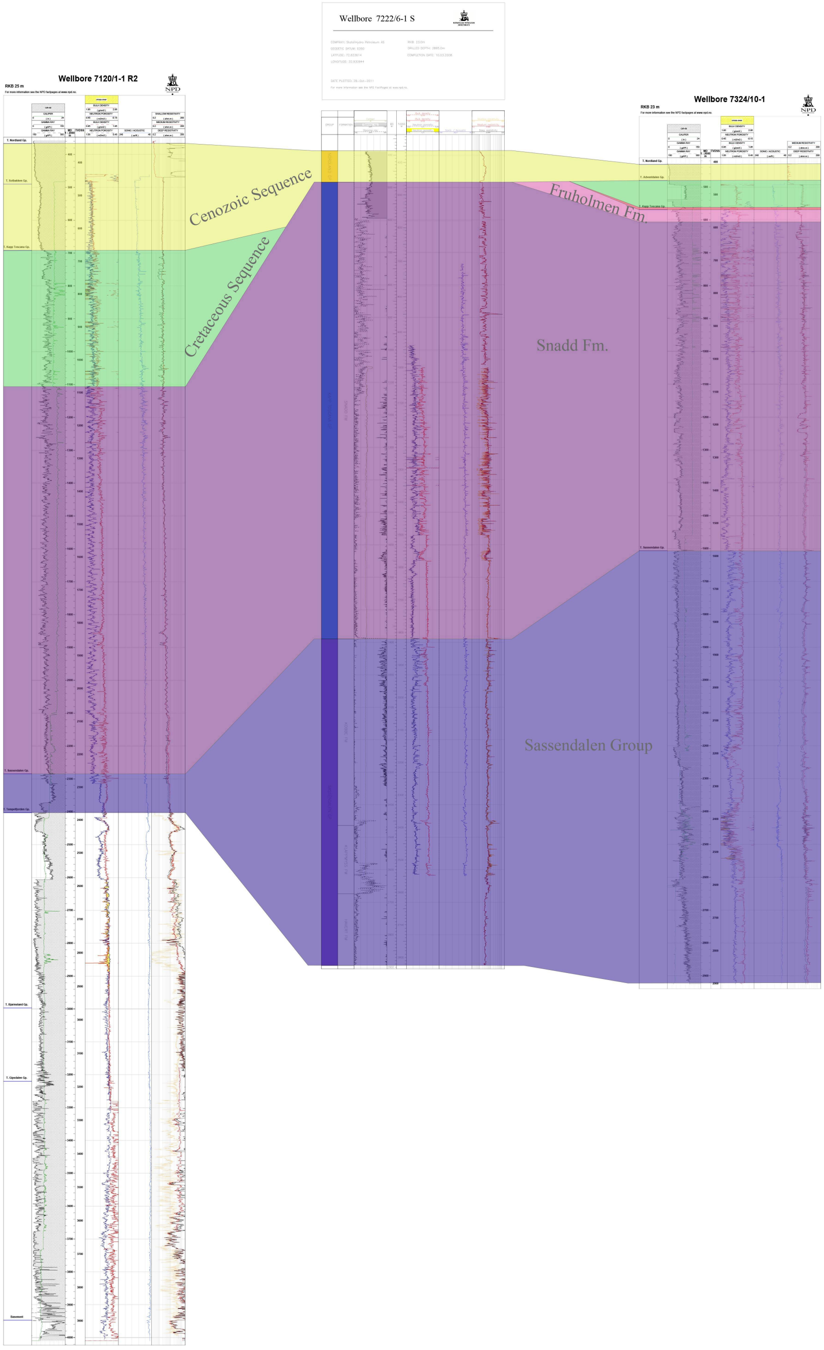
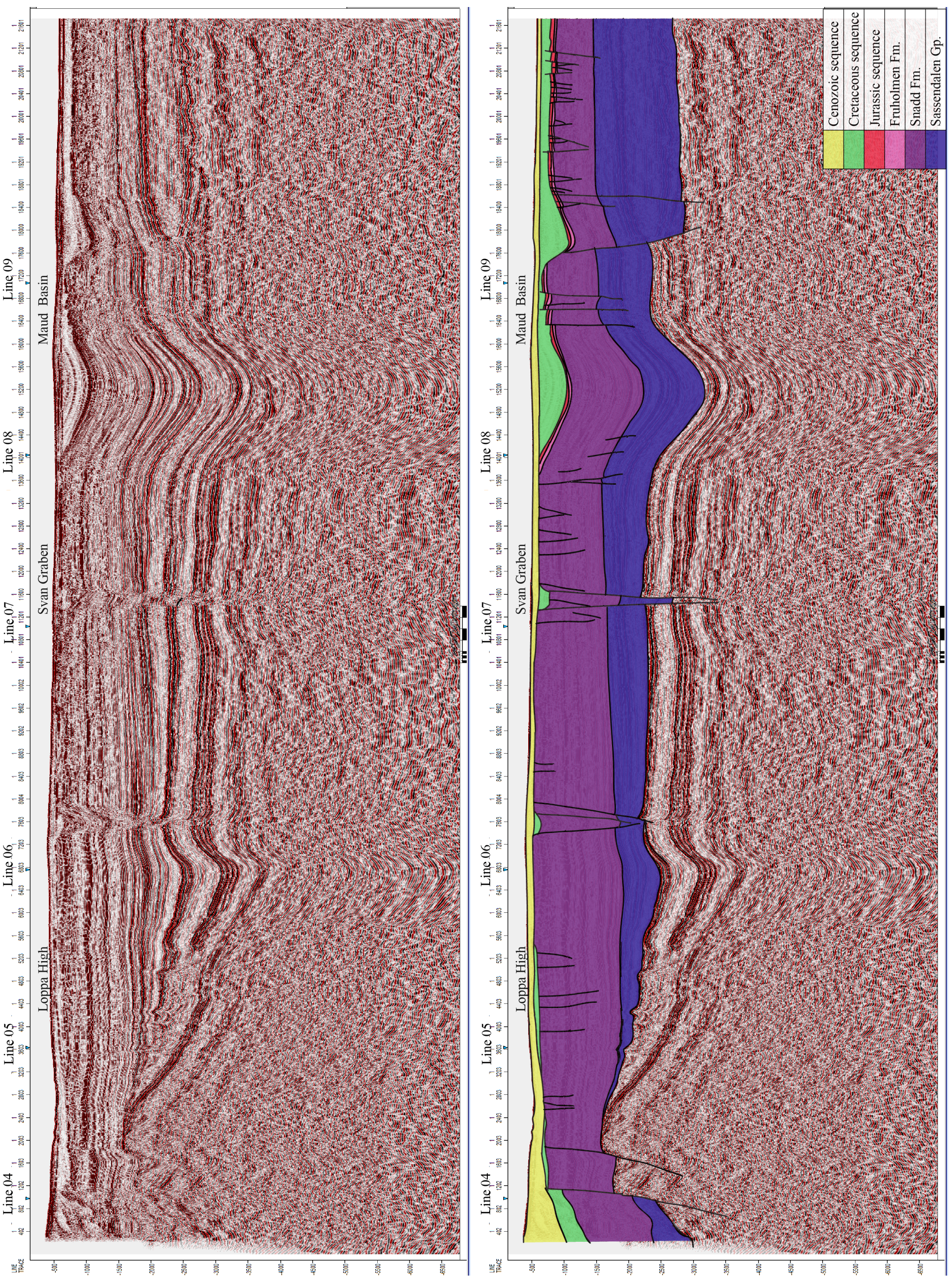


Figure 24: Wells from seismic line 26. Wellbore 7120/1-1R2 is located at the intersection of seismic line 26 and 04, wellbore 7222/6-1S at the intersection of seismic line 26 and 07 and wellbore 7324/10-1 at the intersecion of seismic line 26 and 09. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 26

(b) Seismic profile, line 26

Figure 25: Seismic 2D line 26 and a profile showing the seismic interpretation. The location is shown in Figure 7.

by Cretaceous or Cenozoic erosion at the other two locations.

In Figure 25 we see the final interpretation of seismic line 26. On the northeastern side of the Hoop Fault Complex in the Maud Basin Sassendalen Group is thicker than on the southwestern side. This indicates subsidence of the northern Maud Basin in Early to Mid Triassic times. In the Swaen Graben Sassendalen Group is also a bit thicker than its surroundings, suggesting some subsidence here as well.

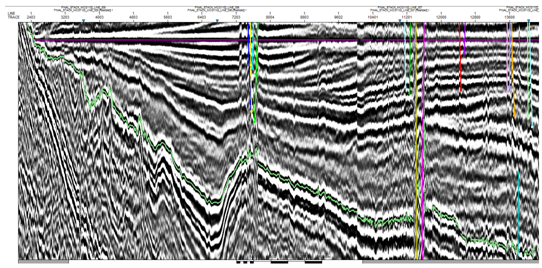


Figure 26: Seismic clinoforms from seismic line 26 showing southwestern progradation. Flattened at Top Sassendalen.

Southwestwards onto the paleo-Loppa High Sassendalen Group is thinning as it is onlapping the high. Approximately at the intersection of line 06 the deposits are thicker, showing the shape of an Early to Mid Triassic subsided basin. At the highest point of the paleo-Loppa High there are no deposits from this time, but in the Tromsø Basin southwest of the Ringvassøy-Loppa Fault Complex Sassendalen Group is present again. This indicates that the high was a positive structure during the time of deposition. Seismic complex sigmoidal clinoforms within the subsequence show sediment transportation to southwest (Figure 26).

Snadd Formation is thinning from southwest towards northeast in the profile. Cretacous or Cenozoic erosion have removed the top of Snadd Formation as well as Fruholmen Formation and The Jurassic sequence southwest of the intersection with seismic line 08. Hence, the original thickness of Snadd at the Loppa High and Tromsø Basin is unknown, but at least it was far greater than at the Maud Basin and Bjarmeland Platform. The reflection configuration in Snadd Formation suggests a depocentre at the Loppa High. Fruholmen Formation shows the same tendency as Snadd Formation where it is present, but southwest of the intersection with seismic line 08 it is completely removed by Cretacous or Cenozoic erosion.

The correlation of seismic line 27 and three wells and seismic lines is shown in Figure 27. Of the three wells only wellbore 7220/6-1 penetrates the Triassic de-

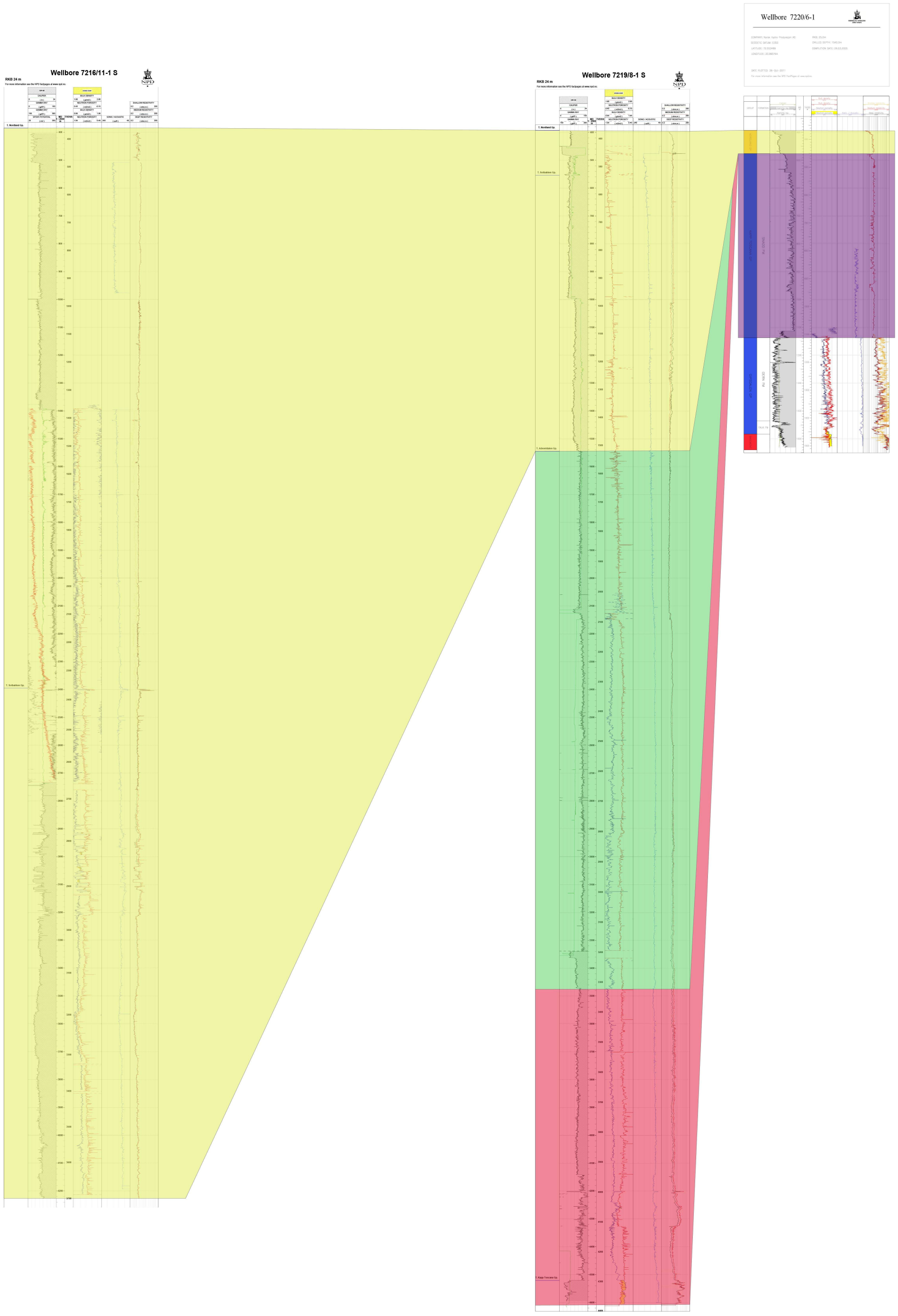
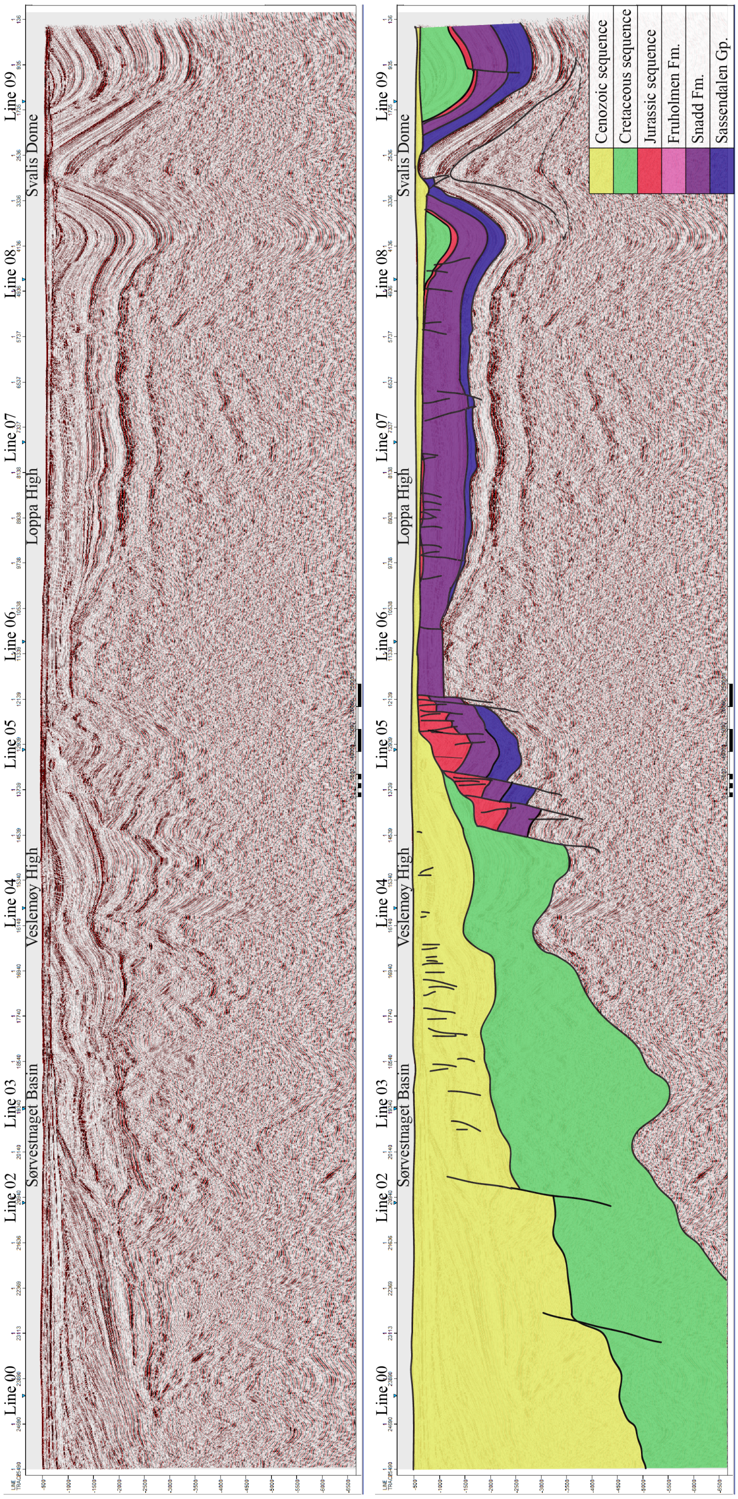


Figure 27: Wells from seismic line 27. Wellbore 7216/11-1S is located at the intersection of seismic line 27 and 00, wellbore 7219/8-1S at the intersection of seismic line 27 and 04 and wellbore 7220/6-1 at the intersecion of seismic line 27 and 06. Blue, Sassendalen Group; purple, Snadd Formation; pink, Fruholmen Formation; red, Jurassic; green, Cretaceous; yellow, Cenozoic.



(a) Seismic line 27 (b) Seismic profile, line 27

Figure 28: Seismic 2D line 27 and a profile showing the seismic interpretation. The location is shown in Figure 7.

positional unit. The well is located at the Loppa High, and the only Triassic subsequence present is Snadd Formation. The interpretation of seismic line 27 is shown in Figure 28.

In the profile Sassendalen Group is thickest on the northeastern side of the Svalis Dome. On the southwestern side of the dome the subsequence is thinning as it is onlapping the paleo-Loppa High. At the highest point of the paleo-Loppa High there are no deposits from Sassendalen Group, but southwest of the Ringvassøy-Loppa Fault Complex Sassendalen Group is present again, getting thicker. This indicates that the paleo-Loppa High was a positive feature, and that the salt in the Svalis Dome was rising in Early to Mid Triassic times. This uplift created accommodation space on both sides of the dome, but mostly on the northeastern side. In the Bjørnøya Basin west of the Loppa High Sassendalen Group indicates subsidence.

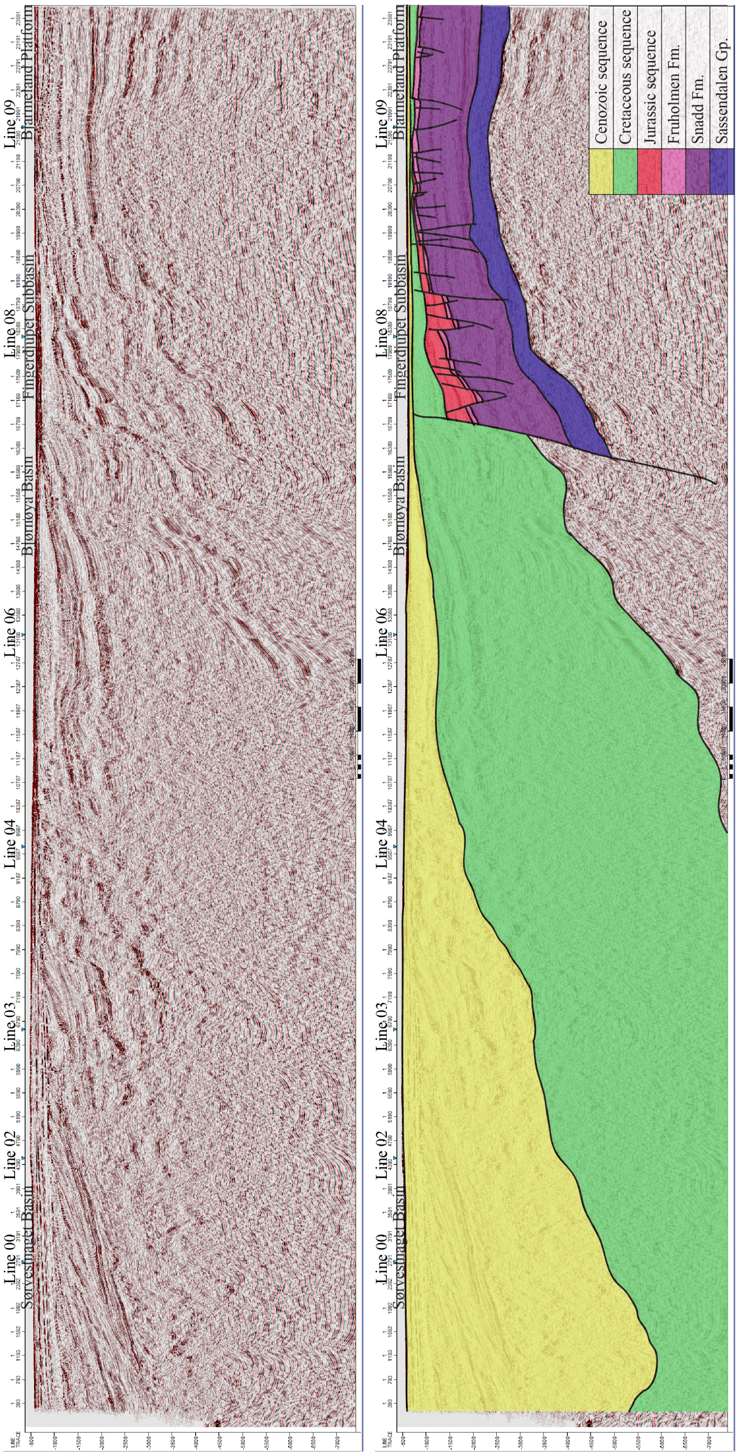
Snadd is at its thinnest over the Svalis Dome and thickest at the Loppa High. This suggests that the dome was still being uplifted by salt movement in Mid to Late Triassic times, creating local accommodation space around it while the Loppa High was part of a large, subsiding area.

The interpretation of seismic line 28 in Figure 29 is the result of correlation with wellbore 7321/9-1 at the intersection with seismic line 08 as well as the interpretation of the intersecting seismic lines. The thickness of Sassendalen Group is fairly uniform, but in the Fingerdjupet Subbasin it is at its thinnest.

Snadd Formation is getting thicker towards southwest in the Fingerdjupet Subbasin, and towards northeast on the Bjarmeland Platform. A lot of horst and graben structures, mostly active in Jurassic and Late Triassic times, have influenced the accommodation space along at the Bjarmeland Platform and the Fingerdjupet Subbasin.

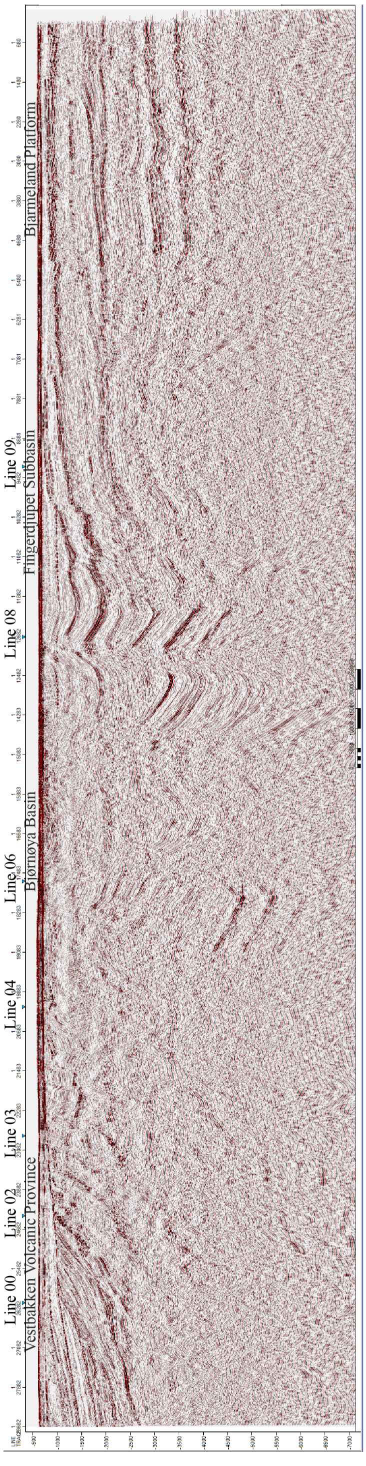
Fruholmen Formation is quite uniform, but it seems to be thickest at the Bjarmeland Platform.

Figure 30 displays the interpretation of seismic line 29. Sassendalen Group is at its thinnest in the western edge of the Bjarmeland Platform, getting thicker to

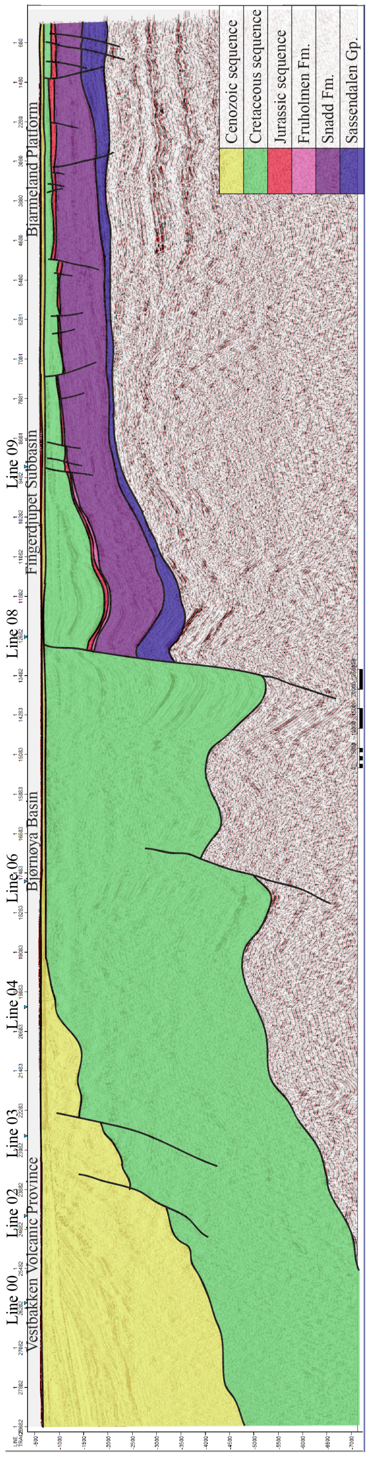


(a) Seismic line 28 (b) Seismic profile, line 28

Figure 29: Seismic 2D line 28 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 29



(b) Seismic profile, line 29

Figure 30: Seismic 2D line 29 and a profile showing the seismic interpretation. The location is shown in Figure 7.

both southwest and northeast. This suggests the presence of a high in Early to Mid Triassic times, separating two depocentres in the profile area.

Snadd Formation is thinning towards northeast and to the major fault (Leirdjupet Fault Complex) west of Fingerdjupet Subbasin, indicating a depocentre at about the eastern edge of Fingerdjupet Subbasin in Mid to Late Triassic times.

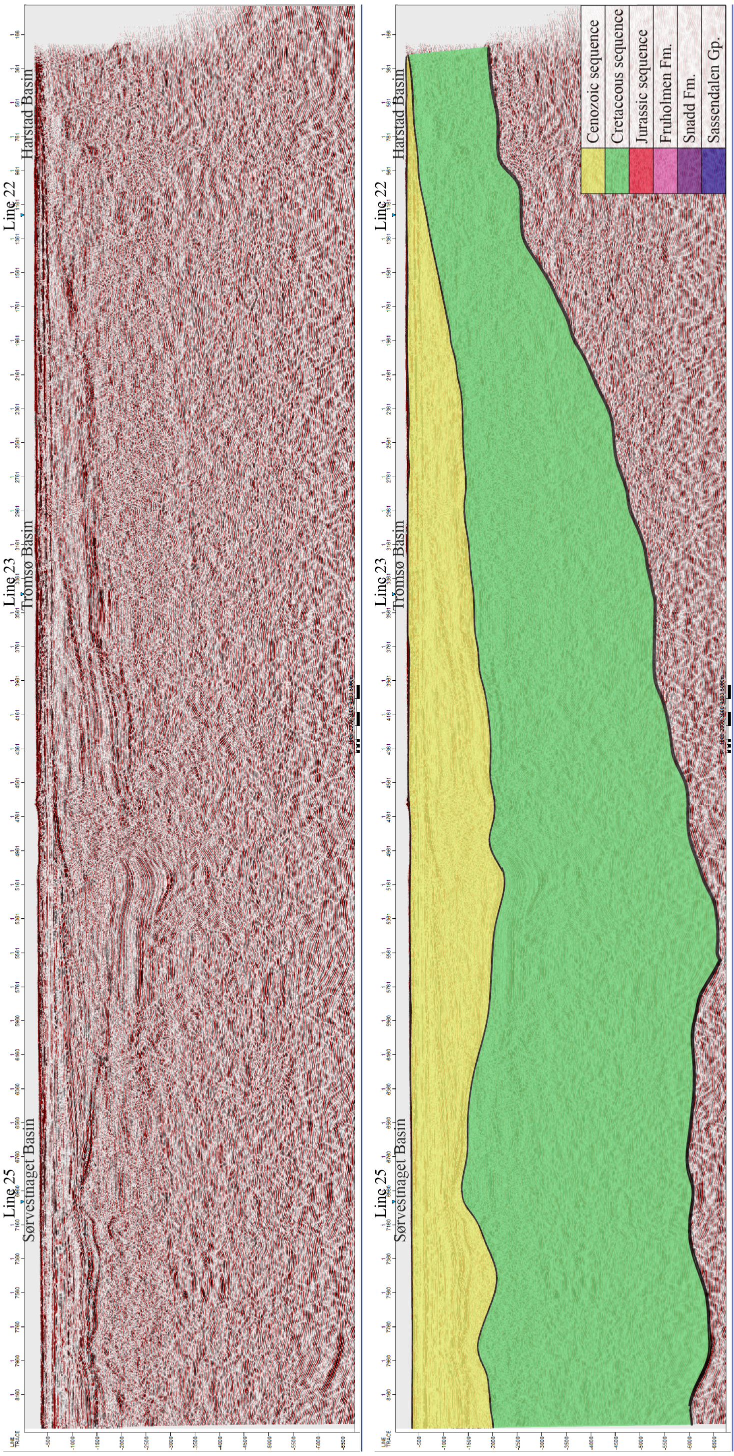
Fruholmen Formation is only visible in the Fingerdjupet Subbasin on the profile, and it is also thinning towards northeast, indicating subsidence of the Fingerdjupet Subbasin in Late Triassic time.

Figures 31 to 33 show the interpretation of seismic lines 01, 02 and 03 respectively. None of these profiles have been interpreted deep enough to say anything about the Triassic depositional unit, but their intersection with crossing seismic lines helped tying the lines when interpreting the crossing lines.

In the profile from seismic line 04 in Figure 34 Sassendalen Group is a bit thicker in the Hammerfest Basin graben compared to the highs north and south of the graben. The faults within the Hammerfest Basin show subsidence of the hanging wall along the faults as the subsequence in general is thinning towards southeast within the blocks. In the Tromsø Basin the subsequence is getting thicker towards northwest. This indicates some subsidence in both the Hammerfest Basin and Tromsø Basin in Early to Mid Triassic times.

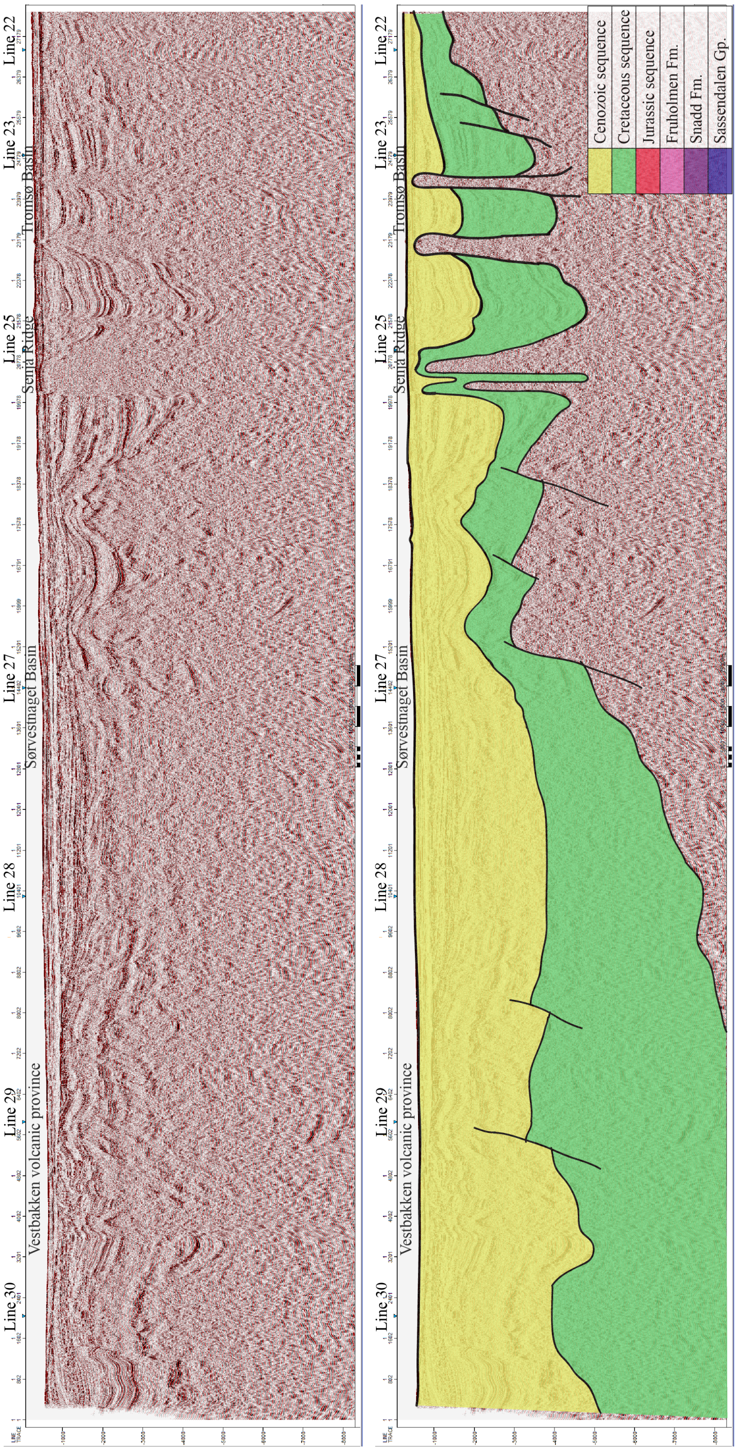
Snadd Formation is generally thinning to southeast, but at the Troms-Finnmark Fault Complex separating the Finnmark Platform from the Hammerfest Basin, the subsequence is thickest at the southeastern side. The top of Snadd has been removed by Cretaceous or Cenozoic erosion in the Tromsø Basin, but at the Veslemøy High Top Snadd is present again. This suggests some subsidence of the Finnmark Platform relative to the Tromsø and Hammerfest Basins. The two basins appears to have been part of one large subsiding area with a depocentre close to the Ringvassøy-Loppa Fault Complex in the Tromsø Basin area in Mid to Late Triassic times.

Fruholmen Formation is a very thin subsequence, thinning towards southeast in the Hammerfest Basin. This indicates a subsidence of the Hammerfest Basin in



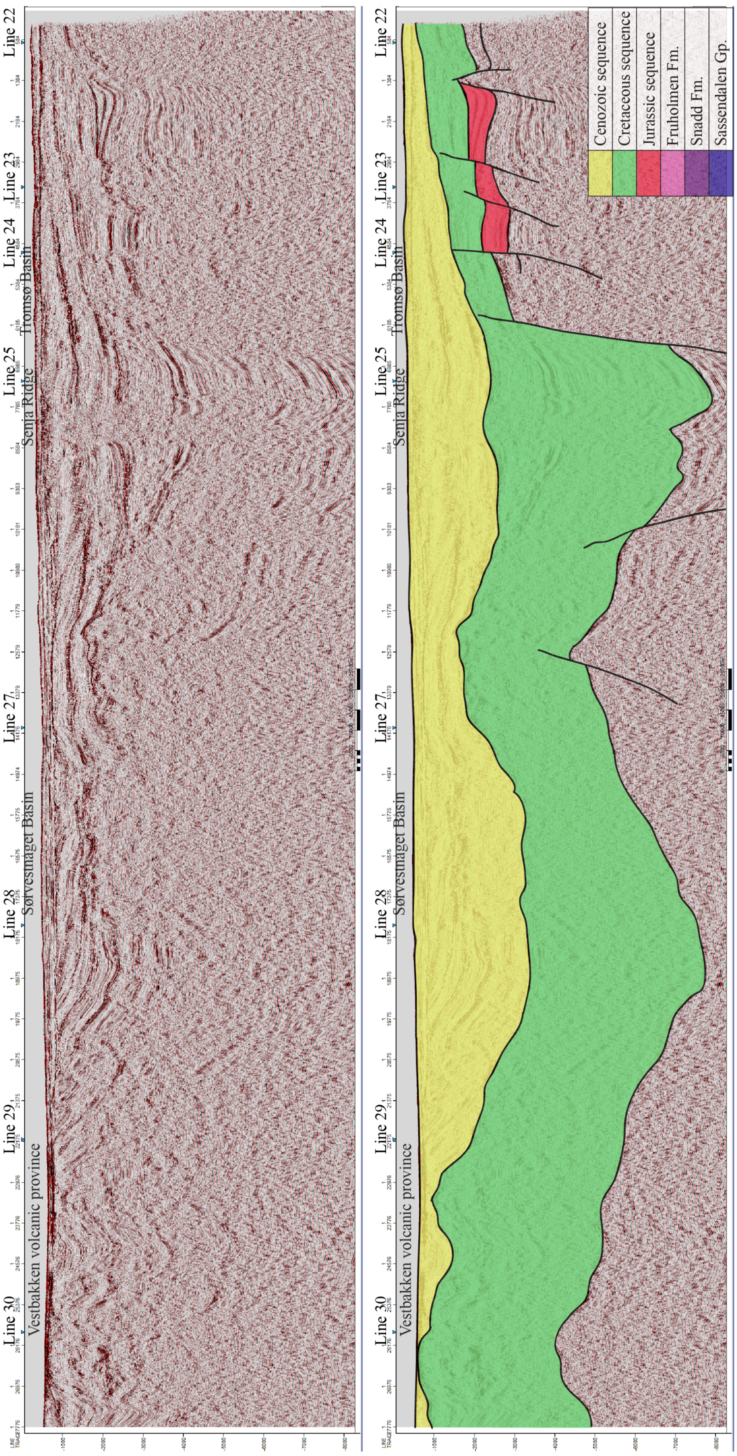
(a) Seismic line 01 (b) Seismic profile, line 01

Figure 31: Seismic 2D line 01 and a profile showing the seismic interpretation. The location is shown in Figure 7.



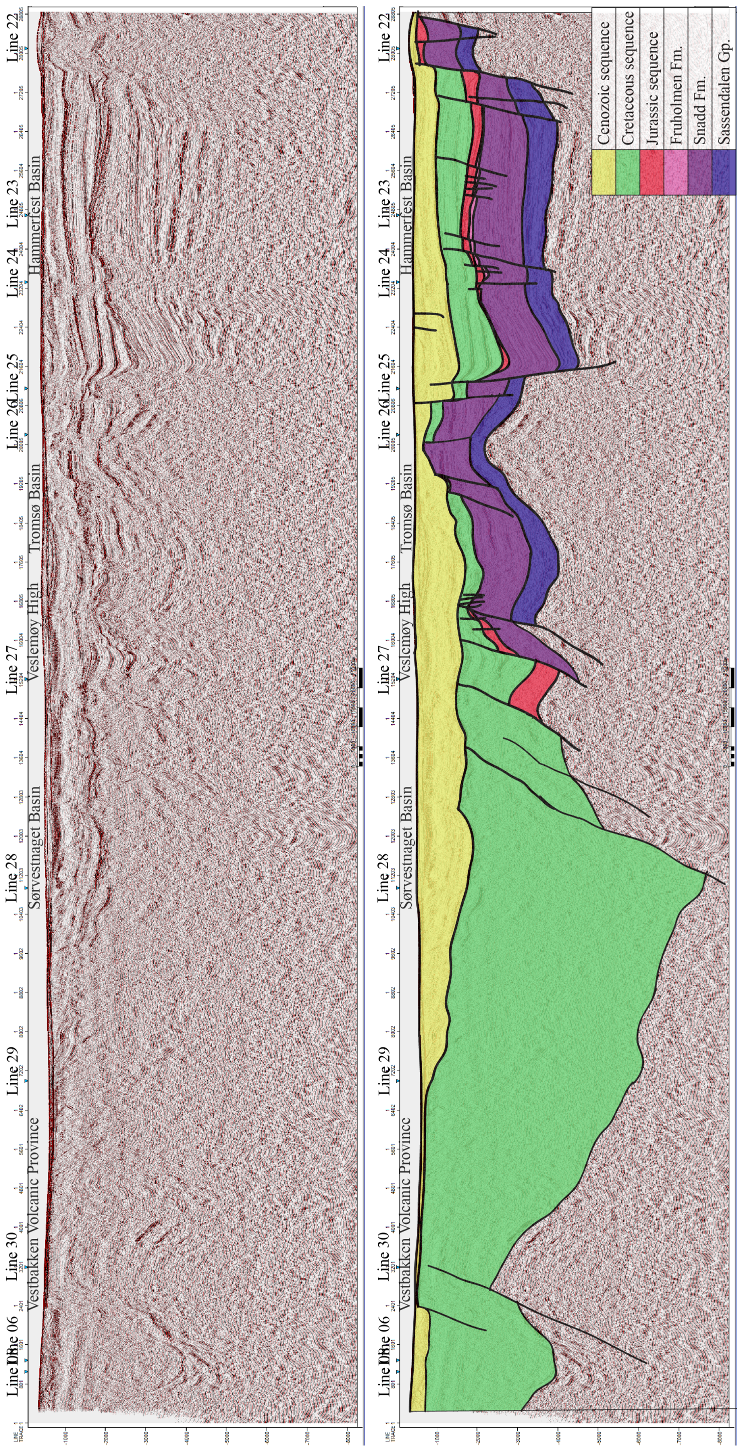
(a) Seismic line 02 (b) Seismic profile, line 02

Figure 32: Seismic 2D line 02 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 03 (b) Seismic profile, line 03

Figure 33: Seismic 2D line 03 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 04 (b) Seismic profile, line 04

Figure 34: Seismic 2D line 04 and a profile showing the seismic interpretation. The location is shown in Figure 7.

Late Triassic time.

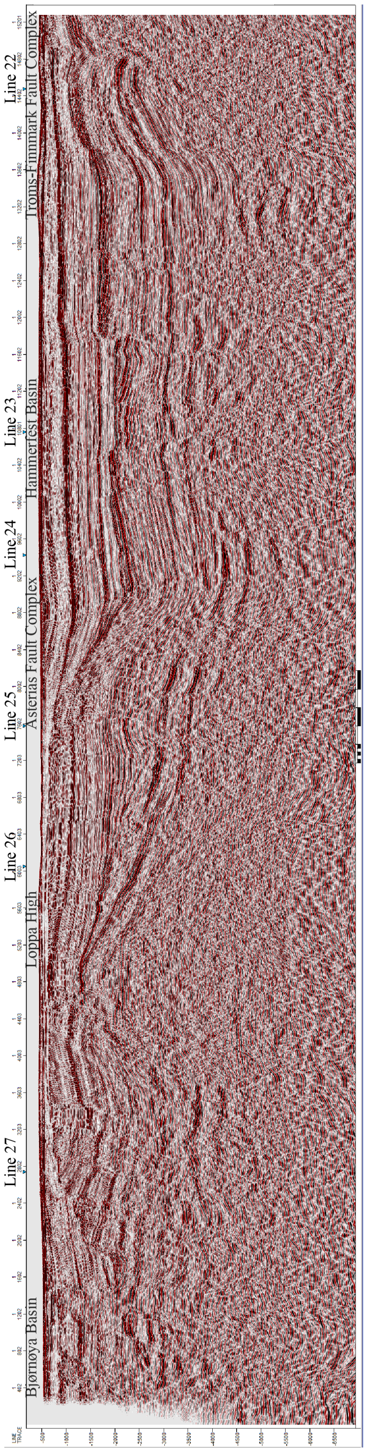
The interpretation of seismic line 05 is shown in Figure 35. Sassendalen Group is thickest in the Hammerfest Basin and thinning towards both the Troms-Finnmark Fault Complex and the Asterias Fault Complex. Both the Troms-Finnmark and Asterias Fault Complexes were active as the subsequence is thicker on the hanging walls. The subsequence is also onlapping the paleo-Loppa High. This indicates subsidence of the Hammerfest Basin and possibly uplift of the paleo-high in Early to Mid Triassic times. The highest point of the paleo-high lacks Sassendalen deposits, which suggests that the high was a positive feature at the time. On the northwestern side of the high the subsequence is getting thicker towards the Bjørnøya Basin. This indicates subsidence of the Bjørnøya Basin as well.

Snadd Formation is thickest at the Loppa High and getting thinner in both directions. As the interpretation in Ekerheim (2012) suggests, it indicates that the two basins and the high acted as a large subsidence basin in Mid to Late Triassic times, and that the depocentre was at the paleo-Loppa High.

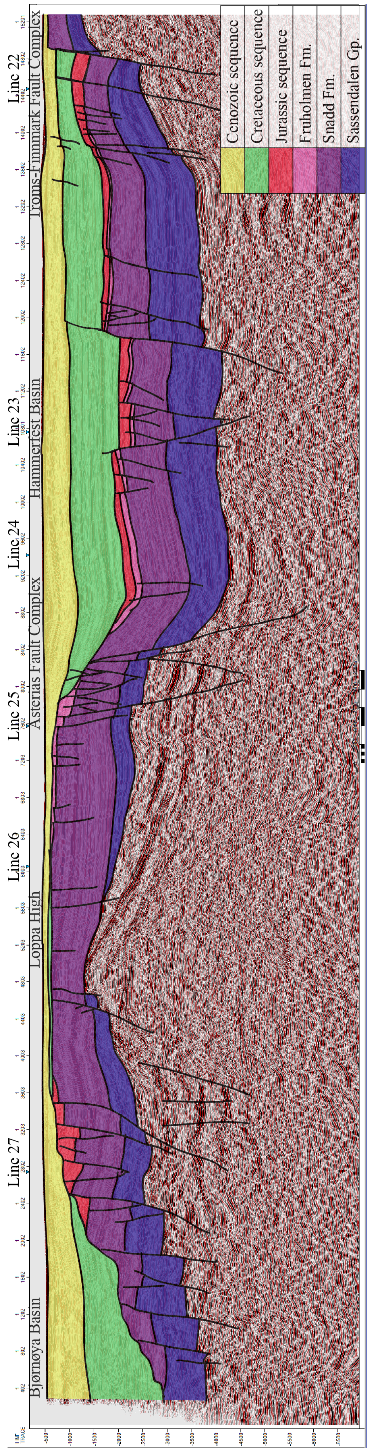
Fruholmen Formation in the Hammerfest Basin is thickest near the Asterias Fault Complex and thinning towards southeast. The subsequence is thickest at the Asterias Fault Complex, but most of the deposits have been removed by Cretaceous or Cenozoic erosion at the Loppa High. Towards the Troms-Finnmark Fault Complex and the Bjørnøya Basin the subsequence is missing, supporting the interpretation of a depocentre at the Loppa High in Late Triassic time.

In Figure 36 the profile from seismic line 06 is shown. We see much of the tendency as in Figure 35. Sassendalen Group is thickest in the Hammerfest Basin. It is onlapping the paleo-Loppa High, indicating subsidence of the Hammerfest Basin along the Asterias and Troms-Finnmark Fault Complexes, and that the paleo-high was a positive feature. Seismic sigmoidal clinoforms show sediment transportation to northwest (Figure 9b) in Early to Mid Triassic times.

Snadd Formation is thickest at the Loppa High, suggesting a large subsiding basin with depocentre at Loppa. The reflectors are fewer and thicker in the Hammefest Basin than on the Loppa High. Faults at the location of the Bjørnøyrenna Fault Complex appears to have been active, giving some subsidence for the Bjørnøya

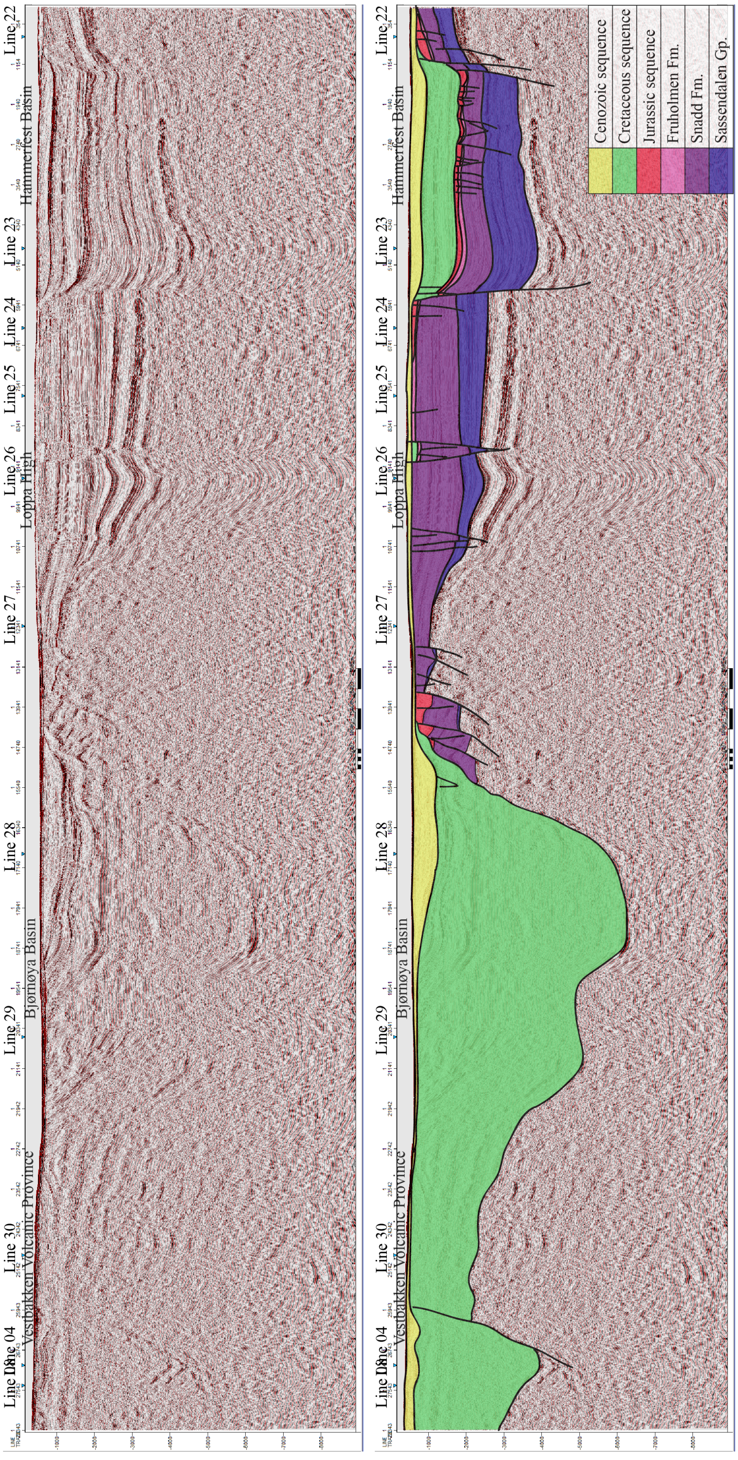


(a) Seismic line 05



(b) Seismic profile, line 05

Figure 35: Seismic 2D line 05 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 06 (b) Seismic profile, line 06

Figure 36: Seismic 2D line 06 and a profile showing the seismic interpretation. The location is shown in Figure 7.

Basin in Mid to Late Triassic times.

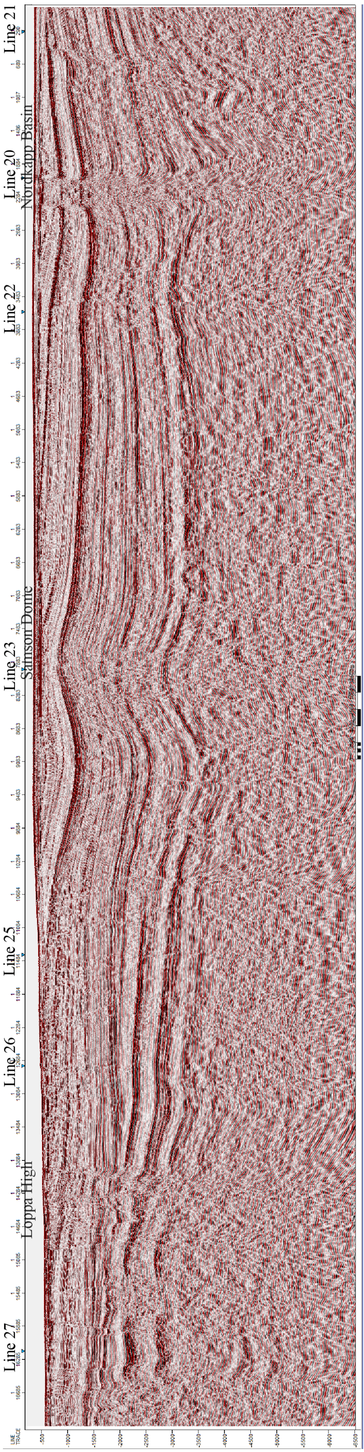
Fruholmen Formation, on the other hand, is thinning in both directions in the Hammerfest Basin and on the Loppa High, indicating some subsidence in both places in Late Triassic time.

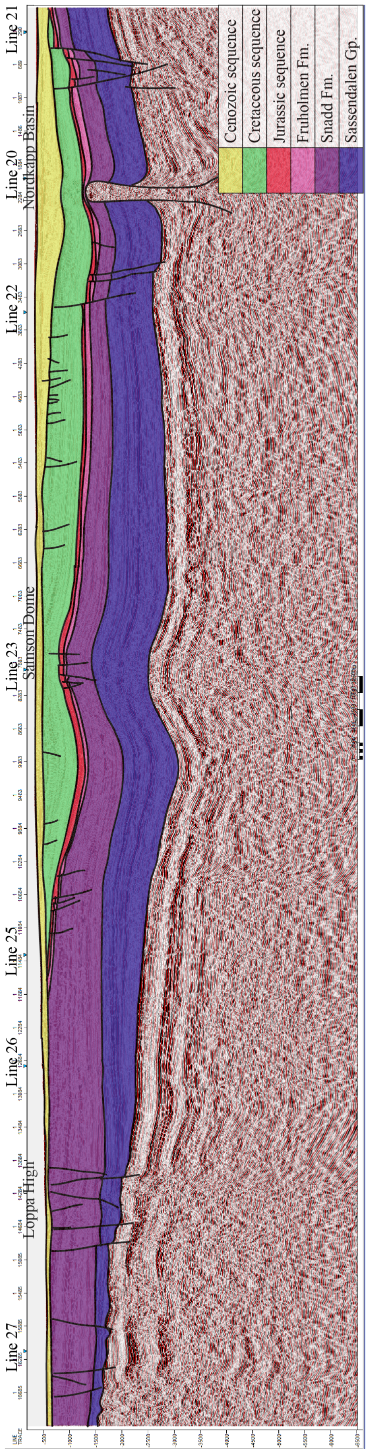
The interpretation of seismic line 07 is shown in Figure 37. Sassendalen Group is thinning from south of the Samson Dome in both directions. On the southeastern side of the salt in the Nordkapp Basin and northwest of the Finnmark Platform there is a thinner section of Sassendalen Group, indicating a local uplift in the Nordkapp Basin dividing the profile into two depocentres in Early to Mid Triassic times. This may be a result from rising salt creating uplift in the Nordkapp Basin and accommodation space on the sides. Uplift of the paleo-Loppa High may have contributed to the accommodation space in the area southeast of the high. Within the subsequence weak reflectors seem to have clinoform configuration, indicating sediment transport towards northwest.

Snadd Formation is clearly thinning from northwest to southeast in the profile. The section between the salt dome in the Nordkapp Basin and the Finnmark Platform is thicker than the sections on either sides, suggesting subsidence here relative to a larger regional basin in Mid to Late Triassic times. The cause of this may be salt movement.

Fruholmen Formation is thickest in the Nordkapp Basin and thinning in both directions, indicating subsidence centered around the Nordkapp Basin in Late Triassic time. Southeast of the Samson Dome the subsequence is quite thick and thinning in both directions as well. This location is an extension of the Hammerfest Basin, and the thickness may be related to subsidence of the basin. Over the salt dome in the Nordkapp Basin the subsequence is thin, which suggests that the salt was still moving upwards. On the Loppa High erosion has removed the subsequence.

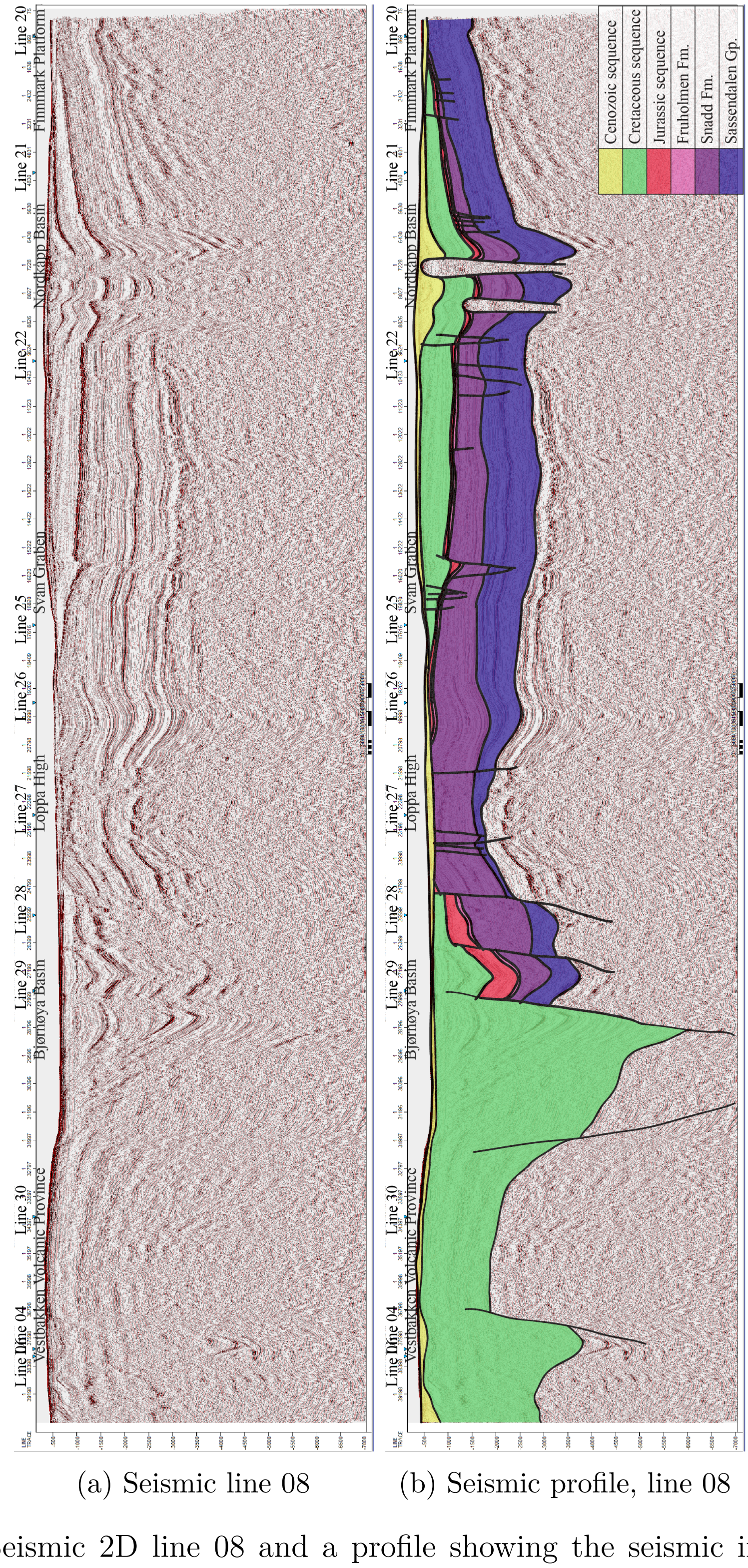
In Figure 38 the profile from seismic line 08 shows that Sassendalen Group is thickest southeast of the Swaen Graben. To northwest it is getting thinner, and seismic clinoforms are onlapping the paleo-Loppa High from southeast (Figure 39). Towards the edge of the Nordkapp Basin in southeast the subsequence is getting





(a) Seismic line 07 (b) Seismic profile, line 07

Figure 37: Seismic 2D line 07 and a profile showing the seismic interpretation. The location is shown in Figure 7.



(a) Seismic line 08 (b) Seismic profile, line 08

Figure 38: Seismic 2D line 08 and a profile showing the seismic interpretation. The location is shown in Figure 7.

thinner as well. However, southeast of the Nordkapp Basin the thinning is from the Finnmark Platform towards the basin. In the Nordkapp Basin the subsequence is thicker again, indicating subsidence due to salt movement in two salt diapirs. Southeast and northwest of the Nordkapp Basin the thickness of Sassendalen Group indicates two depocentres as well; one east of the Samson Dome (Figure 7) and one on the Finnmark Platform in Early to Mid Triassic times. Faults at the Bjørnøyrenna and Leirdjupet Fault Complexes were active as well, giving subsidence in the Fingerdjupet Subbasin.

Snadd Formation is thinning from the Loppa High towards both the Bjørnøya Basin and the Finnmark Platform, but as for Sassendalen Group, Snadd Formation is also thicker in the Nordkapp Basin. This indicates a large Basin centered around the Loppa High and a local, but quite large subsidence of the Nordkapp Basin in Mid to Late Triassic times. Fruholmen Formation seems to follow the same trend, but at the Loppa High it has been removed by erosion.

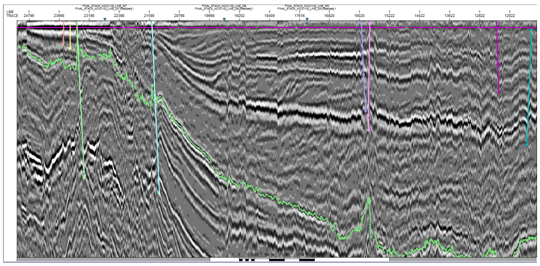
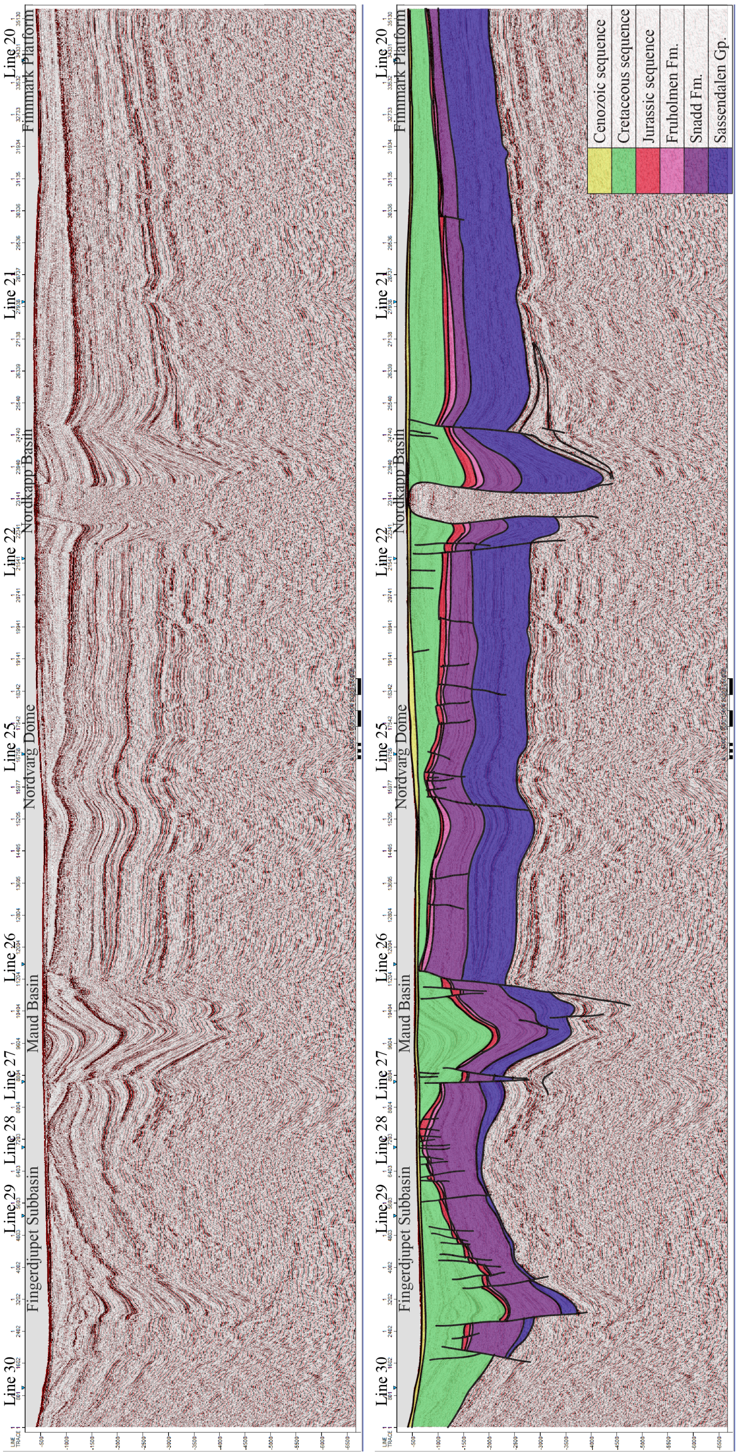


Figure 39: Seismic clinoforms from seismic line 08 showing northwestern progradation. Flattened at Top Sassendalen.

Figure 40 show the profile from seismic line 09. The thickest part of Sassendalen Group is at the middle of the profile from the Nordvarg Dome to the Nordkapp Basin. Southeast of the Nordkapp Basin the subsequence is getting slightly thinner, and from the Maud Basin and northwestwards it is thinning more evidently as it is onlapping the border between the Bjarmeland Platform and the Fingerdjupet Subbasin. Southeast of the Maud Basin seismic clinoforms show sediment transportation from southeast. The Hoop Fault Complex appears to have been active, giving differential subsidence in the Maud Basin. The thickness in the Fingerdjupet Subbasin indicates a structural high separating the areas east and west of it. In the Nordkapp Basin the thickness of Sassendalen Group indicates subsidence southeast of the salt dome in Early to Mid Triassic times.



(a) Seismic line 09 (b) Seismic profile, line 09

Figure 40: Seismic 2D line 09 and a profile showing the seismic interpretation. The location is shown in Figure 7.

Snadd Formation is thinning towards southeast in the profile with exception of a thinner section at the Svalis Dome where the seismic lines 09 and 27 intersect each other, and a thicker section in the Nordkapp Basin. This indicates a large subsidence basin with the Svalis Dome as a local high as well as relative subsidence in the Nordkapp Basin where the salt was still rising in Mid to Late Triassic times.

Fruholmen Formation has two relatively thick sections. One is centered in the Nordkapp Basin and the other northwest of the Nordvarg Dome. In-between and northwest and southeast of these two areas the subsequence is thinning. This indicates two depocentres in the profile in Late Triassic time.

4.2 Time-thickness maps

From the seismic profiles in Section 4.1 I made time-thickness maps of the three Triassic subsequences interpreted.

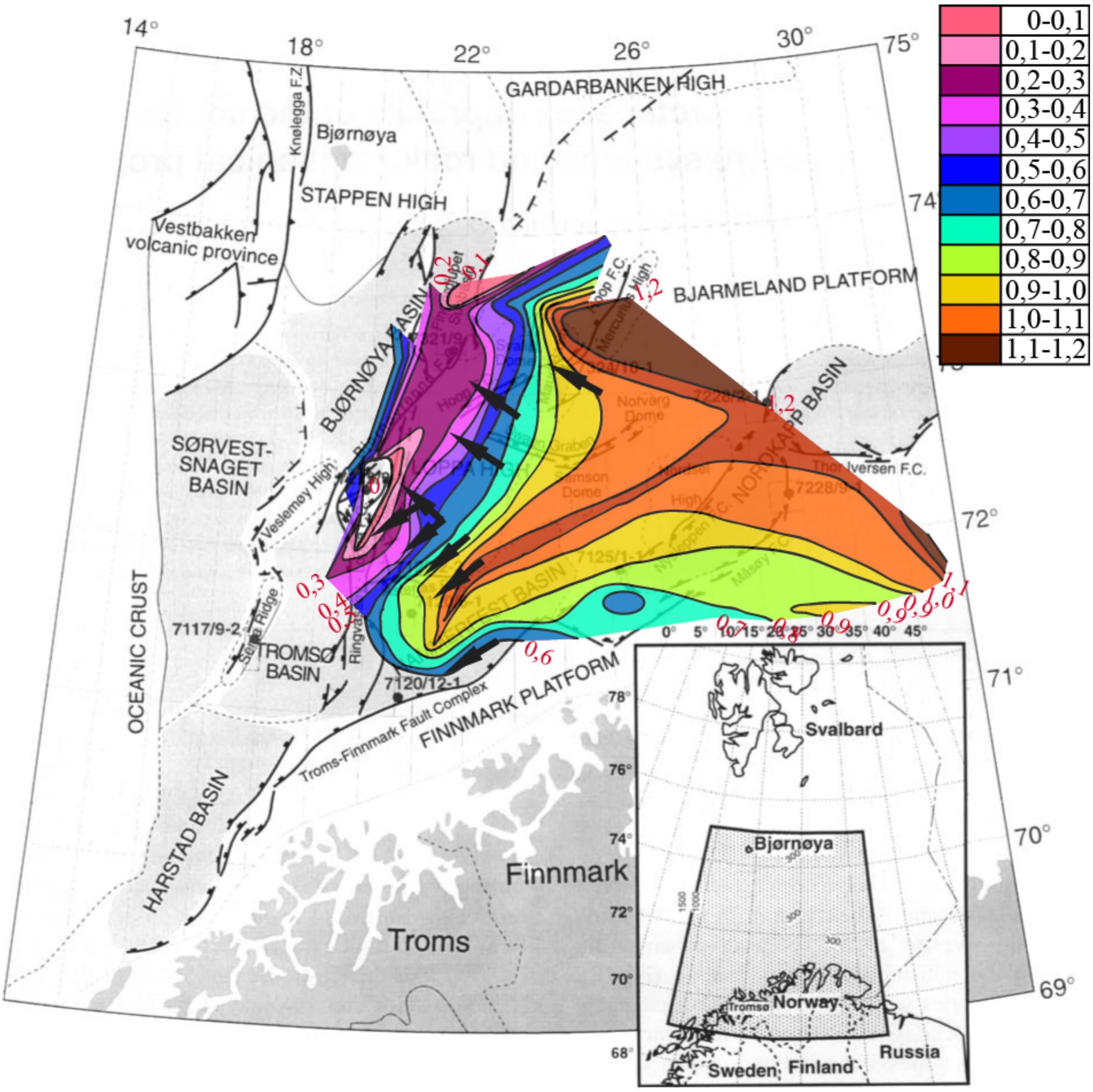


Figure 41: Time-thickness map of the Triassic Sassendalen Group in the study area. The contours are given in seconds. The arrows on the map show the direction of the seismic clinoforms visible on the seismic 2D lines. The structural element map is from Gabrielsen and Kløvjan (1997).

The time-thickness map in Figure 41 shows how Sassendalen Group is getting thinner from east to west and north. At the Loppa High there is an area without Sassendalen sediments, indicating a positive feature in Early to Mid Triassic times. To the northeast of this island Gardarbanken High seems to continue down to the thin section at the Fingerdjupet Subbasin. The map indicates a structural high going from the Gardarbanken High, southwestwards to the Fingerdjupet Subbasin and down to the Polheim Subplatform at the western Loppa High. This structure divides the southwestern Barents Sea into two depositional areas; one west and one east of the structure.

In the eastern area there are two areas of very thick deposits separated by the Nordkapp Basin. Either these two areas represent two separate depocentres or there is a connection northeast of the seismic lines interpreted in this study. Salt movement in the Nordkapp Basin is a reasonable explanation for this separation based on the profiles in Section 4.1. In addition there is a thick flank going from the Nordkapp Basin southwestwards into the Hammerfest Basin in-between the Finnmark Platform and the paleo-Loppa High. South of this basinal extension there is a small section of deposits that is thicker than the surroundings, and in the southeast of the Finnmark Platform there is a thicker section entering the southwestern Barents Sea from southeast.

The seismic clinoforms found in the area point to a sediment supply from east or southeast with a sediment flow into a subsiding basin going from the present day Nordkapp Basin, southwestwards into the present day Hammerfest Basin.

This gives a total picture of Early to Mid Triassic sediment transport from east or southeast into a southeast-northwest trending, subsiding basin. This basin has probably two depocentres separated by the Nordkapp Basin which is being elevated by rising salt. Uplift of a southwest-northeast trending ridge is sheltering the western area from much of the sediment supply from the east. The uplift of the paleo-Loppa High along with subsidence in the area of the Hammerfest and Nordkapp Basins extends the basin southwestwards as well.

At the location of the Polheim Subplatform the uplift is great enough to create an island, leaving it free from Early to Mid Triassic sediments. In-between the

Nordkapp Basin, Hammerfest Basin and Finnmark Platform the Troms-Finnmark Fault Complex was active. That resulted in a local subsidence of a graben consisting of the southern Bjarmeland Platform in-between footwalls belonging to the Finnmark Platform. The thicker section southeast at the Finnmark Platform indicates a more local sediment source in southeast or a local depocentre.

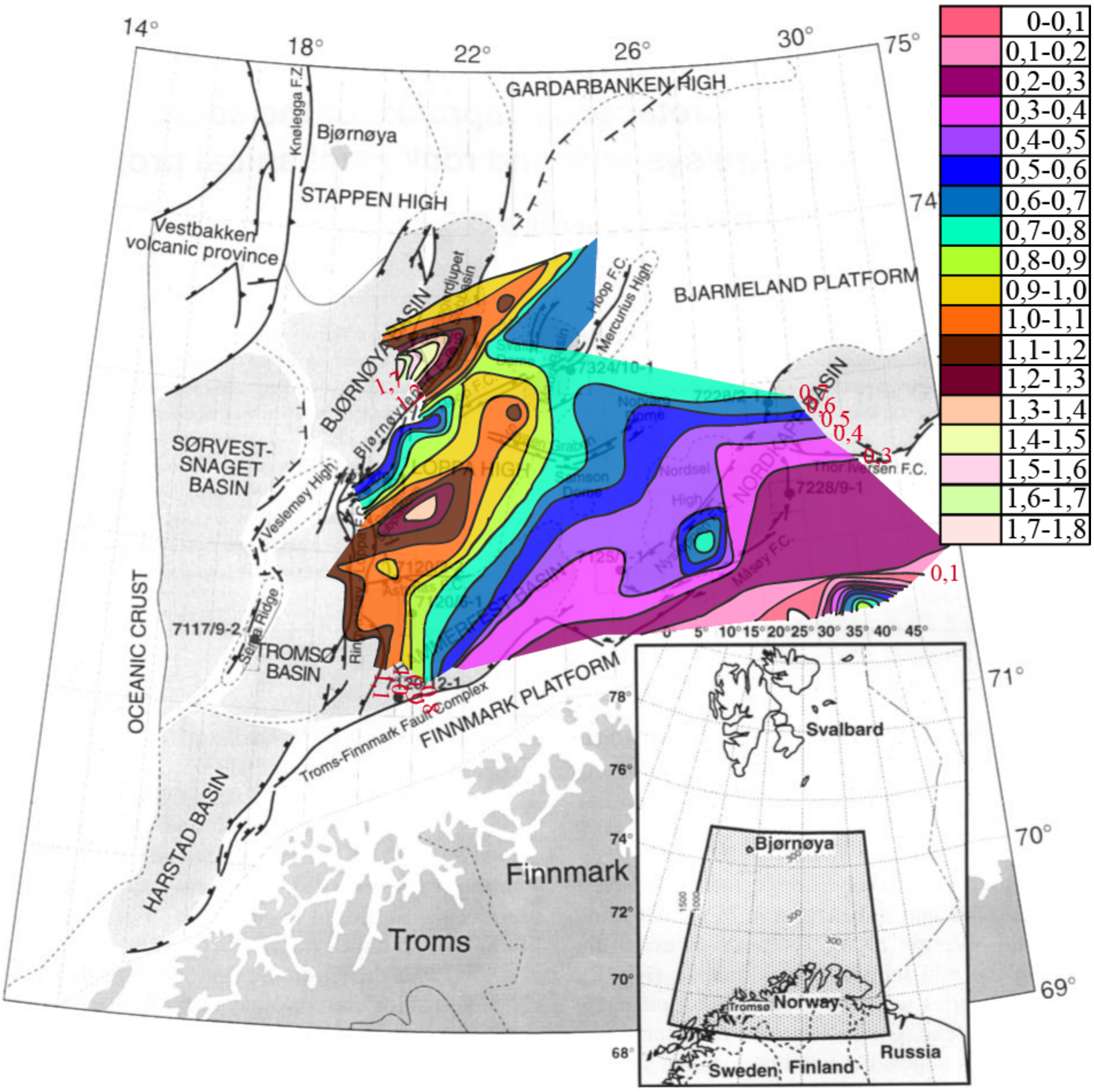


Figure 42: Time-thickness map of the Triassic Snadd Formation in the study area. The contours are given in seconds. The structural element map is from Gabrielsen and Kløvjan (1997).

In Mid to Late Triassic times the locus of subsidence had moved westwards. There seems to be two subsiding basins in the study area in Figure 42. Both are southwest-northeast trending, and they are separated by a thinner section located at the Polheim Subplatform. However, this thinner section may be a result from Cretaceous or Cenozoic erosion. If that is the case, the two thick sections may be one basin and depocentre instead of two. Considering the profiles in Section 4.1 I find this most likely.

Otherwise there is a high going along the western edge of the Loppa High and possibly continuing to the Veslemøy High and the Senja Ridge. This can be a residual from the structural high present in Early to Mid Triassic times. If this is the case then the basin southeast of the high has its depocentre at the Loppa High. Possibly, the Tromsø Basin is a depocentre since the Ringvassøy-Loppa Fault Complex has thicker deposits than the Hammerfest Basin. North of the high we got a depocentre in the Bjørnøya Basin.

In the southwestern part of the Nordkapp Basin there is a local depocentre. At the Finnmark Platform southeast in the study area there is another local depocentre as well.

I haven't located any seismic clinoforms within the Snadd Formation, therefor the location of the provenance area is more uncertain. Either the sediments are transported from east across a fairly stable platform into the NE-SW trending basin located at the Hammerfest, Tromsø and Bjørnøya Basins and the Loppa High area with subsidence as the controlling factor. Otherwise, the source area is in the west, southwest or northwest, filling in the area with less sediments reaching the eastern part of the southwestern Barents Sea, or there is a combination of the two.

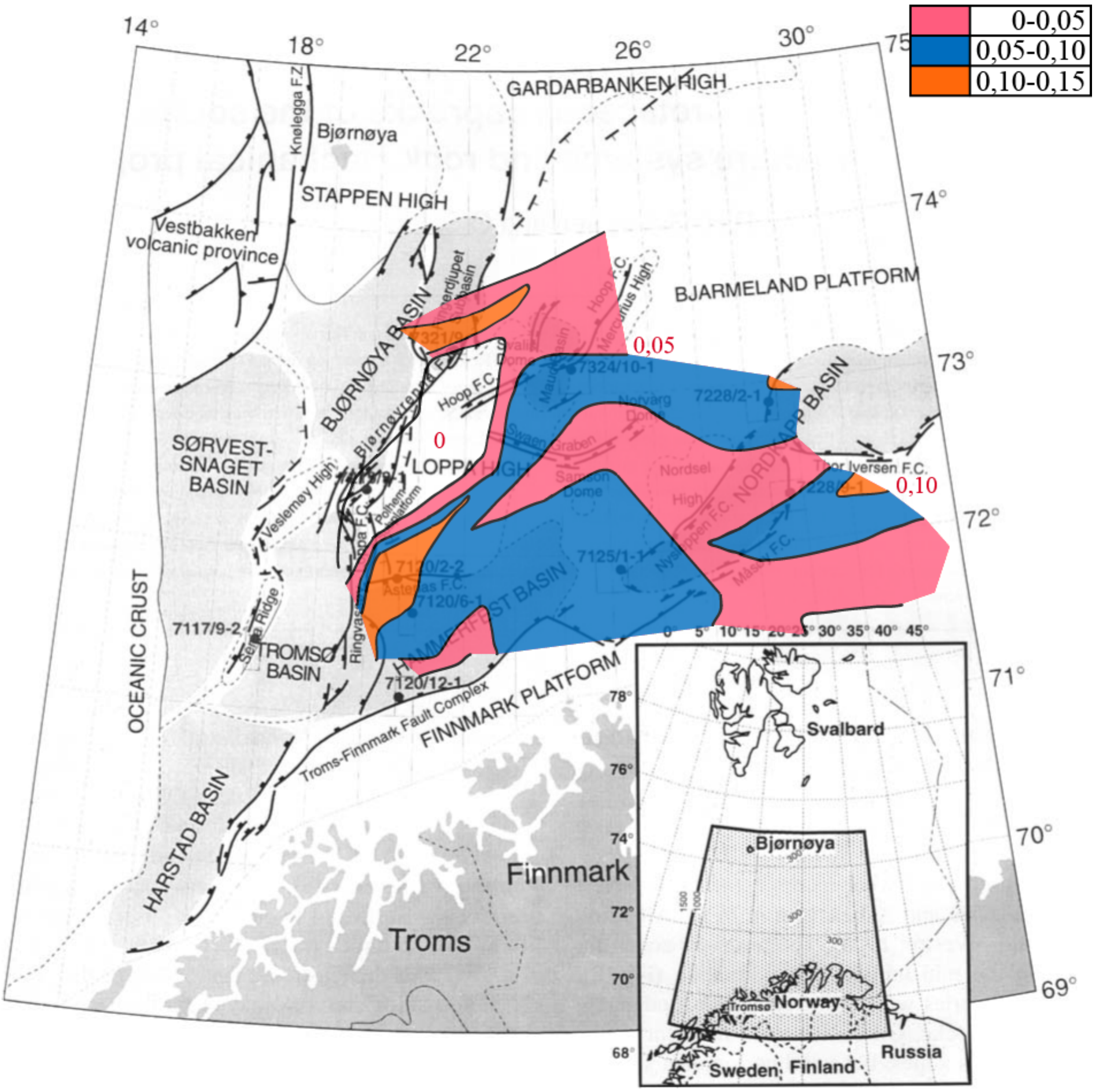


Figure 43: Time-thickness map of the Triassic Fruholmen Formation in the study area. The contours are given in seconds. The structural element map is from Gabrielsen and Kløvjan (1997).

Figure 43 shows how the thickness of Fruholmen Formation is varying in the study area. This is a very thin subsequence compared to the former two. At the Loppa High the whole subsequence has been removed by Cretaceous or Cenozoic erosion. Yet we can pull some information from the map.

There are two thicker sections on the northern and southern side of the Nordkapp

Basin indicating uplift in the southwestern part of the Nordkapp Basin and close to the Thor Iversen Fault Complex in the middle part, or just relative subsidence at the edges of the basin. This is probably related to salt movements. Rising salt in the basin with salt withdrawal at the basin edges may have created more accommodation space seen as the thicker parts south of the Thor Iversen Fault Complex and at the Nysleppen Fault Complex. Another thicker section going from the Loppa High southwest towards the Tromsø and Harstad Basins indicates some subsidence in the Hammerfest Basin and more subsidence in the Tromsø Basin. On the northwestern side of the Loppa High a thicker section indicates subsidence of the Fingerdjupet Subbasin and the Bjørnøya Basin as well.

5 Discussion

In this study I have divided the Triassic depositional unit into three subsequences. Glørstad-Clark et al. (2010), on the other hand, divided the Triassic unit into five subsequences based on maximum flooding surfaces. These subsequences are defined as Induan, Olenekian, Anisian–Early Ladinian, Ladinian–Early Carnian and Upper Triassic. The first three of these subsequences constitute Sassendalen Group which is the first of my subsequences. Snadd Formation, which is my second subsequence, is of Ladinian–Early Norian age. This is equivalent to the fourth subsequence of Glørstad-Clark et al. (2010) as well as some of the fifth. Fruholmen Formation is of Norian–Rhaetian age. This is equivalent to the last part of the fifth subsequence of Glørstad-Clark et al. (2010).

5.1 Infill directions

My Sassendalen Group subsequence clearly indicates a sediment source east or southeast of the study area in Early to Mid Triassic times. The fact that we see the clinoforms (Figures 9b, 13, 16, 23, 26 and 39) tells us that the progradation happened faster than the subsidence of the area, leading to lateral build-out in the direction of the arrows in Figure 41.

By interpreting their five subsequences Glørstad-Clark et al. (2010) conclude that the Early Triassic accommodation space south in the Barents Sea was filled prior to the northern Barents Sea, and that the eastern Barents Sea was filled prior to the western. This conclusion fits well with my interpretation of a source area east or southeast of the southwestern Barents Sea. Glørstad-Clark et al. (2010) points to the Uralian orogenic belt as the main source area, but Novaya Zemlya and more local source areas cannot be excluded (Buiter and Torsvik, 2007; Otto and Bailey, 1995; Torsvik and Andersen, 2002; Smelror et al., 2009; Glørstad-Clark et al., 2010). Glørstad-Clark et al. (2010) also point to the uplifted paleo-Loppa High as a local source area.

By Mid to Late Triassic times there was a significant change in the southwestern

Barents Sea. The paleo-high that divided the area into two regions had ceased to be a structural high. Instead it became the centre for a large-scale, regional subsiding basin. The thickness of the Snadd Formation (Figure 42) is greatest at the western edge of the paleo-Loppa High, and without Triassic interpretation in the deeper Bjørnøya and Tromsø Basins I cannot say how the development was west of the Loppa High. But based on the general eastward thickening in the profiles in Section 4.1 there might have been a change to a major western source area as well as sediment supply from east and southeast.

The contour lines in Figure 42 are mainly SW-NE trending, which suggests infill from west-northwest, and the map suggests two basins, both being SW-NE oriented. From the interpretation of the profiles in Section 4.1 I suggest that there is one depocentre at the Loppa High, and that the reason for the indication of two separated depocentres in the time-thickness map is erosion down in the Snadd Formation at the Loppa High. The fact that Snadd Formation is very thick in both the Tromsø Basin and the area around the Loppa High and Bjørnøya Basin, supports the possibility of a western or southwestern source area.

The Early to Mid Triassic sequences of Glørstad-Clark et al. (2010) show the Triassic sediment deposition as prograding deltas filling in pre-existing Permian topography from the east and southeast. As time goes, the depocentres move further west. In Mid to Late Triassic time Glørstad-Clark et al. (2010) interpret sediment deposition from west or northwest over the paleo-Loppa High. In the Nordkapp Basin and on the Finnmark Platform coastal and channel sands of Carnian age indicates a Baltic provenance area in east or southeast (Worsley, 2008). The Sassendalen subsequence in this study showed an Early to Mid Triassic eastward thickening, while the Mid to Late Triassic Snadd subsequence showed a general westward thickening except for the Nordkapp Basin and the Finnmark Platform. This correlates well to the interpretation of Glørstad-Clark et al. (2010).

According to Glørstad-Clark et al. (2010) Late Paleozoic rifting and uplift played an important role in Triassic infill until Early Ladinian time when the area east of the paleo-Loppa High was filled. In their Late Triassic subsequence Glørstad-Clark et al. (2010) interpreted a western sediment source prograding eastwards over the subsided paleo-Loppa High. They related this western source to either Greenland, the Stappen High or a rifted fault block and suggest Greenland was the most important provenance area for a western sediment source in Late Triassic time. In the seismic data Glørstad-Clark et al. (2010) studied the northwestern Barents Sea as well as the southwestern. In their Upper Triassic time-thickness map western infill is more prominent above 74 °N which is outside my study area. At Svalbard the presence of Mid Triassic sediments originating from Greenland support the possibility of eastward deposition further south.

All-together, the southwestern Barents Sea seems to have been filled through the Triassic period. At first the Baltic provenance area was the most influential, filling the area faster than the basin subsidence could account for. This resulted in a sequence prograding westward across a relatively flat platform onto the dividing high. In Mid Triassic time the high was inverted and a western provenance area became more influential. The seaway was now being filled from both east and west, but at a rate closer to the rate of subsidence.

5.2 Development of accommodation space

Figure 44 is a summary of the most important elements from the profiles in Section 4.1 and the time-thickness map in Figure 41, showing the most important areas of elevation and subssidence in Early to Mid Triassic times. Figure 45 is a summary of the most important elements from the profiles and the time-thickness maps in Figures 42 and 43, and it shows the most important areas of Mid to Late Triassic elevation and subsidence.

From Figure 44 we see that the rising paleo-Loppa High was part of a SSW-NNE trending ridge with the Polheim Subplatform area exposed as an island. This resulted in accommodation space on both sides of the paleo-high, but with an eastern sediment source, most of the sediments were deposited on the eastern side of the ridge in Early to Mid Triassic times.

Figure 45 shows that by Mid Triassic time the paleo-high was inverted to a depocentre for a large subsiding area. This area covers most of the Bjarmeland

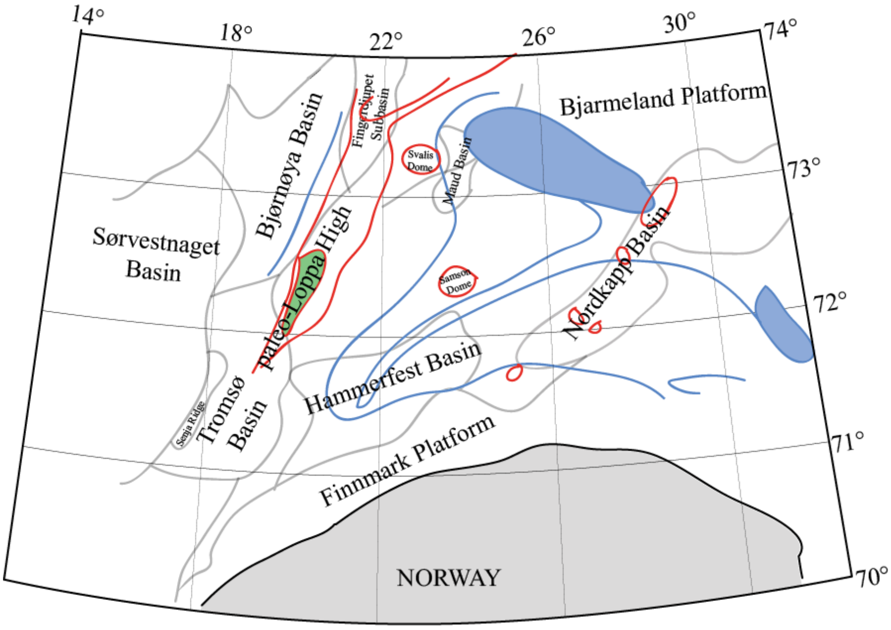


Figure 44: Overview of the Early to Mid Triassic accommodation space. Blue, subduction; red, uplift; green, island. The blue areas mark main depocentres and red circles are rising salt.

Platform, Loppa High, Bjørnøya, Hammerfest and Tromsø Basins. However, the interpretation in both the Bjørnøya and Tromsø Basins are very scarce.

The time-thickness map in Figure 42 indicates two depocentres separated by a high, but the time-thickness map doesn't consider that the subsequence would have been thicker in that area if not for erosion. Hence, when making Figure 45 I relied on the interpretation of the profiles, stating that there is one main depocentre located in the paleo-Loppa High area.

On the northern and western side of the Early to Mid Triassic ridge it appears to be subsidence in both the Tromsø Basin and an early Bjørnøya Basin relative to the ridge. Faults located where the Bjørnøyrenna Fault Complex is today, and faults possibly belonging to the Ringvassøy-Loppa Fault Complex seem to have been active during this subsidence. In Mid to Late Triassic time subsidence in the western Fingerdjupet Subbasin area may be related to the large depocentre in Figure 45.

The Early to Mid Triassic ridge at the western edge of the Bjarmeland Platform seems to have had the most influence on the platform's accommodation space during that time. The general trend is subsidence east of the ridge, and there is a large depocentre between the Maud and Nordkapp Basins. The platform appears quite stable, but both the Hoop Fault Complex and local salt bodies have altered accommodation space. The Svalis and Samson Domes show rising salt throughout the Triassic period. South of the Samson Dome there is more accommodation space, but whether this is due to the salt or just part of the subsidence in the Hammerfest Basin is hard to tell. The Svalis Dome on the other hand, has probably contributed to the accommodation space in the Maud Basin. The Northern Maud Basin has subsided more than the Southern Maud Basin, and the reason is most likely a combination of being closer to the Svalis Dome and fault movement in the Hoop Fault Complex.

Uplift of the paleo-Loppa High has been related to footwall uplift due to Late Permian North Atlantic extension (Gabrielsen et al., 1990; Gudlaugsson et al., 1998; Ziegler, 1988, 1989), and it is though to have played an important role in accommodation space development in Early to Mid Triassic times. According to Glørstad-Clark et al. (2010) the uplifted paleo-high was a barrier in Early to Mid Triassic times, shielding the area northwest of it from the sediment progradation from east and southeast. Glørstad-Clark et al. (2010) observed renewed episodes of footwall uplift at the paleo-Loppa High in Induan–Anisian times. These minor episodes gave local source areas and sediment deposition close the the paleo-high. According to Gabrielsen et al. (1990) the uplift may also have started the salt movement of the Nordvarg, Svalis and Samson Domes.

Compressional influence from the Uralian Orogeny at about 500-1000 kilometers to the east-southeast is also thought to have affected accommodation space in the Barents Sea area, but since Greenland was only 100 kilometers away from Spitsbergen, the extensional rifting between Norway and Greenland is thought to have had the greatest influence (Glørstad-Clark et al., 2010). According to Dengo and Røssland (1992); Doré (1991); Faleide et al. (1984, 1993a,b); Gudlaugsson et al. (1998) extension dominated from Late Devonian–Early Carboniferous times.

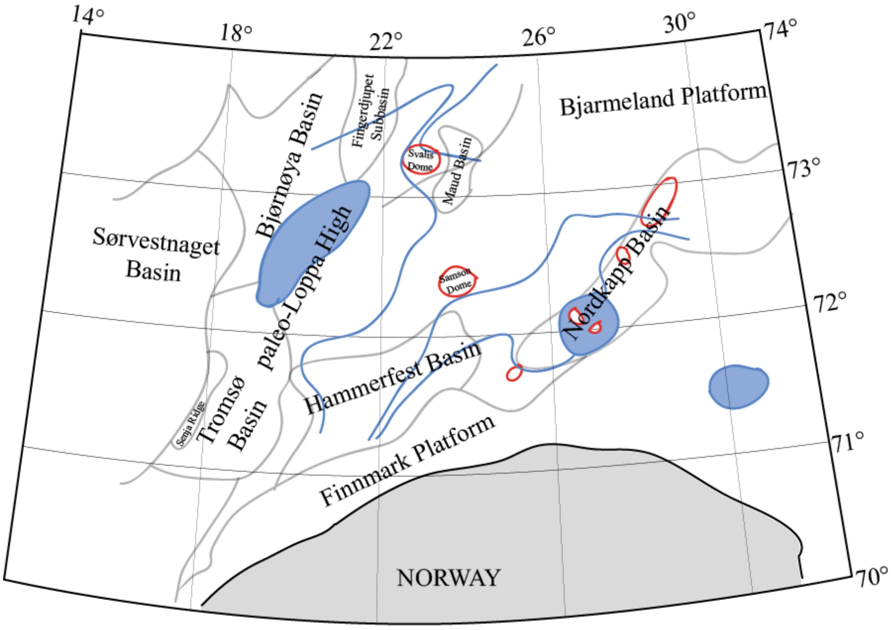


Figure 45: Overview of the Mid to Late Triassic accommodation space. Blue, subduction; red, uplift. The blue areas mark main depocentres and red circles are rising salt.

In Mid Triassic time the paleo-Loppa High developed into a basin due to renewed extension in the rift system between Greenland and Norway (Berglund et al., 1986; Faleide et al., 1984; Gabrielsen et al., 1990; Golonka et al., 2003; Jacobsen and van Veen, 1984; Wood et al., 1989; Ziegler, 1988). The change from uplift to subsidence of the high suggests a prominent change in stress regime (Glørstad-Clark et al., 2010).

South of the paleo-Loppa High the Asterias and Troms-Finnmark Fault Complexes were active, giving subsidence in the Hammerfest Basin. The Hammerfest Basin show a general trend of more subsidence westwards, as well as having a subsiding graben in the middle. This may indicate a western extensional influence in Early to Mid Triassic times.

In Mid to Late Triassic time the Hammerfest Basin shows minor, local graben subsidence, and it seems to be a local depocentre at the western side of the Ringvassøy-Loppa Fault Complex. However, scarce Triassic interpretation in the Tromsø Basin as well as erosion in Snadd leaves the possibility of the depocentre being located farther to the west. If this is the case, the Loppa depocentre in Figure 45 should be extended south in the Tromsø Basin.

In-between the Hammerfest and Nordkapp Basins the Bjarmeland Platform extends south towards the Finnmark Platform. Where the two platforms meet the Troms-Finnmark Fault Complex has given Early to Mid Triassic subsidence to the Bjarmeland Platform, seen as a north-trending graben in Figure 12. The Finnmark Platform appears to have stayed quite stable throughout the Triassic period, but with local subsidence in the east. In Figures 44 and 45 this is indicated by local depocentres south of the Nordkapp Basin. This location seems to coincide with the location of the Tiddlybanken Basin in Figures 4 and 5. Gabrielsen et al. (1990) doesn't say much about the Tiddlybanken Basin, but Figure 4b indicates a Late Paleozoic origin.

There is a link between the area with the salt in the southwestern end of the Nordkapp Basin and the Hammerfest Basin, showing gradually more subsidence to the west-southwest. This fits with the structural map of Gernigon and Brönner (2012) (Figure 4) where the Hammerfest and Nordkapp Basins are prolongations of the North Atlantic rifting. This prolongation is related to reactivation of faults in the basement, originating from the Devonian collision between Baltica and Laurentia. This connection to the distant rifting should result in increasing extensional influence to the southwest in periods of extensional tectonics in the west.

According to Faleide et al. (1984) there was a regional basin in this area during the Triassic, with the Nordkapp Basin differing from the rest of the area by its salt tectonic. Differential subsidence partly governed the sedimentation in the area (Faleide et al., 1984), which can be related to both salt tectonics and fault movement in zones of weakness.

Figures 44 and 45 show rising salt bodies encountered in this study. Of course, there might be several more as this is a 2D seismic study with a large grid spacing. In the Nordkapp Basin there are several salt bodies, and in Sassendalen Group rising salt has resulted in a general uplift with local subsidence in-between the salt bodies in Early to Mid Triassic times. The general uplift is interpreted based on the Sassendalen Group being thicker outside the Nordkapp Basin, which indicates that as the salt withdrew and rose in the Nordkapp Basin, accommodation space was created outside the basin. The rising salt in the Nordkapp Basin may be the reason for Figure 44 showing two depocentres instead of one.

In Mid to Late Triassic times the salt bodies seem to rise at a slower rate, and listric normal faults at the Nysleppen Fault Complex show more accommodation space within the Nordkapp Basin than outside the basin. In Figure 45 there is a depocentre in the Nordkapp Basin. This depocentre is a caused by accommodation space created between salt bodies. Salt tectonics seem to have been most influential in creating accommodation space within the basin in Mid to Late Triassic times.

According to Koyi et al. (1993) the salt in the southwestern Nordkapp Basin started forming pillows in the Early Triassic time. Jensen and Sørensen (1988); Gabrielsen et al. (1990) on the other hand, believe the salt movement started in Early to Mid Triassic times without a pillow stage. They concluded that the basin developed as a secondary rim syncline with a group of diapirs closely spaced in the middle (Gernigon and Brönner, 2012; Gabrielsen et al., 1990). Gernigon and Brönner (2012) claim that some diapirs evolved with a pillow stage and some without. The ones without a pillow stage are believed to have evolved due to differential loading up faults in old zones of weakness (Gernigon and Brönner, 2012). The actuating factor is thought to be lateral extension weakening the overburden. These diapirs tend to result in pronounced accommodation space on the hanging wall. This seems to be the case for the Snadd Formation in Figure 22.

6 Conclusions

2D interpretation of the regional Triassic depositional unit in the southwestern Barents Sea has resulted in a description of Triassic infill history. The unit is interpreted as three subsequences; the Sassendalen Group from Early to Mid Triassic time, the Snadd Formation from Mid to Late Triassic time and the Fruholmen Formation From Late Triassic time.

In Late Paleozoic time the southwestern Barents Sea was part of an epicontinental seaway connecting the Boreal Sea in the north to the European basins in the south. In Late Carboniferous to Permian time large ammounts of evaporites and a large carbonate platform were deposited.

The Sassendalen Group marks a change in climate and depositional regime at the Permian–Triassic border. The base of Sassendalen is a strong reflector marking the transition from the layer of carbonates with a high acoustic impedance to a softer, clastic layer.

In the Early to Mid Triassic the paleo-Loppa High was part of a SSW-NNE trending ridge that split the southwestern Barents Sea in an eastern and a western area. The uplift of the paleo-high happened sequentially during Permian–Early Triassic times, and it is related Late Permian extensional tectonics between Norway and Greenland. Sassendalen Group shows how the time was dominated by sediment supply from east and southeast. Seismic clinoforms are clear evidence of a prograding infill from east and southeast towards west and southwest in the Hammerfest Basin area, and towards west and northwest onto the paleo-ridge. The ridge prevented much of the sediments from reaching the western area. At the Polheim Subplatform area at the Loppa High the uplift had created an island that acted as a local sediment source according to more local studies (e.g. Glørstad-Clark et al. (2010)).

In the area east of the ridge the sediment supply was greater than the regional subsidence as indicated by the clinoforms, and by the Mid Triassic most of this area was filled in. The infill was greatest in what appears to be a SE-NW oriented basin cut by the Nordkapp Basin, and an extension of the basin going from the

Nordkapp Basin southwestwards to the Hammerfest Basin. Here, the Asterias and Troms-Finnmark Fault Complexes were controlling much of the subsidence. These fault zones are old, possibly originating from weak zones in the Caledonian basement. The reactivation of the faults is also related to extensional influence from the rifting at the Mid-Atlantic Ridge separating Norway and Greenland.

Though there was a regional subsidence controlling most of the accommodation space, other factors played a role as well. The thick evaporite depositions from Carboniferous time started moving in the Early Triassic. In the Nordkapp Basin salt diapirs started rising and altering accommodation space. This salt movement is believed to have been induced by lateral extension (Gernigon and Brönner, 2012). In Early to Mid Triassic times the salt tectonics resulted in most accommodation space outside the Nordkapp Basin. This was probably the reason for turning the eastern area into two main depocentres separated by the Nordkapp Basin.

This study also observed salt influencing accommodation space in the Maud Basin, at the Samson Dome and the Svalis Dome. In the Maud Basin both salt movements related to the Svalis Dome and fault movements in the Hoop Fault Complex altered the accommodation space, giving most subsidence to the northern part of the Maud Basin. This salt movement may have been induced by the uplift of the paleo-high (Gabrielsen et al., 1990).

In Mid Triassic time the paleo-high was inverted, turning the area into a depocentre for a regional subsidence basin covering most of the Bjarmeland Platform, Bjørnøya, Tromsø and Hammerfest Basins and the Loppa High. This inversion was caused by renewed extension in the North Atlantic rift system. Sediment supply from east-southeast was still important, but not as dominating as in the Early Triassic time. A western provenance area depositing sediments over the Loppa area was probably contributing to the infilling, resulting in basinal infill from both east and west.

Locally, the salt tectonics still influenced accommodation space, but the regional subsidence was the most important factor. Fault Movements at the Asterias and Troms-Finnmark Fault Complexes still gave some local subsidence in the Hammerfest Basin, and in the Tromsø Basin there might be a prolongation of the Loppa depocentre. The Nordkapp Basin differs from the rest of the area by being controlled by salt tectonics. The salt bodies created more accommodation space in Mid to Late Triassic time, and this turned the basin into a local depocentre.

7 References

Abrahamson, P. (2013). Barents sea: Complete integration of well data and seismic data. *GEO ExPro*, pages 58–62.

Baglo, O. E. (1989). Strukturell utvikling av nøkkendomen: saltdiapirisme og forkastningstektonikk. Unpublished cand. scient. thesis, University of Oslo, 158 pp.

Berglund, L. T., Augustson, G., Færseth, R., and Ramberg-Moe, H. (1986). The evolution of the hammerfest basin. In Spencer, A., editor, *Habitat of Hydrocarbons on the Norwegian Continental Margin*, pages 319–338. Norwegian Petroleum Society (NPF), Graham & Trotman.

Boggs, S. (2010). *Principles of Sedimentology and Stratigraphy*. Pearson Educational International, Perason Education, Upper Saddle River, New Jersey, 4th edition.

Buiter, S. J. H. and Torsvik, T. H. (2007). Horizontal movements in the eastern barents sea constrained by numerical models and plate reconstructions. *Geophysical Journal International*, 171:1376–1389.

Bullimore, S. A., Larssen, G., Laursen, I., Sollid, K., Ashton, N., and Henriksen, S. (2004). Concepts in predicting lithology in prograding systems from high-resolution seismic imaging: Examples from the arctic barents sea. Part of unpublished PhD thesis.

Dengo, C. A. and Røssland, K. G. (1992). Extensional tectonic history of the western barents sea. In Larsen, R. M., Brekke, H., Larsen, B. T., and Talleraas, E., editors, *Structural and Tectonic Modelling and its Application to Petroleum Geology*, pages 91–107. Norwegian Petrol. Soc. Spec. Publ. No. 1, Amsterdam: Elsevier.

Dimakis, P., Braathen, B. I., Faleide, J. I., Elverhøy, A., and Gudlaugsson, S. T. (1998). Cenozoic erosion and the preglacial uplift of the svalbard-barents sea region. *Tectonophysics*, 300:311–327.

Doré, A. G. (1991). The structural foundation and evolution of mesozoic seaways between europe and the arctic. *Palaeogeogr. Palaeoclimat. Palaeoecol. 87*, pages 441–492.

Ekerheim, S. (2012). Regional geological evolution and play analysis in the south-western barents sea. Specialization project, Norwegian University of Science and Technology.

Emery, D. and Myers, K. J. (1996). Sequence stratigraphy. *Blackwell Science, Oxford*, page 297.

Faleide, J. I., Gudlaugsson, S. T., Eldholm, O., Myhre, A. M., and Jackson, H. R. (1991). Deep seismic transects across the sheared western barents sea-svalbard continental margin. *Tectonophysics*, 189:73–89.

Faleide, J. I., Gudlaugsson, S. T., and Jacquart, G. (1984). Evolution of the western barents sea. *Marine and Petroleum Geology*, 1:123–150.

Faleide, J. I., Vågnes, E., and Gudlaugsson, S. T. (1993a). Late mesozoic-cenozoic evolution of the southwestern barents sea. In Parker, J. R., editor, *Petroleum Geology of Northwest Europe, Proceedings of the 4th Conference*, pages 933–950, London. The Geological Society of London.

Faleide, J. I., Vågnes, E., and Gudlaugsson, S. T. (1993b). Late mesozoic-cenozoic evolution of the southwestern barents sea in a regional rift-shear tectonic setting. *Marine and Petroleum Geology*, 10:186–214.

Fønstelien, S. and Horvei, A. (1979). Thoughts and considerations arising from the study of a "prospective" feature in the troms i area. In *Proceedings, Norwegian Sea Symposium*, volume 20, pages 1–10, Tromsø.

Gabrielsen, R. H. (1984). Long-lived fault zones and their influence on the tectonic development of the south-western barents sea. *Journal of the Geological Society of London*, 141:651–662.

Gabrielsen, R. H., Faerseth, R. B., Jensen, L. N., Kalheim, J. E., and Riis, F. (1990). Structural elements of the norwegian continental shelf. part 1: the barents sea region. *Norw. Petrol. Direct. Bull. No. 6.*

Gabrielsen, R. H. and Kløvjan, O. S. (1997). Late jurassic-early cretaceous caprocks of the southwestern barents sea:fracture systems and rock mechanical properties. In Møller-Pedersen, P. and Koestler, A. G., editors, *Hydrocarbon Seals: Importance for Exploration and Production*, pages 73–89. NPF Special Publication 7.

Gernigon, L. and Brönner, M. (2012). Late palaeozoic architecture and evolution of the southwestern barents sea: insight from a new generation of aeromagnetic data. *Journal of the Geological Society*, 169:449–459.

Glørstad-Clark, E., Faleide, J. I., Lundschien, B. A., and Nystuen, J. P. (2010). Triassic seismic sequence stratigraphy and paleogeography of the western barents sea area. *Marine and Petroleum Geology*, 27:1448–1475.

Golonka, J., Bocharova, N. Y., Ford, D., Edrich, M. E., Bednarczyk, J., and Wildharber, J. (2003). Paleogeographic reconstructions and basin development of the arctic. *Marine and Petroleum Geology*, 20:211–248.

Gudlaugsson, S. T., Faleide, J. I., Fanavoll, S., and Johansen, B. (1987). Deep seismic reflection profiles across the western barents sea. *Geophysical Journal of the Royal Astronomical Society*, 89:273–278.

Gudlaugsson, S. T., Faleide, J. I., Johansen, S. E., and Breivik, A. J. (1998). Late palaeozoic structural development of the south-western barents sea. *Marine and Petroleum Geology*, 15:73–102.

Hanisch, J. (1984a). The cretaceous opening of the northeast atlantic. *Tectonophysics*, 101:1–23.

Hanisch, J. (1984b). West spitzbergen fold belt and cretaceous opening of the northeast atlantic. In Spencer, A., editor, *Petroleum Geology of the North European Margin, Proceedings of the North European Margin*, pages 187–198. Norwegian Petroleum Society (NPF), Graham & Trotman.

Jacobsen, V. W. and van Veen, P. (1984). The triassic offshore norway north of 62 degrees n.: petroleum geology of the north european margin. In Spencer, A., Johnsen, S., Mørk, A., Nysæther, E., Songstad, P., and Spinnangr, Å., editors, *Petroleum Geology of the North European Margin, Proceedings of the North European Margin Symposium*, pages 317–327, London. Graham & Trotman.

Jenkins, F. A. and White, H. F. (1957). Fundamentals of optics. New York: McGraw-Hill.

Jensen, L. N. and Sørensen, K. (1988). Geology and salt tectonics of the nordkapp basin, barents sea (abstract). In Binzer, K., Marcussen, I., and Konradi, P., editors, *18. Nordiske Geologiske Vintermøde*, pages 187–188. Danmarks Geologiske Undersøgelse.

Jensen, L. N. and Sørensen, K. (1992). Tectonic framework and halokinesis of the nordkapp basin. In Larsen, R. M., Brekke, H., Larsen, B. T., and Talleraas, E., editors, *Structural and Tectonic Modelling and its Application to Petroleum Geology*, pages 109–120. Norwegian Petrol. Soc. Spec. Publ. No. 1, Amsterdam: Elsevier.

Johansen, S., Ostisty, B., O., B., Fedorovsky, Y., Martirosjan, V., Christensen, O., Cheredeev, S., Ignatenko, E., and Margulis, L. (1993). Hydrocarbon potential in the barents sea region: play distribution and potential. In Vorren, T., Bergsager, E., Dahl-Stamnes, Ø., Holter, E., Johansen, B., Lie, E., and Lund, T., editors, *Arctic Geology and Petroleum Potential*, volume 2 of *Special Publication*, pages 273–320. Norwegian Petroleum Society (NPF), Elsevier, Amsterdam.

Koyi, H., Talbot, C. J., and Tørudbakken, B. O. (1993). Salt diapirs of the southwest nordkapp basin: analogue modelling. *Tectonophysics*, 228:167–187.

Larssen, G. B., Elvebakk, G., Henriksen, L. B., Kristensen, S.-E., Nilsson, I., Samuelsberg, T. A., Stemmerik, L., and Worsely, D. (2002). Upper paleozoic lithostratigraphy of the southern norwegian barents sea. *Norsk Geologisk Undersøkelser, Bulletin 444*, 43.

Lippard, S. J. and Roberts, D. (1987). Fault systems in caledonian finnmark and the southern barents sea. *Nor. geol. unders. Bull. 410*, pages 55–64.

MCG (2011). Barents sea. *http://www.mcgeophysical.no/northwest-europe/barents-sea*.

Mitchum, R. M. J., Vail, P., and Sangree, J. B. (1977a). Seismic stratigraphy and global changes in sea-level, part 6: stratigraphic interpretation of seismic reflection patterns in depositional sequences. In Payton, C., editor, *Seismic Stratigraphy: Applications to Hydrocarbon Exploration*, volume 26 of *Am. Assoc. Petroleum Geologists Mem.*, pages 117–133, Tulsa. American Association of Petroleum Geologist.

Mitchum, R. M. J., Vail, P., and Thompson, S. (1977b). Seismic stratigraphy and global changes in sea-level, part 2: the depositional sequence as the basic unit for stratigraphic analysis. In Payton, C., editor, *Seismic Stratigraphy: Application to Hydrocarbon Exploration*, volume 26 of *Am. Assoc. Petroleum Geologists Mem.*, pages 53–62, Tulsa. American Association of Petroleum Geologist.

Moretti, I., Colletta, B., and Vially, R. (1988). Theoretical model of block rotation along linear faults. *Tectonophysics*, 153:313–320.

Mørk, A., Embry, A., and Weitschat, W. (1989). Triassic transgressive-regressive cycles in the sverdrup basin, svalbard and barents shelf. In Collinson, J., editor, *Correlation in Hydrocarbon Exploration, Proceedings of a Norwegian Society Conference*, pages 113–130, London. Graham & Trotman.

Mørk, A. and Worsley, D. (1982). Depositional and diagenetic environments of the triassic and lower jurassic succession of svalbard. In Embry, A. F. and Balkwill, H., editors, *Arctic Geology and Geophysics*, pages 371–398, Calgary, Alberta, Canada. Canadian Society of Petroleum Geologists.

Müller, R., Nystuen, J., Eide, F., and Lie, H. (2005). Late permian to triassic basin infill history and palaeogeography of the mid-norwegian shelf - east greenland region.

Nødttvedt, A., Johannessen, E. P., and Surlyk, F. (2008). The mesozoic of western scandinavia and east greenland. episodes 31. pages 59–65.

Nøttvedt, A., Cecchi, M., Gjelberg, J. G., Kristiansen, S. E., Lenøy, A., Rasmussen, A., Rasmussen, E., Scott, P. H., and van Veen, P. M. (1993). Svalbard-barents sea correlation: a short review. In Vorren, T. O., Bergsager, E., Dahl-Stamnes, Ø. A., Holter, F., Johansen, B., Lie, E., and Lund, T. B., editors, *Arctic Geology and Petroleum Potential*, pages 363–375. Norwegian Petrol. Soc. Spec. Publ. No. 2, Amsterdam: Elsevier.

Otto, S. C. and Bailey, R. J. (1995). Tectonic evolution of the northern ural orogen. *Journal of the Geological Society of London*, 154:903–906.

Ramberg, I. B., Bryhni, I., and Nøttvedt, A. (2007). *LANDET BLIR TIL Norges geologi.* Norsk Geologisk Forening.

Rich, J. L. (1951). Three critical environments of deposition and criteria for recognition of rocks deposited in each of them. *Geol. Soc. America Bull.*, 62:1–20.

Riis, F., Lundschien, B. A., Høy, T., Mørk, A., and Mørk, M. B. E. (2008). Evolution of the triassic shelf in the northern barents sea region. *Polar Research*, 27(3):318–338.

Rønnevik, H. and Jacobsen, H. P. (1984). Structural highs and basins in the western barents sea. In Spencer, A., editor, *Petroleum Geology of the North European Margin, Proceedings of the North European Margin*, pages 98–107. Norwegian Petroleum Society (NPF), Graham & Trotman.

Rønnevik, H. C., Bescow, B., and Jacobsen, H. P. (1982). Structural and stratigraphic evolution of the barents sea. *Can. Soc. Petroleum Geologists Mem.*, 8:431–440.

Sheriff, R. E. (1980). Seismic stratigraphy. *International Human Resources Development Corp.*, page 227.

Sheriff, R. E. and Geldart, L. P. (1995). *Exploration Seismology, utdrag.* Cambridge University Press, second edition.

Skjold, L., van Veen, P., Kristensen, S., and Rasmussen, A. (1998). Triassic sequence stratigraphy of the southwestern barents sea. In de Graciansky, P.-C., Hardenbol, J., Jaquin, T., and Vail, P., editors, *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*, number 60 in Special Publication, pages 651–666, Tulsa. Society for Sedimentary Geology, Society for Sedimentary Geology (SEPM).

Sloss, L. L. (1963). Sequences in the cratonic interior of north america. *Geol. Soc. Am. Bull.*, 74:93–114.

Smelror, M., Petrov, O., Larssen, G., and Werner, S. (2009). *Atlas: Geological History of the Barents Sea*, page 134. Geological Survey of Norway, Trondheim.

Talleraas, E. (1979). The hammerfest basin - an aulacogen? In *Norwegian Sea Symposium*, pages 1–13. Norwegian Petroleum Society (NPF).

Torsvik, T. H. and Andersen, T. B. (2002). The talmyr fold belt, arctic siberia: timing of prefold remagnetisation and regional tectonics. *Tectonophysics*, 352:335–348.

Trusheim, F. (1959). Über halokinese und ihre bedeutung für die strukturelle entwicklung norddeutschlands. *Zeitung Deutsche Geologische Gesellschaft*, 109:111–151.

Vail, P., Mitchum, R. M. J., and Thompson, S. (1977a). Seismic stratigraphy and global changes in sea-level, part 3: relative changes of sea-level from coastal onlap. In Payton, C., editor, *Seismic Stratigraphy: Applications to Hydrocarbon Exploration*, volume 26 of *Am. Assoc. Petroleum Geologists Mem.*, pages 63–81, Tulsa. American Association of Petroleum Geologist.

Vail, P., Mitchum, R. M. J., and Thompson, S. (1977b). Seismic stratigraphy and global changes in sea-level, part 4: global cycles of relative changes of sea-level. In Payton, C., editor, *Seismic Stratigraphy: Applications to Hydrocarbon Exploration*, volume 26 of *Am. Assoc. Petroleum Geologists Mem.*, pages 83–97, Tulsa. American Association of Petroleum Geologist.

van Veen, P. M., Skjold, L. J., Kristiansen, S. E., Rasmussen, A., Gjelberg, J. G., and Stolan, T. (1993). Triassic sequence stratigraphy in the barents sea. In Vorren, T. O., Bergsager, E., Dahl-Stamnes, Ø. A., Holter, E., Johansen, B., Lie, E., and Lund, T. B., editors, *Arctic Geology and Petroleum Potential*, volume 2, pages 515–538. Norwegian Petroleum Geologists (NGF), Special Publication, Elsevier, Amsterdam.

Wood, R., Edrich, S., and Hutchison, I. (1989). Influence of north atlantic tectonics on the large-scale uplift of the stappen high and loppa high, western barents shelf. *Extensional Tectonics and Stratigraphy of the North Atlantic Margins. American Association of Petroleum Geologists, Memoirs*, 46:559–566.

Worsley, D. (2008). The post-caledonian development of svalbard and the western barents sea. *Polar Research*, 27(3):298–317.

Ziegler, P. A. (1988). Evolution of the arctic-north atlantic and the western tethys. *American Association of Petroleum Geologists, Memoir, No. 43*, page 198.

Ziegler, P. A. (1989). Evolution of the north atlantic - an overview. In Tankard, A. J. and Balkwill, H. R., editors, *Extensional Tectonics and Stratigraphy of the North Atlantic Margins. American Association of Petroleum Geologists, Memoir*, volume 46, pages 11–129. Canadian Geological Foundation and AAPG, Tulsa.