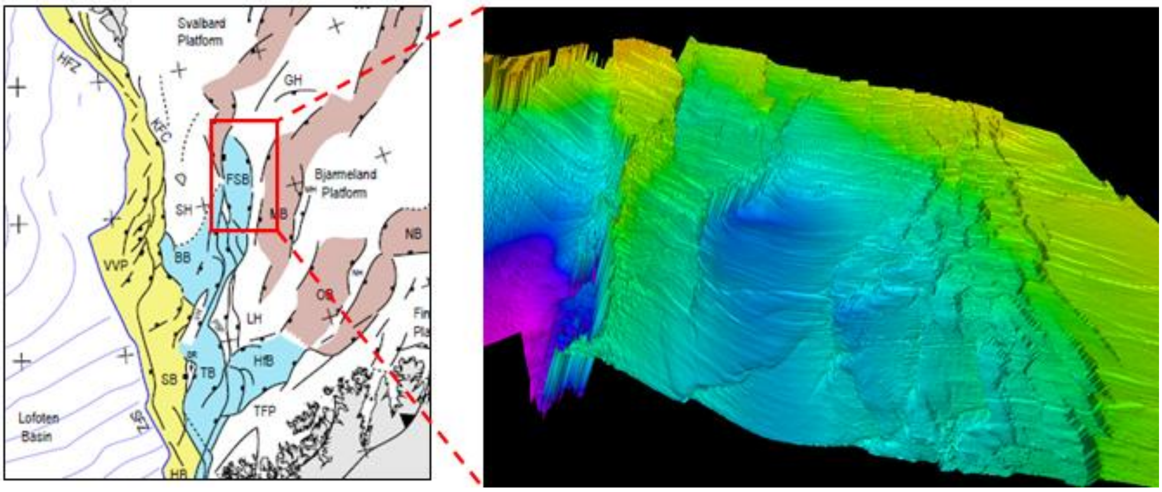
Master Thesis, Department of Geosciences

Structural and stratigraphical evolution of the Fingerdjupet Subbasin, SW Barents Sea.

Maria Evensen Dahlberg



UNIVERSITY OF OSLO

FACULTY OF MATHEMATICS AND NATURAL SCIENCES

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Master Thesis in Geosciences

Discipline: Petroleum Geology and Petroleum Geophysics

Department of Geosciences

Faculty of Mathematics and Natural Sciences

University of Oslo

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Abstract

Several phases of uplift and erosion in the Barents Sea have left a lot of the Cretaceous to Cenozoic strata missing; however, the Fingerdjupet Subbasin is one of the basins where the Lower Cretaceous strata are still present, combined with well-controll. The Fingerdjupet Subbasin is an N-S trending Early Cretaceous extensional basin that was formed in response to the opening of the North Atlantic rift and the regional and local subsidence in the Barents Sea.

This thesis describes the structural and stratigraphical evolution of the Fingerdjupet Subbasin. Structural and stratigraphical interpretation has been performed in both 2D and 3D, both on paper and with software, to identify and map out important phases of tectonic activity in the study area and link it to the depositional patterns. Based on the detailed structural and stratigraphical interpretation performed on the Upper Jurassic to Lower Cretaceous strata, eight sequences were identified and described in order to obtain a picture of the basin evolution through time. Time-thickness maps corresponding to the eight sequences were made to analyze lateral geometries and vertical depositional patterns in the study area. The geological history of the Fingerdjupet Subbasin is finally discussed with emphasis on the regional geological setting to fully understand the basin evolution.

The Fingerdjupet Subbasin has proven to be a highly dynamic basin with records of tectonic events in at least two phases during the Early Cretaceous, and differential subsidence in this period. The two phases of extension is dated to Early Barremian and Intra Aptian. The Fingerdjupet Subbasin is defined by Gabrielsen et al. (1990) as the eastern shallower part of the Bjørnøya Basin, only separated by the Leirdjupet Fault Complex. However, this work indicates that the Fingerdjupet Subbasin appears to be geologically closer related to the Bjarmeland Platform until Early Barremian time.

Abstract

Preface

This master thesis is the result of the two year master program at the University of Oslo department of Geosciences, “Petroleum geology and petroleum geophysics”. This master thesis has been supervised by Professor Jan Inge Faleide, Emiritus Johan Petter Nystuen, Associate Professor Ivar Midtkandal, and Senior Engineer Michael Heeremans.

Acknowledgements

First off, I would like to thank my supervisors and professors at the University of Oslo for all the help, encouragements and interest in this master thesis. I would also like to thank all the people involved in preparing the data set used in this thesis. Thanks to TGS and Fugro for access to selected 2D lines of their NBR survey. Special thanks to TGS for providing me with the 3D seismic data used in this work.

Thanks to all my fellow students, and especially the students in room 210 for encouragements and motivation during the period of writing this thesis. Thanks to my discussion partner and fellow MSc student Myrsini for great discussions and collaboration through this thesiswork, and the master program. A special thanks to my partner Anders for making the life outside the University work for us both, and last but not least I would like to thank my family and friends for always supporting and caring for me.

Maria Evensen Dahlberg

Contents

1 Introduction

The Barents Sea is an epicontinental sea covering approximately 1.2 million km^2 (Worsley, 2008). The continental shelf, which the Barents Sea is situated on, is bounded to the north by Franz Josef's Land and Svalbard archipelago and to the south by the Kola Peninsula and the Norwegian coast. The boundaries to the east and the west are respectively Novaya Zemlya and the Norwegian-Greenland Sea (figure.1-1) (Faleide et al., 1984). Since the Caledonian orogony the Barents Sea has been affected by several stages of tectonism. During the Mesozoic and Cenozoic the western part of the Barents Sea has been the most active (Gabrielsen et al., 1990).

Over the years the Barents Sea has become an important area for hydrocarbon exploration after the area was opened for drilling in the 1980. Major discoveries in Snøhvit gas field, Goliat oil field, and the prospect Skrugard oil field (NPD, 2014) has made this an interesting area. The complexity of the geology provides an increasing interest to further research in the area. This is to be able to understand more of the structural and stratigraphical aspects, and continue the hydrocarbon exploration with successful outcomes.

The main objective of this thesis work is to study the Fingerdjupet Subbasin with main emphasis on the Mesozoic evolution of fault systems, and tie tectonic events to the different phases of faulting observed. The Fingerdjupet Subbasin is one of the areas in the Barents Sea where the Lower Cretaceous strata is present, and can provide detailed information about tectonic phases in the time period. The main results of this thesis work will hopefully provide an increased knowledge and understanding of the relationships between the structural and stratigraphical framework in the Fingerdjupet Subbasin.

2D and 3D regional seismic lines are the main data set used in this work, and the three wells in Fingerdjupet are used to tie the seismic to the key horizons within the Late Jurassic to Early Cretaceous stratigraphy. The software used to interpret the data-set is Schlumberger's interpretation tool Petrel. Paper based interpretation of six key lines was done in order to obtain a detailed stratigraphic framework for the study area. The sequences identified in the paper based interpretation were studied regionally and time-thickness maps were generated to observe the lateral and vertical depositional patterns of each sequence. A structural and stratigraphical interplay of the geological history in the Fingerdjupet Subbasin will be presented throughout this work.

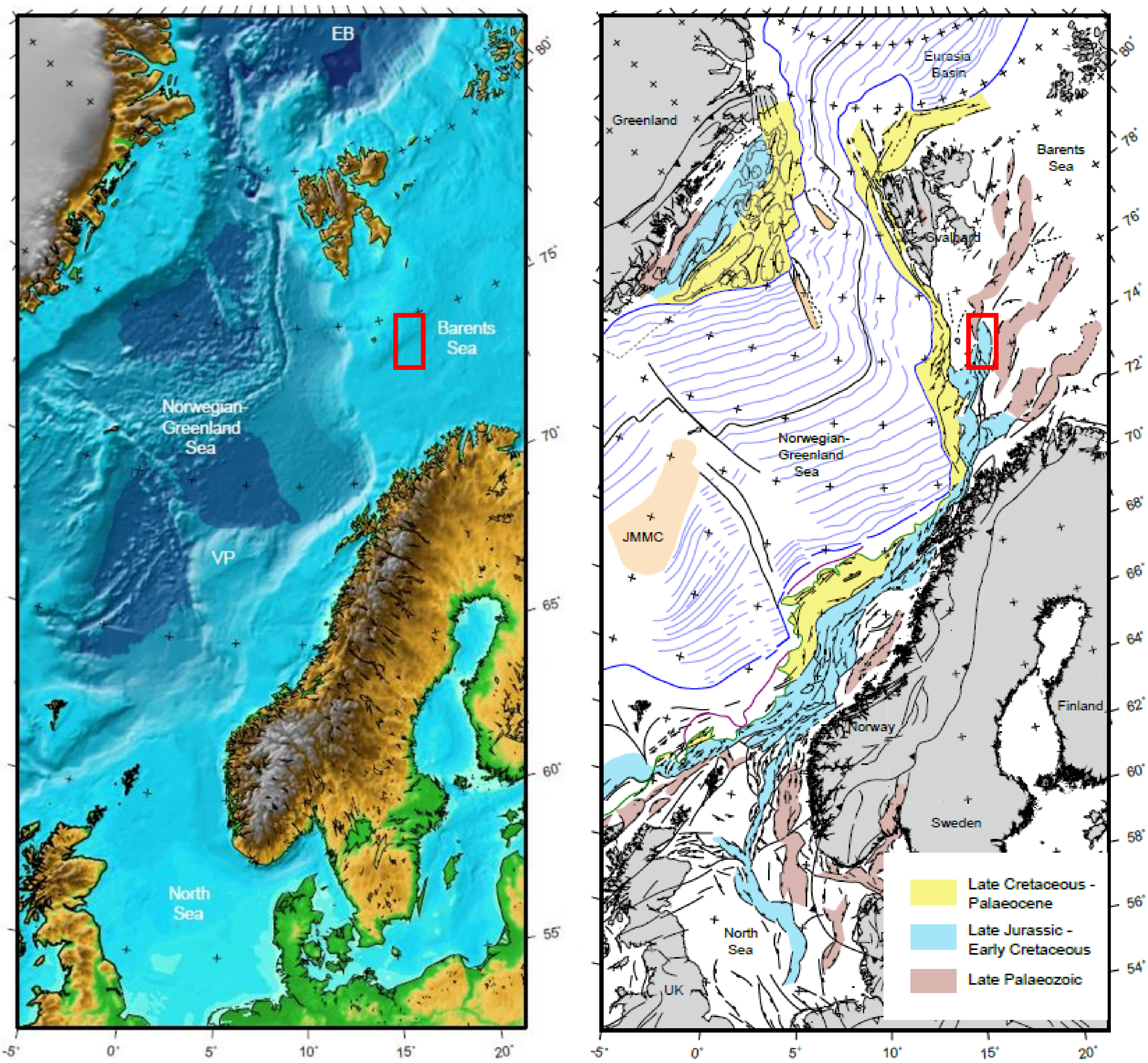


Figure 1-1: Regional setting and location of the study area. Left figure is also displaying the structural elements in the North Sea, the Norwegian Sea, and in the Barents Sea. (Modified from Faleide et al. (2008)).

2 Geological framework

Prior to the breakup of the Norwegian-Greenland Sea, most of the present Norwegian continental shelf (NCS) was part of one major epicontinental sea in the northern Pangea. The North Sea, the mid-Norwegian Margin, and the Western Barents Sea therefore shears a common geological history and possess a great similarity in stratigraphy and lithological development, but there are also some differences, especially in the Cretaceous to Cenozoic (Gabrielsen et al., 1990, Faleide et al., 2010).

The regional geology of the SW Barents Sea is generally well understood since it has been the topic in many studies throughout the years (Rønnevik and Motland, 1981, Rønnevik and Jacobsen, 1984, Worsley, 2008, Gudlaugsson et al., 1998, Faleide et al., 2010, Faleide et al., 1984, Faleide et al., 1996, Faleide et al., 1993a, Faleide et al., 1993, Smelror et al., 2009, Glørstad-Clark et al., 2011, Glørstad-Clark et al., 2010)

2.1 Regional setting

The Barents Sea is a wide epicontinental sea located on the northwestern part of the Eurasian continental shelf. The area has experienced several phases of tectonic activity, leading to several deep basins (Faleide et al., 2010). The Eurasian continental shelf was formed by two major continental collisions, with subsequent younger continental separations (Doré, 1995). The oldest collision was between the continent Baltica in the east and Laurentia in the west in mid Paleozoic time, with the closing of the Iapetus Ocean, resulting in the Caledonian orogony and formation of the united Laurentia and Baltica, the continent Laurussia. The second continental collision occurred during late Paleozoic between Laurussia and western Siberia with formation of the northern Urals; this collision affected the eastern part of the Barents Sea and was also a major process in the establishment of the super-continent Pangea. Break-up of continents during late Paleozoic and Mesozoic represents the extensional forces affecting the area. The young passive continental margins in the western and northern Barents Sea are however, a result of Cenozoic extension when the Norwegian-Greenland Sea opened, as well as the forming of the Eurasia basin (Faleide et al., 2008, Faleide et al., 1993a, Faleide et al., 1993).

The Barents Sea consists of sedimentary strata ranging from Paleozoic up to Quaternary (Gudlaugsson et al., 1998). The successions are thick and relatively consistent throughout the area, but show vertical and lateral variations in thickness and in facies

2.1.1 Main geological provinces

The Barents Sea can roughly be divided into two major geological provinces, an eastern and a western. These two provinces show significantly differences when it comes to tectonic complexity, with the western Barents Sea being far more complicated structurally than the eastern and the northeastern Barents Sea. The western province is mainly a result of post-Caledonian rifting, and the two extensional phases related to the continental breakup and formation of the North Atlantic (Smelror et al., 2009). The eastern province of the Norwegian Barents Sea has experienced less tectonic activity and is dominated by relatively stable platforms that have been present since Late Carboniferous (Gabrielsen et al., 1990). Since the study area in this thesis is located within the western region, this will be the main focus in this chapter and a figure representing the western Barents Sea can be seen in figure 2.1.

Faleide et al., (1993a,b) further divided the western Barents Sea into three geological provinces based on their geological history and appearance. These provinces in the western Barents Sea can be seen in figure 2.1 marked with numbers.

The three provinces are described as below by (Faleide et al., 1993a, Faleide et al., 1993):

1. The Svalbard Platform with relatively flat-lying sequences of Upper Paleozoic and Mesozoic sediments, mainly of Triassic age.

2. The basin province between the Svalbard Platform and the Norwegian coast characterized by a mixture of subbasins and highs with an accentuated structural relief which is increasing westwards. The basins are filled with sediments of Jurassic-Cretaceous age and Paleocene-Eocene as we move westwards in the Barents Sea towards the Norwegian-Greenland Sea.

3. The western continental margin which again is subdivided into three main segments. (a) A southern sheared margin along the Senja Fracture Zone, (b) a central rifted complex located south-west of Bjørnøya, which is associated with volcanism (Vestbakken Volcanic Province) and (c) a northern, initially sheared and later rifted margin along the Hornsund Fault Zone. The transition from continent to ocean occurs over a narrow zone along the line of Early Cenozoic breakup and the margin is covered by a thick sedimentary wedge of Late Cenozoic age.

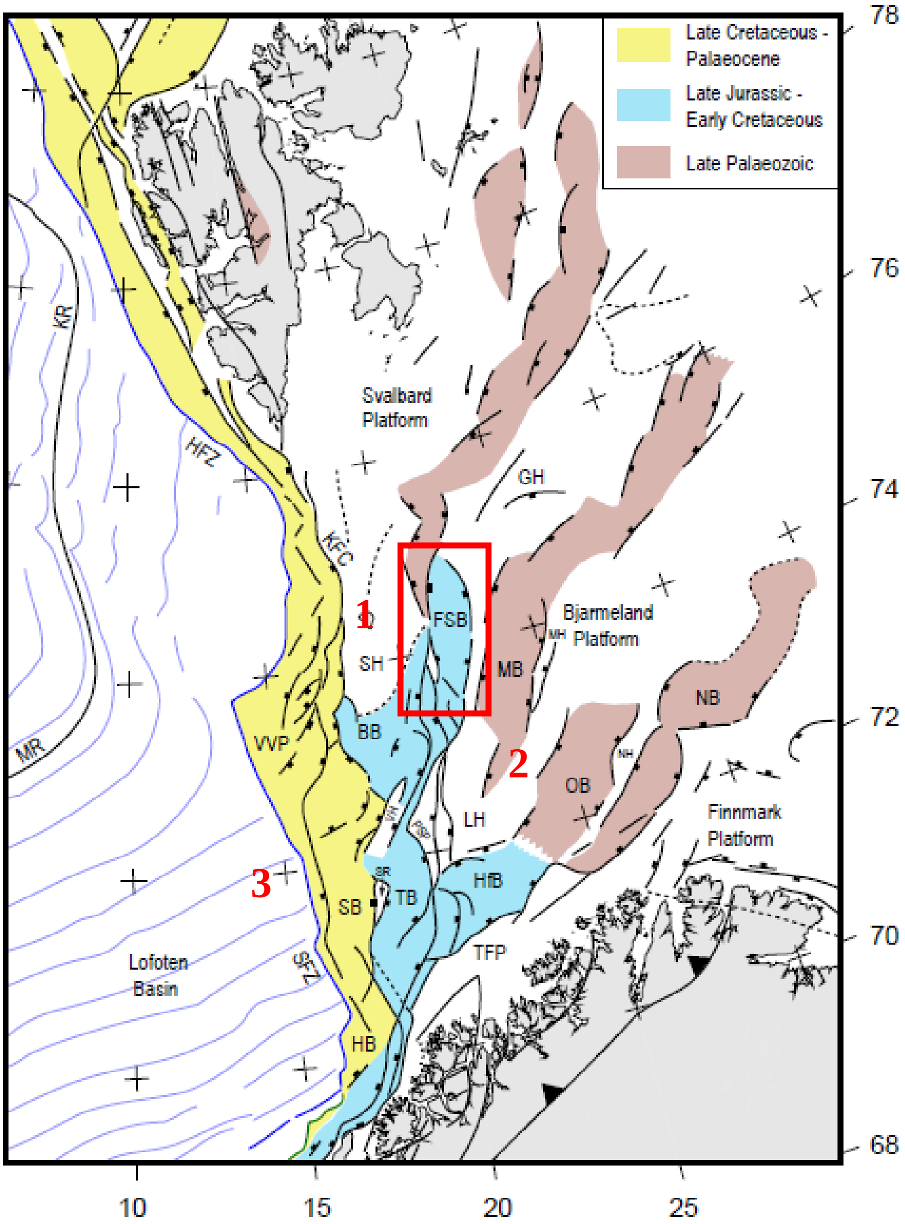


Figure 2-1: Structural elements of the western Barents Sea. Numbers 1-3 shows the location of the three geological provinces described by Faleide et al., 1993. Red square indicates the study area of this thesis. SFZ: Senja Fracture Zone. TFFC: Troms-Finnmark Fault Complex. RLFC: Ringvassøy-Loppa Fault Complex. BFC: Bjørnøyrenna Fault Complex. LFC: Leirdjupet Fault Complex (Faleide et al., 2010)

2.1.2 Structural elements in the Barents Sea

The western Barents Sea is a mixture of basins, platforms, structural highs and fault complexes. All this reflects the tectonic processes that have affected the area throughout time (Worsley, 2008). The western Barents Sea continental shelf is bordered by two western fault zones, Hornsund and Senja fracture zones. To the south the Troms-Finnmark Fault Zone is found. There are two main trends of the major structures observed in the Barents Sea. N-S to NNE-SSW trending structures predominated in the western and northwestern areas (e.g Ringvassøy-Loppa Fault Complex, Senja Fracture Zone, Knølegga Fault, Bjørnøyrenna Fault Complex, Leirdjupet Fault Complex), whereas ENE-WSW trends of major faults are more common in the eastern Barents Sea (e.g Troms-Finnmark Fault Complex, Måsøy Fault Complex, Nysleppen Fault Complex, Hoop Fault Complex) (Faleide et al., 2010, Gabrielsen et al., 1990). The main structural elements of the Barents Sea can be observed in figure 2-1.

2.1.3 Stratigraphy and structural evolution

Sedimentation and erosion in the SW Barents Sea have been controlled by tectonic events that have taken place throughout time, in combination with eustatic sea level changes and climatic conditions. Post-orogenic sedimentation that followed the Caledonian Orogeny was characterized by several phases of extension with blockfaulting in Devonian, Carboniferous and Permian times, predominantly in the western Barents Sea area. The Eastern Barents Sea was dominated by the formation of large stable carbonate platforms (Bjarmeland Platform, Finnmark Platform) and basins like Nordkapp, Maud and Olga basins. Warm and arid climate gave rise to evaporites during Late Carboniferous and early Permian; halokinesis of these salt accumulations had later significant effect on basin development and sedimentation during Mesozoic and Cenozoic times (Gabrielsen et al., 1990, Faleide et al., 2010)

The Triassic to Early Jurassic has been considered a rather tectonically quiet period in the Barents Sea area (Gabrielsen et al., 1990). Extensional tectonics with blockfaulting again fully commenced in the Middle Jurassic and increased in frequency during Late Jurassic and Early Cretaceous when the present-day major structural elements of the Barents Sea were established (Gabrielsen et al., 1990). Very high rates of subsidence took place in the Tromsø Basin and western parts of the Bjørnøya Basin, whereas basin inversion appears to have occurred locally during Early Cretaceous (e.g Loppa High). Towards the end of the Cretaceous, reverse faulting and folding increased and gave rise to erosion in large areas, particularly in the northern part of the western Barents Sea. These processes affected the Bjørnøya Basin and the Fingerdjupet Subbasin, the study area of this thesis (see below) (Gabrielsen et al., 1990).

By the opening of the Norwegian-Greenland Sea in Paleogene, deep basins developed in the western margin, and in addition contraction has been recorded. However, the timing of the contraction is unclear. The western margin also suffered magmatic activity (Vestbakken Volcanic Province). Most of the Barents Sea area was uplifted and eroded in Neogene, not at least by glaciations in Late Pliocene and Pleistocene (Gabrielsen et al., 1990). Large ice-streams moved westwards and fed the large Bjørnøya Fan with glacial debris derived by erosion in the Barents Sea (Hjelstuen et al., 2007). In the Early Cretaceous the opening of the Canadian Basin and the formation of the Alpha Ridge led to crustal updoming and magmatic activity in the north (Grogan et al., 1998). This widespread igneous activity in the High Artic at Cretaceous times (peak in Aptian) have been identified as a LIP (large igneous province). The High Artic Large Igneous Province (HALIP) covered large areas of the Barents Sea and evidences for this can be observed on Svalbard, Franz Josefs Land and the Canadian Artic Islands. This HALIP is associated with uplift in the Artic areas (Maher Jr, 2001).

The Upper Paleozoic strata are characterized by clastic sediments in Paleozoic, gradually changing to more carbonate-rich sediments and massive limestones in the upper Carboniferious to the lower Permian, and back to clastics in the Uppermost Permian (figure 2-2). Direct knowledge of the crystalline basement in the SW Barents Sea is limited, but it is thought to be metamorphosed when the Caledonian Mountain Chain was formed. The Devonian stratigraphy and structural development is not known in the Barents Sea, but on mainland Svalbard a Devonian unit implying a tectonic regime of both extensional and compressional domain is found. Most of the overlying Carboniferous strata are characterized by clastic material deposited in extensional basins (Faleide et al., 2010).

The Mesozoic and the Cenozoic successions are mainly characterized by alternating sandstone and shale, with layers of carbonates. The sandstones of Lower to Middle Jurassic age make up the main reservoir rocks of the SW Barents Sea. The Upper Jurassic to Lower Cretaceous mainly consists of shales and claystones. The uplift and erosion in late Cenozoic left the SW Barents Sea with 1000-1500 m of strata missing. On top of the Mesozoic and Paleogene rocks lies the late Pliocene and Pleistocene glacial sediments (Faleide et al., 2010).

The lithostratigraphy of the Barents Sea is shown in figure 2.2. The figure is modified from Glørstad-Clark et al. (2010), and displays the most important tectonic phases in the Barents Sea.

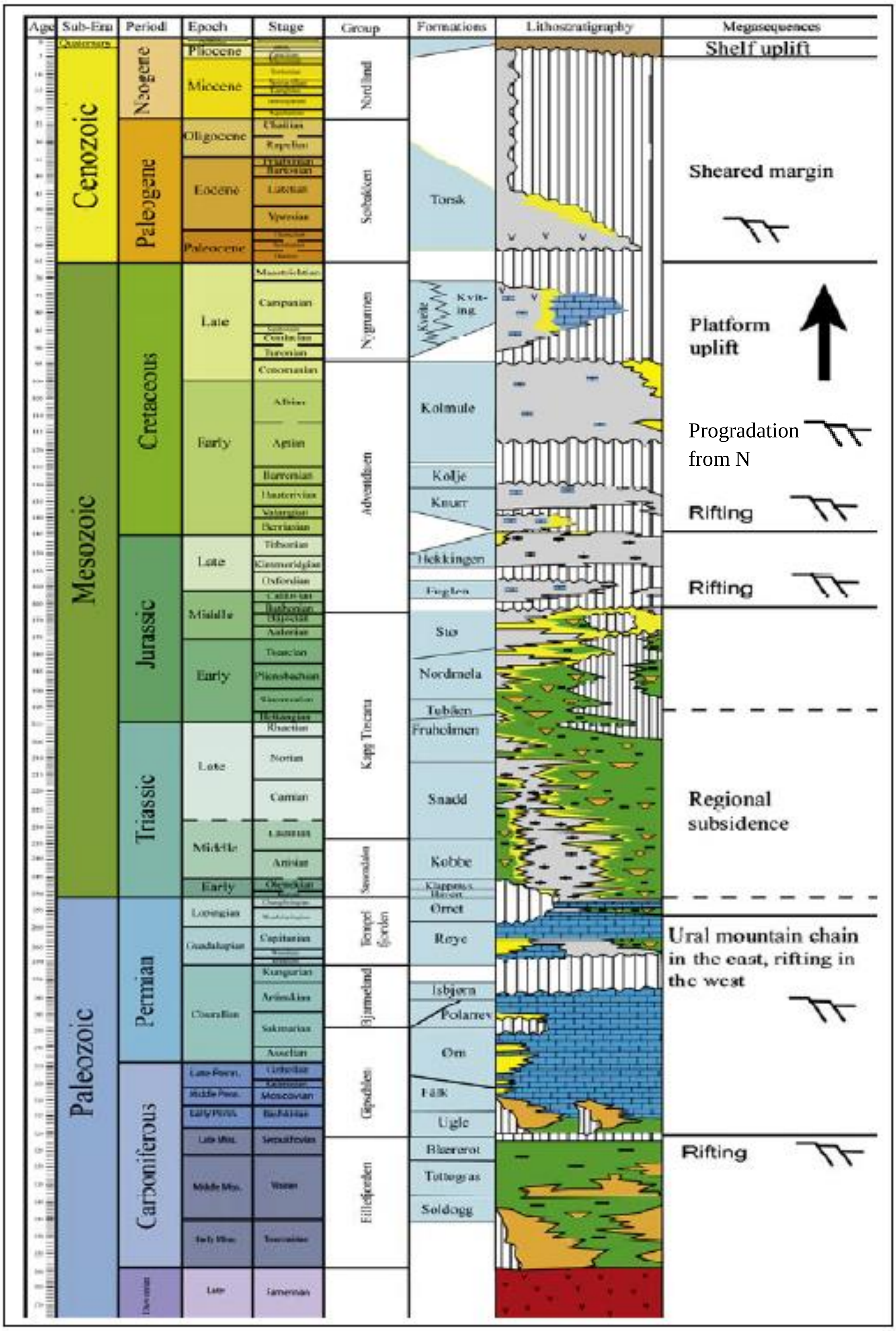


Figure 2-2: Stratigraphic chart of the western Barents Sea with the major phases of tectonic activity. (Modified from Glørstad-Clark et al. (2010))

2.2 Bjørnøya Basin and Leirdjupet Fault Complex

The Bjørnøya Basin is a major basin located between the Loppa High and Bjarmeland Platform to the south-east and east, respectively, and the Stappen High with the island of Bjørnøya to the north-west (figure 2-1). The Bjørnøya Basin was formed by extension and rifting during Late Jurassic- Early Cretaceous and is bounded by the Bjørnøyrenna Fault Complex, separating the basin from the Loppa High. The main sedimentary succession of the Bjørnøya Basin is of Early Cretaceous age (Gabrielsen et al., 1990)

The Leirdjupet Fault Complex continues towards the north from the northeastern part of the Bjørnøyrenna Fault Complex, separating the western part of the Bjørnøya Basin from the Fingerdjupet Subbasin in the eastern part of the Bjørnøya Basin. The fault complex has a large throw towards the western part of the Bjørnøya Basin. The characteristics of the fault complex changes from one single fault in the south to a set of faults in the north with decreasing throw (Gabrielsen et al., 1990)

Leirdjupet Fault Complex has been active during several periods. Major periods of movement along the fault complex have been in the (Early?) Carboniferous, Middle Jurassic and Early Cretaceous. There is also some evidence of movement in the time interval between Late Carboniferous and Permian and in Triassic. Due to uplift and erosion of the area the younger sediments of Late Cretaceous and Cenozoic are missing but there could also be movement related to these periods (Gabrielsen et al., 1990, Bjørnestad, 2012)

The Bjørnøya Basin is associated with the Late Jurassic-Early Cretaceous subsidence and is one of the deepest basins in the Barents Sea. When Stappen High was uplifted it the Cenozoic the tilted and truncated margin towards the north was formed. The Early Cretaceous sedimentary succession in the Bjørnøya Basin is very thick (Jurassic sequence found at 5-7 s TWT). When the Bjørnøyrenna Fault Complex and Stappen High were reactivated in the Late Cretaceous and the Cenozoic respectively, the Bjørnøya Basin was affected by faulting and local basin inversion (Faleide et al., 1993a, Gabrielsen et al., 1990)

The Bjørnøya Basin trends NE-SW and has some characteristics of a half graben, this can especially be observed in the NW-SE trending seismic sections close to the Stappen High which experienced uplift in the Paleogene. As in the rest of the southwestern Barents Sea the youngest sediments has been eroded and is not present. Dome-structures within the basin have been observed and Faleide et al. (1984) proposed salt as the main cause, however Rønnevik and Jacobsen (1984) concluded that salt diapirs is not present in the Bjørnøya Basin (Gabrielsen et al., 1990).

2.3 Fingerdjupet Subbasin

The Fingerdjupet Subbasin was first defined by Gabrielsen et al. (1990) as the shallow part of the Bjørnøya Basin formed in Early Cretaceous. The general fault trends observed in the Fingerdjupet Subbasin were formed during Late Jurassic tectonics and later reactivation during the Cretaceous and also possibly in Cenozoic times. The main subsidence of the basin is believed to have taken place in the Early Cretaceous, as a result to an extensional tectonic phase from Late Jurassic to Early Cretaceous. The basin area is supposed to be underlain by a thick Permian sedimentary succession, as also in the area of the Loppa and Stappen highs to the south-east and the northwest, respectively. From mid-Triassic (Ladinian) to late Middle Jurassic (Callovian) times the area of the present Fingerdjupet Subbasin is thought to have been part of the regional platform of the western Barents Sea (Gabrielsen et al., 1990).

The margins of the basin (figure 2-3) are defined by the Leirdjupet Fault Complex in the west and the Bjarmeland Platform in the east and Loppa High in the south and southeastern part. Within the basin a set of NNE-SSW trending fault blocks are present as well as a major horst in the northern part of the western margin. Late Cenozoic erosion has left the Late Cretaceous and Cenozoic history largely unknown. The western boundary of the Loppa High has been active at least four times since the Devonian, and the southernmost part of the Fingerdjupet Subbasin could have been affected by this (Gabrielsen et al., 1990).

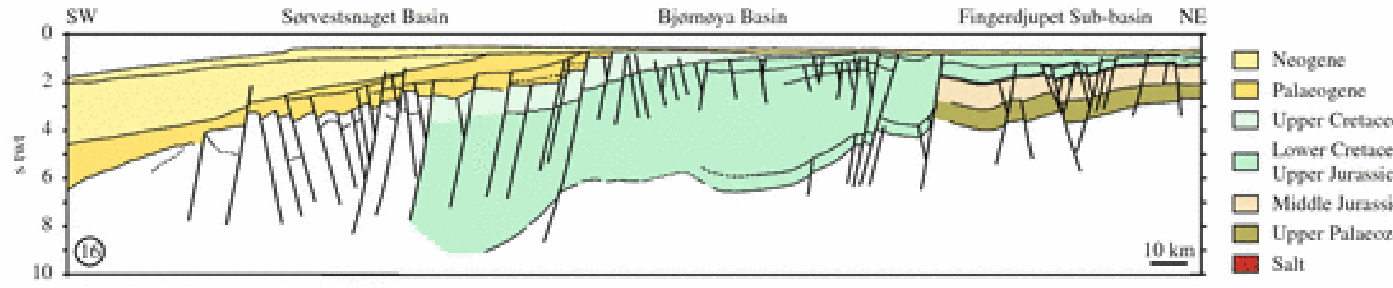


Figure 2-3: Seismic line displaying the Fingerdjupet Subbasin, with the Leirdjupet and Bjørnøya Basin to the SW (Faleide et al., 2010).

2.4 Bjarmeland Platform and Loppa High

The Bjarmeland Platform is located east of the Fingerdjupet Subbasin and the Loppa High to the southeast and south (figure 3-2). The Bjarmeland Platform is believed to have developed from a pre-platform basin to a carbonate platform in the time period representing a depositional change from early Carboniferous silisiclastic to late Carboniferous to Permian carbonates formations. After the Late Paleozoic the platform shows little or no signs of tectonic activity. The Bjarmeland Platform is believed to have Paleozoic and Precambrian rocks at the base. A fault zone probably terminated the platform to the west in the Late Permian to Early Triassic times. (Gabrielsen et al., 1990)

The Loppa High is a result of tectonics during two phases, the Late Jurassic to Early Cretaceous and the Late Cretaceous to Cenozoic. The Loppa High was also a part of the regional cratonic platform that is underlying the Bjørnøya Basin from the Landinian to Callovian. During the Cretaceous the Loppa High was an island cut at its margins by deep canyons that penetrated into Triassic sediments. The Neogene uplift removed all Paleogene shales that covered the Loppa High. High positive gravity and magnetic anomalies are characteristic for the area because of the relatively shallow basement of Caledonian metamorphic rocks underlain the western part of the Loppa High (Gabrielsen et al., 1990).

2.5 Oil and gas in the Barents Sea

The southern parts of the Barents Sea were in 1980 opened for exploration and the first discovery was made already in the 1981. The varieties of geological processes that have affected the Barents Sea have created a complex system of basins and structural elements, and the presence of salt has made it even more complex. The possible reservoirs lie in several stratigraphic levels all the way from the Devonian up to the Cenozoic. However, the main reservoir rock is the Jurassic sandstones. The source-rocks are also found in several stratigraphic levels with the Upper Jurassic and Triassic anoxic shales being the most important once. However, several events of uplift and erosion in the Barents Sea from the Palozcene until the Pliocene-Pleistocene have changed the hydrocarbon potential in the area from an area overfilled with hydrocarbons to and where hydrocarbons have been redistributed over large areas and also depletion of hydrocarbon accumulations (Ohm et al., 2008).

The majority of the findings in the Barents Sea are made in the Hammerfest Basin (Faleide et al., 2010). The most successful fields in the Barents Sea are the Snøvit Field, Goliath Field, and the upcoming Skrugard oil field (NPD, 2014)

3 Seismic interpretation

The workflow throughout this thesis can be summarized as seen in figure 3-1

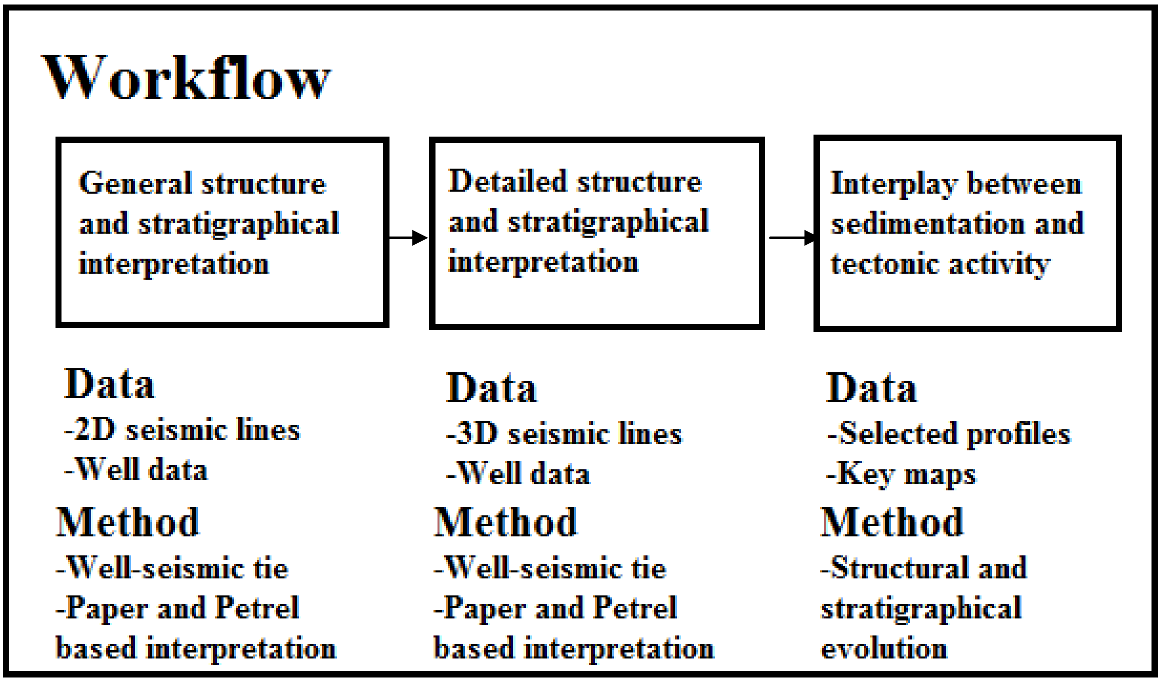


Figure 3-1: Workflow of this thesis. Partly based on Fitriyanto (2011).

3.1 Data

2D seismic data from the study area are used as the main data set for this thesis. The lithostratigraphy of the studied succession has been established by correlation to the three exploration wells located in the area of interest (7321/7-1, 7321/8-1, 7321/9-1; Fig 2). In addition, parts of a 3D data cube provided by TGS are used to supplement the interpretation. General information on the wells can be found in table 3.1, and more information on the three wells will be presented in chapter 3.2 Seismic to well correlation.

Table 3-1: Table with general information of the three wells in the Fingerdjupet Subbasin (NPD, 2014)

Wellbore name	7321/7-1	7321/8-1	7321/9-1
NS degrees	73° 25' 55.57" N	73° 20' 11.99" N	73° 16' 7.34" N
EW degrees	21° 4' 31.75" E	21° 24' 57.27" E	21° 41' 0.68" E
Drilled in production licence	140	141	141
Drilling operator	Mobile Exploration Norway INC	Norsk Hydro Produksjon AS	Norsk Hydro Produksjon AS
Completion date	22.10.1988	03.09.1987	28.11.1988
Type	Exploration	Exploration	Exploration
Status	Plug and abandoned	Plug and abandoned	Plug and abandoned
Content	Gas shows	Shows	Shows
Total depth (MD) [m RKB]	3550.0	3482.0	1800.0
Formation at TD	Snadd Fm (middle Triassic)	Røye Fm (Late Permian)	Snadd Fm (Late Triassic)

The location of the wells is in the southern part of the Fingerdjupet Subbasin, east of the Leirdjupet Fault Complex and northwest of the Loppa High (figure 3-2). A near Base Cretaceous (BCU) reflection an Intra Aptian reflection can be identified by acceptable confidence to the formation tops in the wells. The lithostratigraphy of the Fingerdjupet Subbasin will be presented in chapter 3.2 Seismic to well correlation.

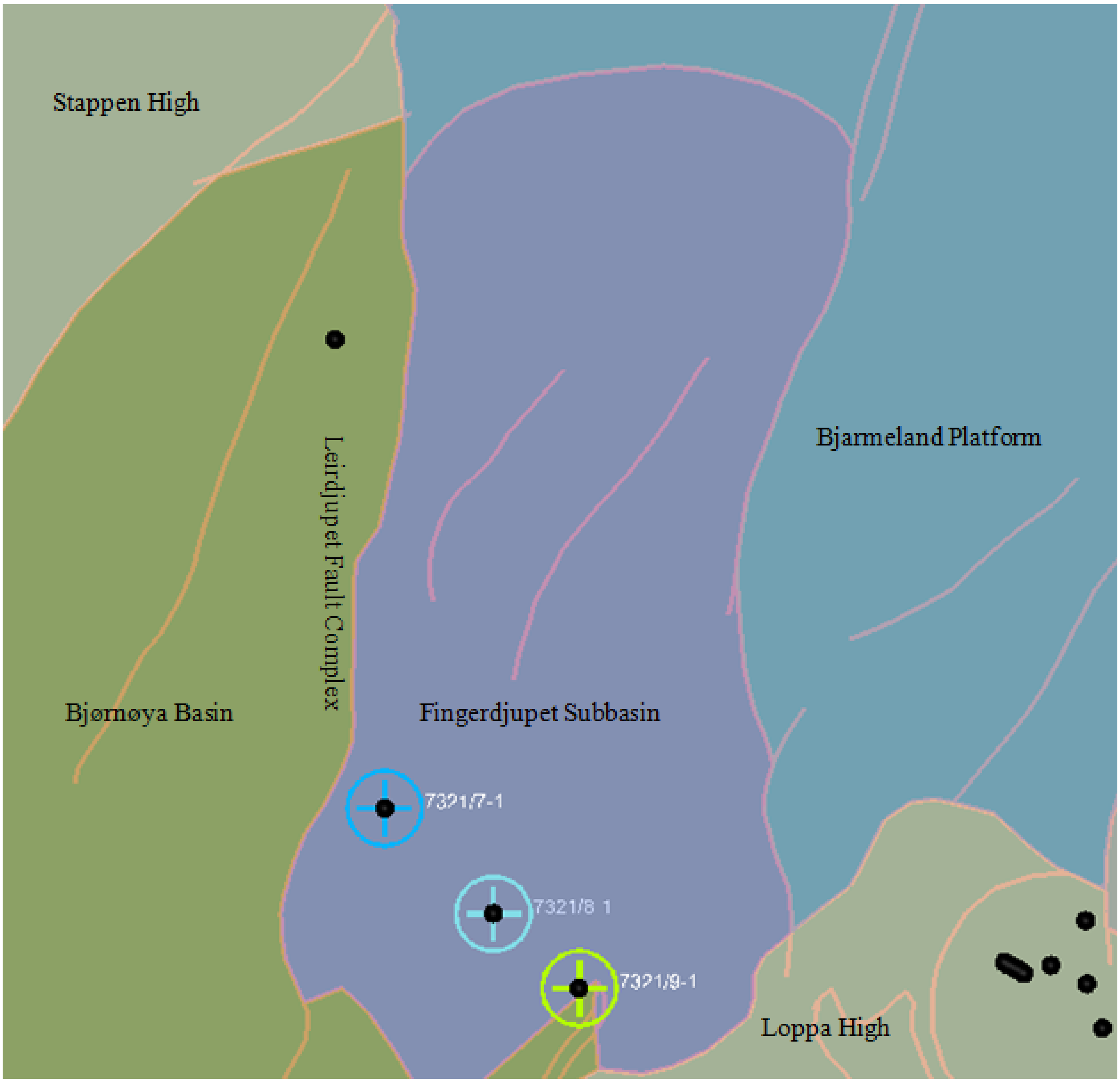


Figure 3-2: Position of the three main wells in the Fingerdjupet Subbasin. The main structural elements close to the Fingerdjupet are displayed (NPD, 2014)

3.2 Seismic to well correlation

A brief description of the formations of the Upper Jurassic to Upper Cretaceous in the Fingerdjupet Subbasin wells will be given below. The information on the formations are found in Worsley et al. (1988)

The Upper Jurassic to Lower Cretaceous Adventdalen Group comprises the following five formations:

Fuglen formation

The Fuglen formation is the oldest formation in the Adventdalen group. The unit consists of pyritic mudstones with thin layers of interbedded siltstone. The age of this unit is suggested to be Late Callovian to Oxfordian.

Hekkingen Formation

This unit mainly consists of dark (brown to dark grayish) shales and claystones, but there are some thin layers of interbedded clastic components like siltstone, sandstone, limestone and dolomite. The clastic components are often found near basinal margins. The top of this formation marks the boundary of the base Cretaceous. The age of this unit is suggested to be Late Oxfordian/Early Kimmeridgian to Ryazanian.

Knurr Formation

The Knurr Formation consists of dark grey to grayish brown claystones, and at the base of the formation sandstones occur. The unit has limestones and dolomites interbedded. At the top of the formation the claystones have red to yellowish color. The age of the Knurr formation is suggested to be Ryazanian/Valanginian to Early Barremian.

Kolje Formation

Shales and claystones with dark brown and dark grey color dominate the Kolje Formation. In this unit pale limestones and dolomite are found, and at the top of the formation thin beds of sandstones and siltstones occur. The age of the Kolje Formation is suggested to be Early Barremian to Late Barremian/Early Aptian.

Kolmule Formation

The uppermost formation of the Adventdalen Group is the Kolmule Formation. The formation consists mainly of shale and claystones with some minor parts of limestone and dolomite. There are also some silty layers in this formation. The age of this unit is suggested to be Aptian to mid-Cenomanian.

The two reflectors with a determined age are presented below.

The Base Cretaceous Unconformity (BCU) reflection correlates to the top of the Hekkingen Formation. The reflector is characterized by its distinctive strong amplitude, high frequency and positive reflection. The depth to the reflector varies from approximately 1900 ms (TWT) up to termination beneath Quaternary in the areas where the reflector is truncated at the seafloor. A set of faults are truncation this reflector. Most of the faults in the Fingerdjupet Subbasin continue all the way up to the Intra Aptian (H5) horizon and some even further up to the base of the Quaternary. In the remaining part of the Bjørnøya Basin and eastwards the fault activity has been less extensive with smaller offsets individual faults, and also some major extensional faults.

The Intra Aptian reflector is also interpreted as a strong amplitude, high frequency and positive reflector. However, the amplitude varies in the deepest part of the Fingerdjupet Subbasin and appears as a weaker reflection. The reflector is a regional unconformity with onlapping units above. This reflector has a set of faults terminating close to it, and there is two very characteristic packages below (M.S.1 – 2.3and 2.4) with wedge-shaped deposition in 2.4 and with a clear depo-center. The reflector mostly varies from 1000-1500 ms (TWT) but also this reflector truncates at the sea floor at the Loppa High. In the wells section (figure 3-5) this horizon corresponds to and reflector near Top Kolje Formation. This is in the well section observed as a change in gamma-ray response.

Figure 3-3shows both the two described horizons (BCU and Intra Aptian), as well as the other reflectors that have been tracked in the area. More information about the packages and the bounding horizons can be found in chapter 3.4 Description and Interpretation of the Fingerdjupet Subbasin under the sub-chapter 3.4.2 Megasequences.

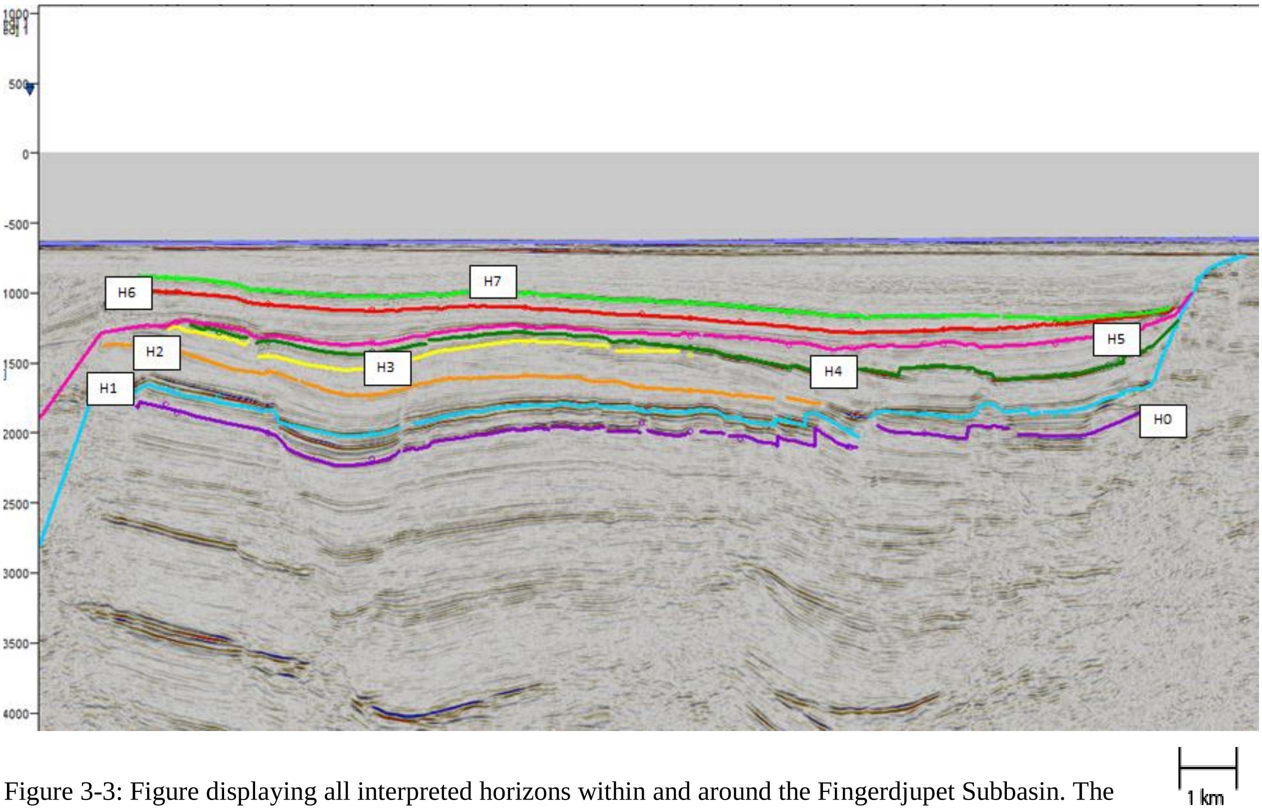


Figure 3-3: Figure displaying all interpreted horizons within and around the Fingerdjupet Subbasin. The names of the horizons and the name of the sequences discussed later can be observed from Figure 3-5

A seismic well tie through well 7321/7-1 to the interpreted horizons of BCU and Intra Aptian can be observed in figure 3-4.

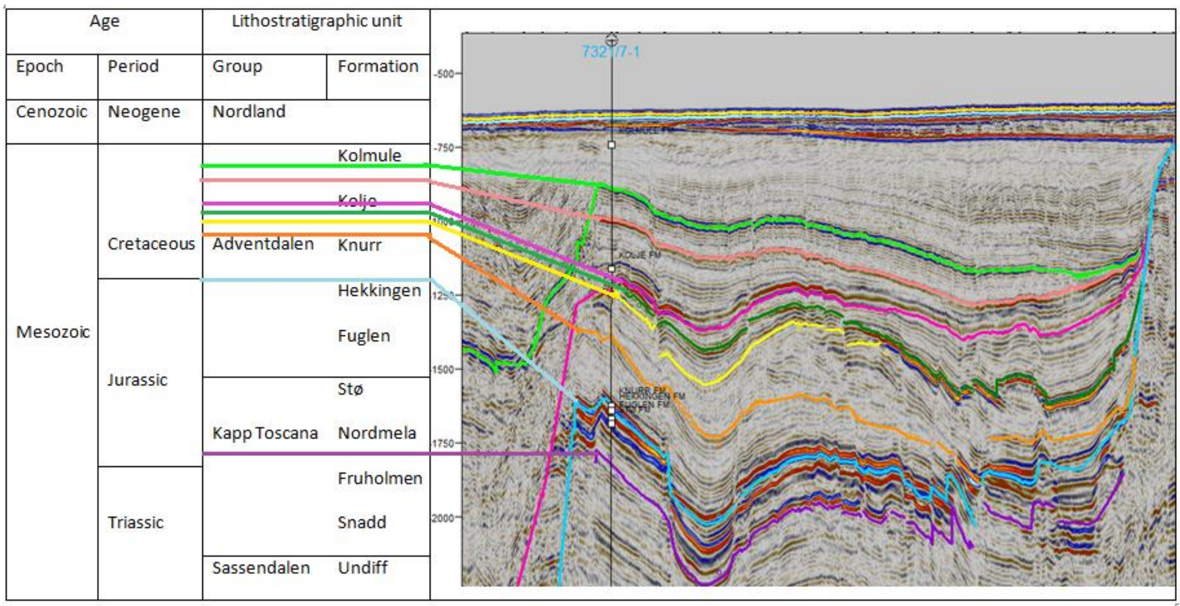


Figure 3-4: Seismic to well tie of well 7321/7-1 on the uplifted footwall of the Leirdjupet Fault Complex.

The three wells present in the Fingerdjupet Subbasin with location as shown in figure 3-2 will be presented both in the seismic section and in log sections to be able to look at the stratigraphy in detail. The general information on the three wells can be seen in table 3-1.

Based on the gamma log readings of the three wells the stratigraphy of the Fingerdjupet Subbasin is possible to determine for each of the groups. The gamma-logs, resistivity and acoustic logs for the three wells are displayed in figure 3-5.

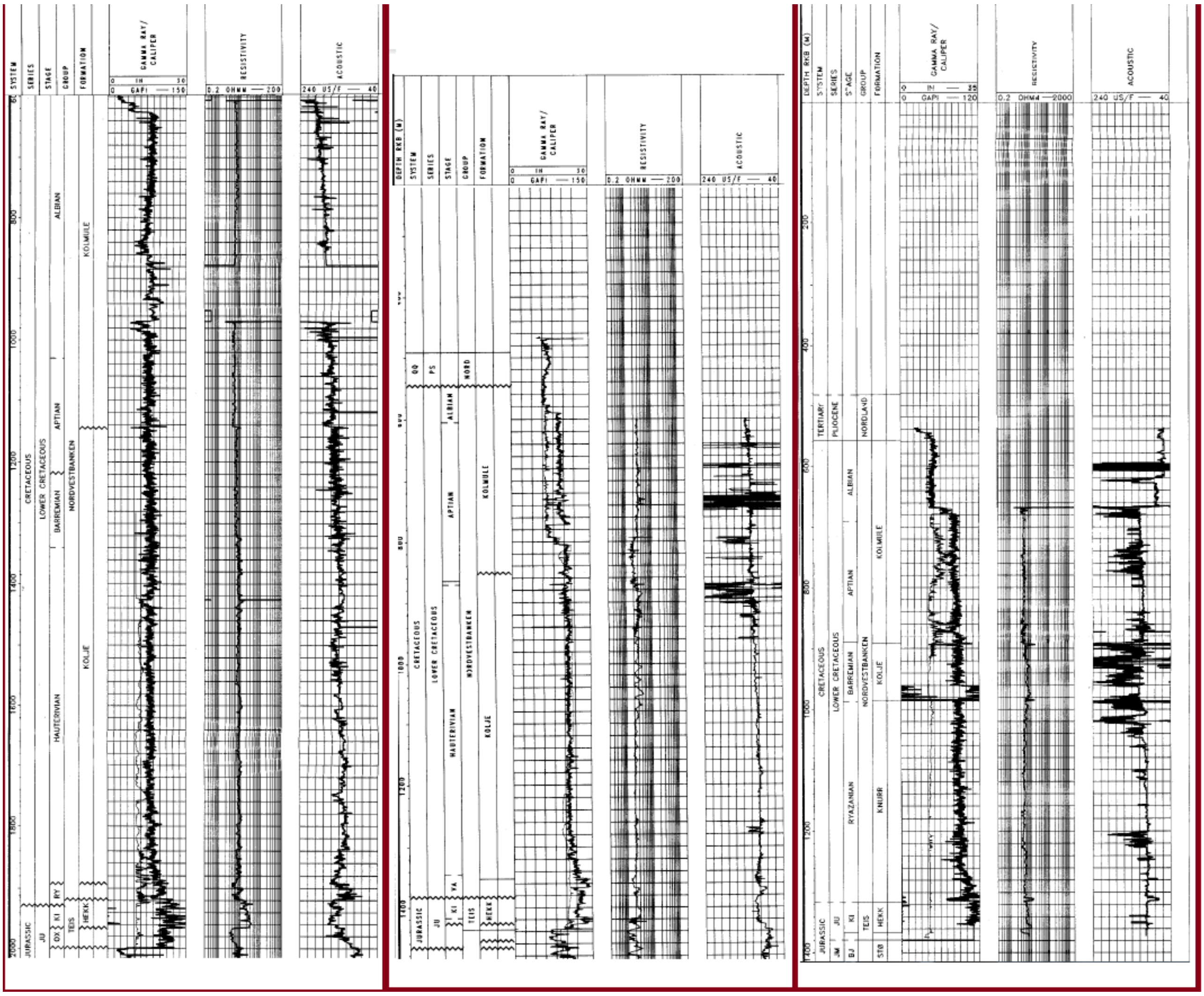


Figure 3-5: Well sections of the three wells in the Fingerdjupet Subbasin. From the left; well 7321/7-1, 7321/8-1 and 7321/9-1. The wells are displaying gamma-ray, resistivity and acoustics (NPD, 2014).

Based on the gamma-logs for the three wells 7321/7-1, 7321/8-1 and 7321/9-1 the Hekkingen formation appears as the shaliest unit with the highest gamma-ray readings, and a generally higher resistivity then the units above especially in well 7321/7-1. The interpretation on the log indicates that this unit is a claystone of dark brown to black color. The Knurr Formation above the Hekkingen Formation has lower gamma-ray readings and appears in well 7321/7-1 and 7321/8-1 as a thin unit (approximately 20 ms TWT) of siltstone. In well 7321/9-1 however the Knurr Formation is interpreted to be over 300 ms TWT. These interpretations are based on the seismic, and the well sections support this. By looking at the seismic section in a composite line cutting through the three wells it becomes clear that this is a miss-tie between the well-logs and the seismic section. Not only does the seismic reveal the miss-tie but the fact that the Knurr Formation is that much more extensive in an area with generally the same conditions and accommodations space does is not logic. The well 7321/9-1 has a thick Knurr Formation and a thin Kolje Formation, whereas the other two wells have a thin Knurr Formation and a thick Kolje Formation. By studying the seismic section it becomes clear that the thick Knurr Formation of 7321/9-1 is not correct. This can be observed in figure 3-6. In well 7321/7-1 the units below the Hekkingen Formation is a sandier interval with fairly high resistivity readings compared to the rest of the section.

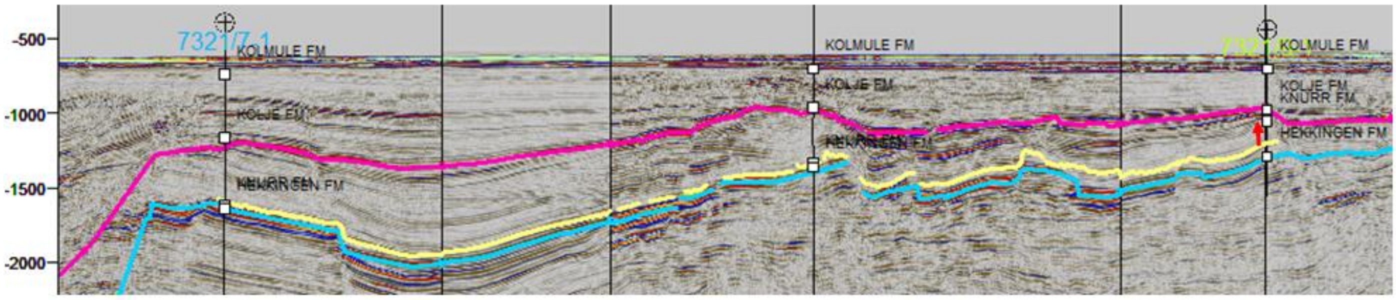


Figure 3-6: Miss-tie between the three wells in the Fingerdjupet Subbasin. The yellow line displays the seismic horizon that corresponds to the top Knurr Formation in well 7321/7-1 and 7321/8-1. In well 7321/9-1 the reflector lies below the interpreted top Knurr Formation in the well. Blue line corresponds to the near base Cretaceous reflector, and the pink line is the Intra Aptian reflector.

The Kolje Formation appears from the logs as an alternating silt and claystone with a bit higher gamma-ray readings then the previous two formations. There are some shaly parts in this unit and there are also some carbonates found. This log interpretation fits well with what Worsley et al. (1988) describes in each formation.

3.3 Seismic interpretation procedures

To be able to get a general picture of the regional geology and structuring of the area 2D seismic data were used to interpret the area and the periphery. Schlumberger's software PETREL was used as an interpretation tool for this. The Fingerdjupet Subbasin was first mapped and delineated with main emphasis on the two main horizons BCU and Intra Aptian. Six selected lines were then manually interpreted on paper in order to obtain knowledge of the structuring of the basin, and the sequence stratigraphy of its Lower Cretaceous succession.

Due to limitations of the software this manual method of interpretation has proven to give more precise and detailed results than automatic picking of surfaces by the PETREL software.

First the seismic lines with a detailed description and interpretation are presented; afterwards the main surfaces of BCU and Intra Aptian are discussed. The objective of this step is to create a general picture of the infill history of the Fingerdjupet Subbasin by mapping out the most relevant reflectors and getting information about variation in thickness of the different packages, and infill history. Time-thickness maps of the horizons are made to get a most direct measurement as possible and to visualize thickness variation both horizontally and vertically. This will be presented in a sub-chapter about the megasequences.

To understand the infill history of the Fingerdjupet Subbasin and the dynamics of its structural development, faults bounding the basin as well as faults inside the basin need to be described, interpreted and correlated with the infill-history. To be able to obtain a picture of the importance of the faults parts of a 3D cube provided by TGS was interpreted in great detail. The surface of the BCU made from this detailed study, shows fault networks in the area. These faults where then interpreted and a fault model was made. This will be presented in the chapter 3.3.5 about fault interpretation.

3.4 Description and interpretation of the Fingerdjupet Subbasin

3.4.1 2D Seismic Interpretation

The 2D lines are used to do a regional interpretation of Fingerdjupet Subbasin from Upper Jurassic upwards to the top of the Lower Cretaceous package of strata, where a thin Quaternary package followed by the seabed lies directly on top of the eroded package of Lower Cretaceous sediments.

Six 2D lines (figure 3-7) were selected for illustrating the main structural and stratigraphical features in the southern part of the study area, where the wells are present. The main lines were picked on basis of quality, as well as the location of the seismic sections relative to position of the wells in the area. These lines were first manually interpreted and afterwards a regional interpretation of the 2D data with a basis in the key lines was done in PETREL.

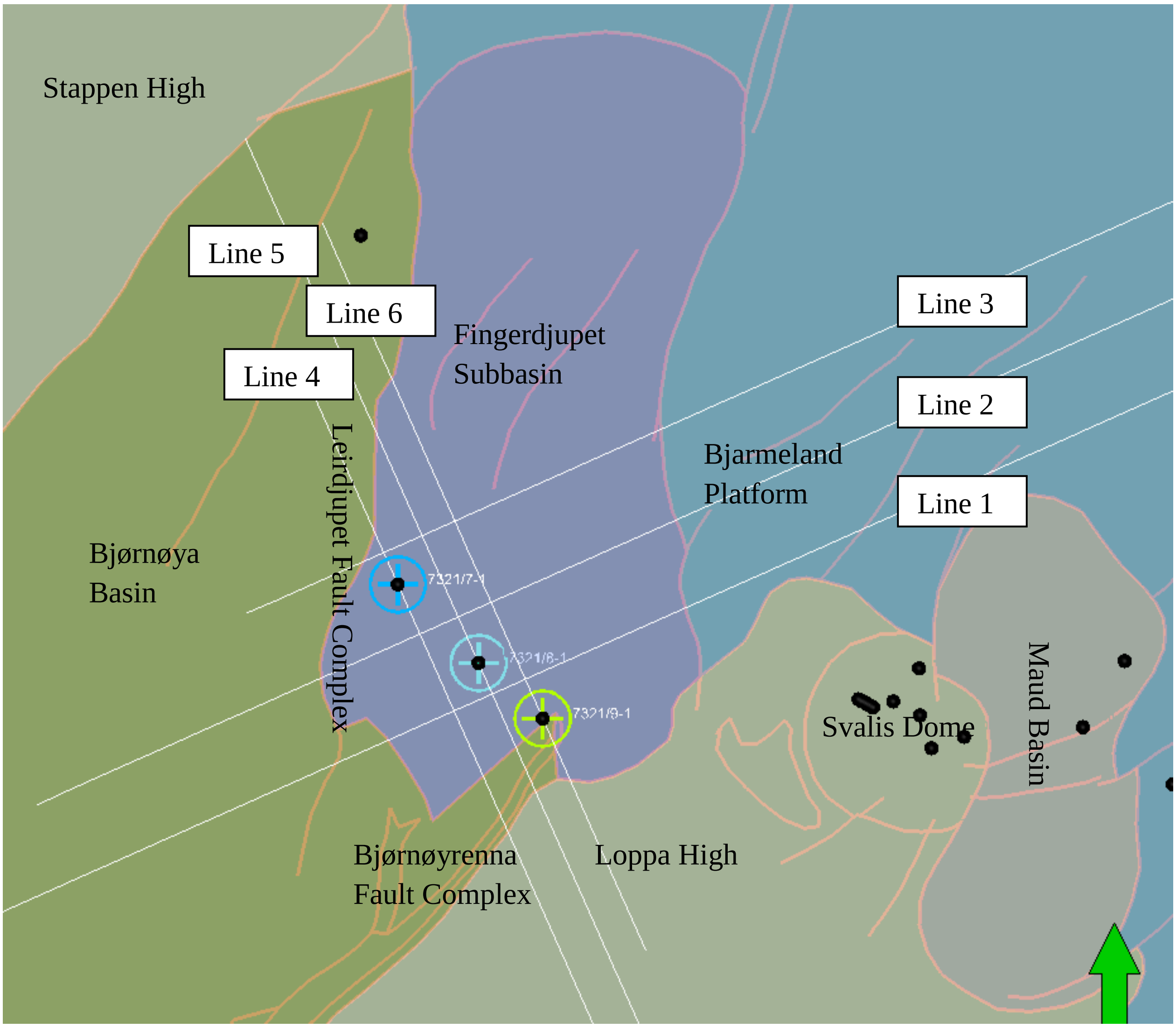


Figure 3-7: The three key lines and their position displayed on a simplified structural map (NPD, 2014).

The seismic succession is divided into three megasequences (Figure 3-8). The lowermost megasequence, M.S.1, consists of one single sequence (1.1), the middle megasequence, M.S.2, comprises the sequences 2.1-2.4, and the uppermost megasequence, M.S.3, of the sequences 3.1-3.3. The boundaries between the sequences are here termed horizons and numbered H0 to H7, with H0 at the base of megasequence M.S.1 and sequence 1.1.

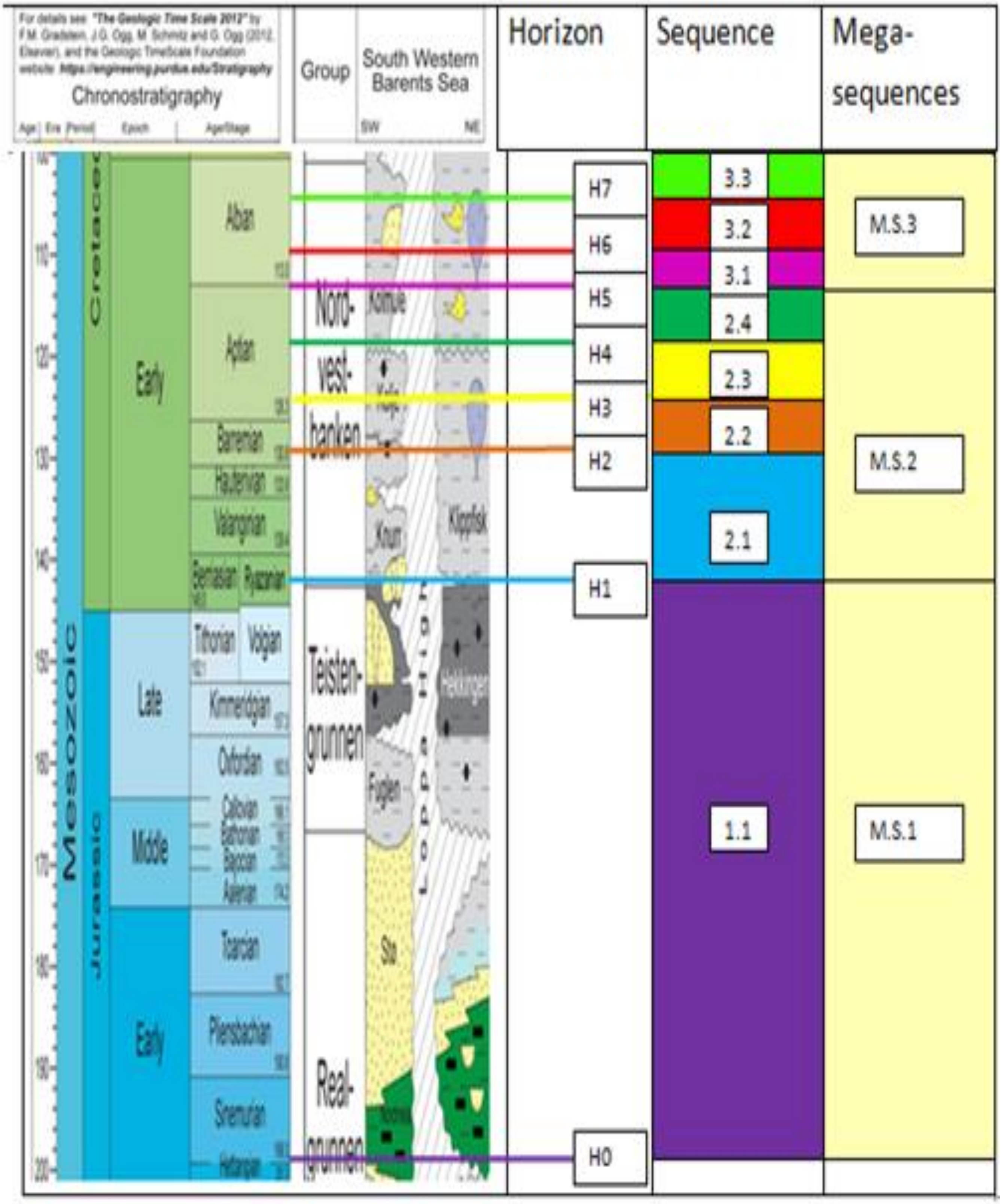

Chronostratigraphy
Group
South Western Barents Sea
SW
NE
Horizon
Sequence
Mega-sequences
Mesozoic
Jurassic
Early
Late
Middle
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Ryazanian
Tithonian
Volgian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Nordvestbanken
Teistengrunnen
Realgrunnen
Kolmule
Knurr
Klippfisk
Hekkingen
Fuglen
Stø
Loppa High
H7
H6
H5
H4
H3
H2
H1
H0
3.3
3.2
3.1
2.4
2.3
2.2
2.1
1.1
M.S.3
M.S.2
M.S.1

Figure 3-8: Key figure displaying the horizons, sequences and megasequences in relation to the lithostratigraphy of the South Western Barents Sea (NORLEX, 2014)

Line 1

Line 1 is the southernmost SW-NE line (figure 3-7). The line cuts through parts of the Leirdjupet Fault Complex to the SW and the Bjarmeland Platform to the NE. The line crosses north of well 7321/9-1 and south of well 7321/8-1. The succession in this part of the subbasin is cut by many faults. Figure 3-9a shows a part of the line with location in the Fingerdjupet Subbasin.

Line 2

Line two crosses in the middle between well 7321/8-1 and 7321/7-1. As in Line 1, the Leirdjupet Fault Complex is located in the southwesternmost part of the section and the Bjarmeland Platform to the NE (Figure 3-9b). The central part of the Fingerdjupet Subbasin is well defined by the maximum thickness here of the megasequences.

Line 3

Line 3 is the northernmost of the keylines that is oriented SW-NE. The seismic section shows the Fingerdjupet Subbasin with its depo-center with maximum thickness. As in the two previous lines the Leirdjupet Fault Complex is observed in SW, and the shallower part of the Bjarmeland Platform is observed to the NE. The well 7321/7-1 is south of this line. This line is shown as figure 3-9c.

Line 4

Line 4 is the westernmost line of the NW-SE oriented lines. The line cuts straight through well 7321/7-1. The northwestern part of the seismic section shows the Leirdjupet Fault Complex, while the southeastern part shows the Bjørnøya Fault Complex and the Loppa High. A picture displaying this line can be seen in figure 3-10a.

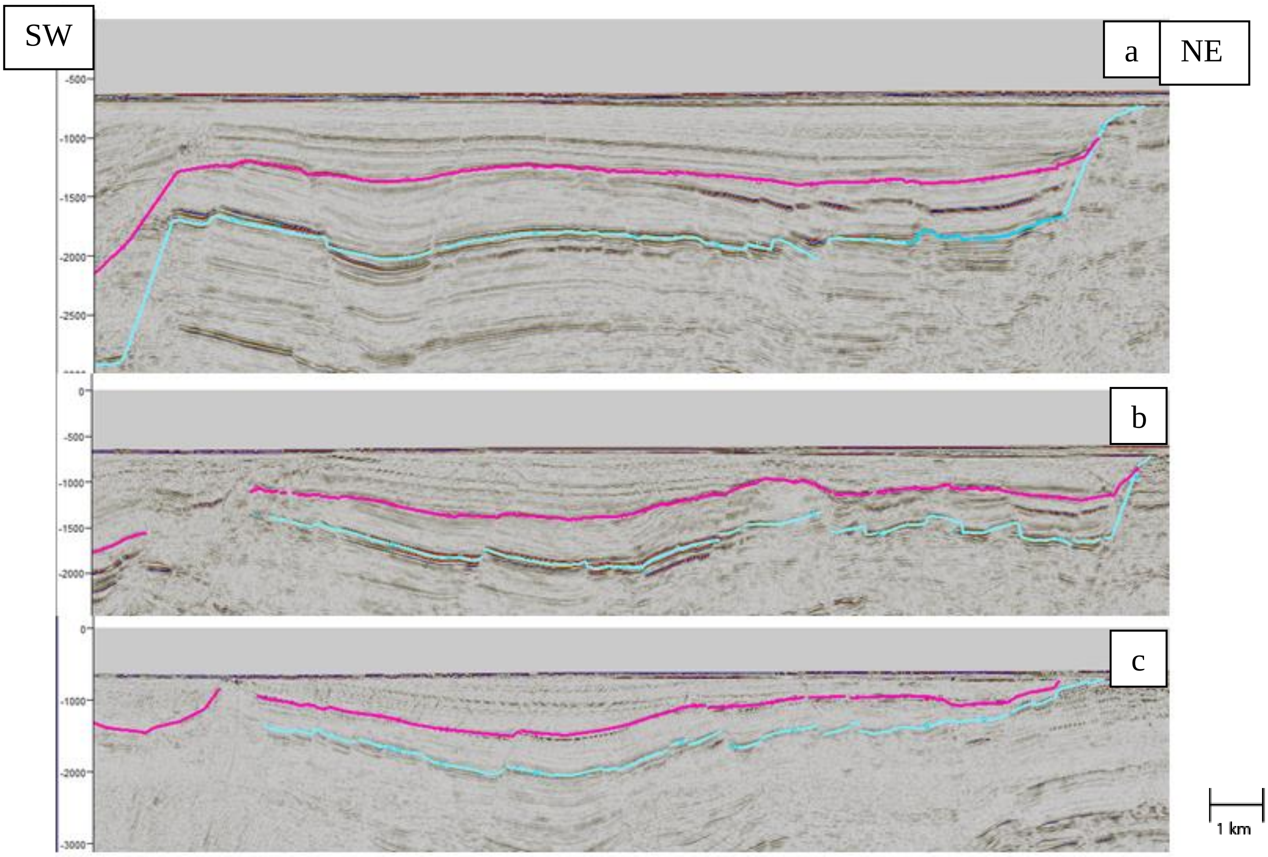


Figure 3-9: Seismic lines displaying the three lines in a SW/NE direction. Line 1 is displayed at the top (a), Line 2 in the middle (b) and Line 3 at the bottom (c). To the left on the pictures the Leirdjupet Fault Complex can be seen, and to the right the Bjarmeland Platform is observed. See figure 3-7 for the position of the lines. Blue horizon represents the BCU and the pink horizon the Intra Aptian reflector.

Line 5

Line 5 is presented as the middle line of the three NW-SE oriented lines. The line goes through well 7321/8-1. The Bjørnøya Fault Complex can be observed and also the Leirdjupet Subbasin in the northwestern and southeastern part of the succession, respectively.

Line 6

Line 6 is the easternmost line of the chosen NW-SE oriented lines. The line also reaches the Leirdjupet Fault Complex and the Loppa High, and it crosses through well 7321/9-1. Also a small part of the Bjørnøya Basin west of the Leirdjupet Fault Complex can be seen in this seismic line. However, the Fingerdjupet Subbasin is the main structural element within this seismic section. The line is located in the area where the Fingerdjupet Subbasin is at its widest. Figure 3-10c displays a snapshot of this line.

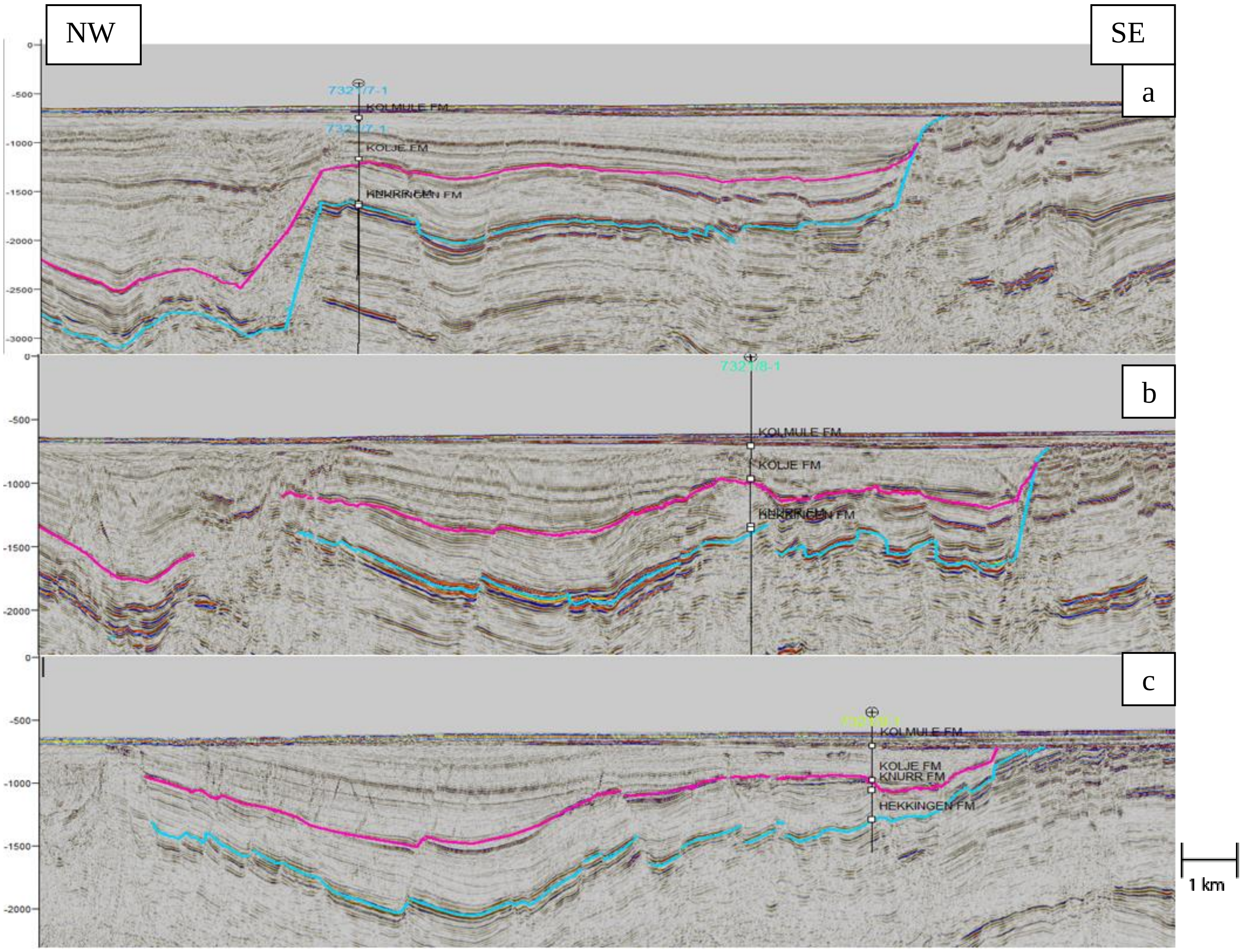


Figure 3-10: Seismic lines displaying the three lines in a SE/NW direction. Line 4 is displayed at the top (a), Line 5 in the middle (b) and Line 6 at the bottom (c). To the left on the pictures the Leirdjupet Fault Complex can be seen, and to the right the Loppa High. See figure 3-7 for position of the lines. Blue line reprensets the BCU and the pink line represent the Intra Aptian horizon.

After the megasequences and the sequences were defined the most characteristic and important faults where interpreted, and given names and numerical codes according to the observations made on the key-lines. A detailed interpretation of the faults will be presented in chapter 3.3.5 Fault interpretation.

3.4.2 Megasequences

The regional sequence stratigraphy interpretation is summarized in figure 3-8. The figure shows the megasequences and the sequences together with the interpreted horizons. The timing and the correlation to the lithostratigraphy of each interval is uncertain in lack of enough well data control regarding lithostratigraphy versus biostratigraphy and age.

The following chapters describe each megasequence with the corresponding seismic sequences, illustrated with examples from the seismic data. The figures include both the interpretation and thickness maps to illustrate the lateral and vertical variations through time, in addition characteristic features of each sequence are displayed.

Megasequence 1 M.S.1

Jurassic sequence 1.1

Description

Megasequence M.S.1 contains only one sequence (1.1) (figure 5). In all the interpreted lines sequence 1.1 is recognized as a lateral consistent package in thickness, with little or no signs of wedge-shaped geometry. The lower boundary of this sequence is a reflector that has a strong amplitude and is negative. The top boundary is the strong reflection at the base Cretaceous that is described in chapter 3.2 about seismic to well correlation.

The sequence is rather consistent and uniform both in thickness and characteristics throughout the whole area of interest, but it is more easily tracked in the shallow part of the Fingerdjupet Subbasin compared to the deepest western part of the Bjørnøya Basin and in the uplifted platform areas, where the sequence is mainly eroded. The sequence contains several penetrating faults and appears partly tilted in the main areas of the Fingerdjupet Subbasin. This can be observed from figure 3-11. No specific seismic facies in this sequence are observed. Figure 3-11(a-d) contains some key features of this Upper Jurassic sequence. The constant thickness of the sequence is displayed both in the seismic section and can also be observed when looking at the time-thickness map generated between horizon H0 and H1.

The thickness varies mainly between 50 ms TWT and 150 ms TWT which is a rather small variation over this large area.

Interpretation

Sequence 1.1 tends to have little or no signs of syn-tectonic origin, as interpreted from the lack of any wedge-shaped geometry towards major faults in the basin. The lack of any specific seismic facies also supports the assumption that deposition took place in a low-energy environment under calm conditions of water circulation. The minor thickness variations of this sequence indicate that the Fingerdjupet Subbasin has had differential subsidence. Whether or not the thickness of this sequence is large enough to resolve seismic facies can be discussed. The well data shows that this sequence contains both shales and sandstones and several formations. But in the seismic it appears as a relatively small interval.

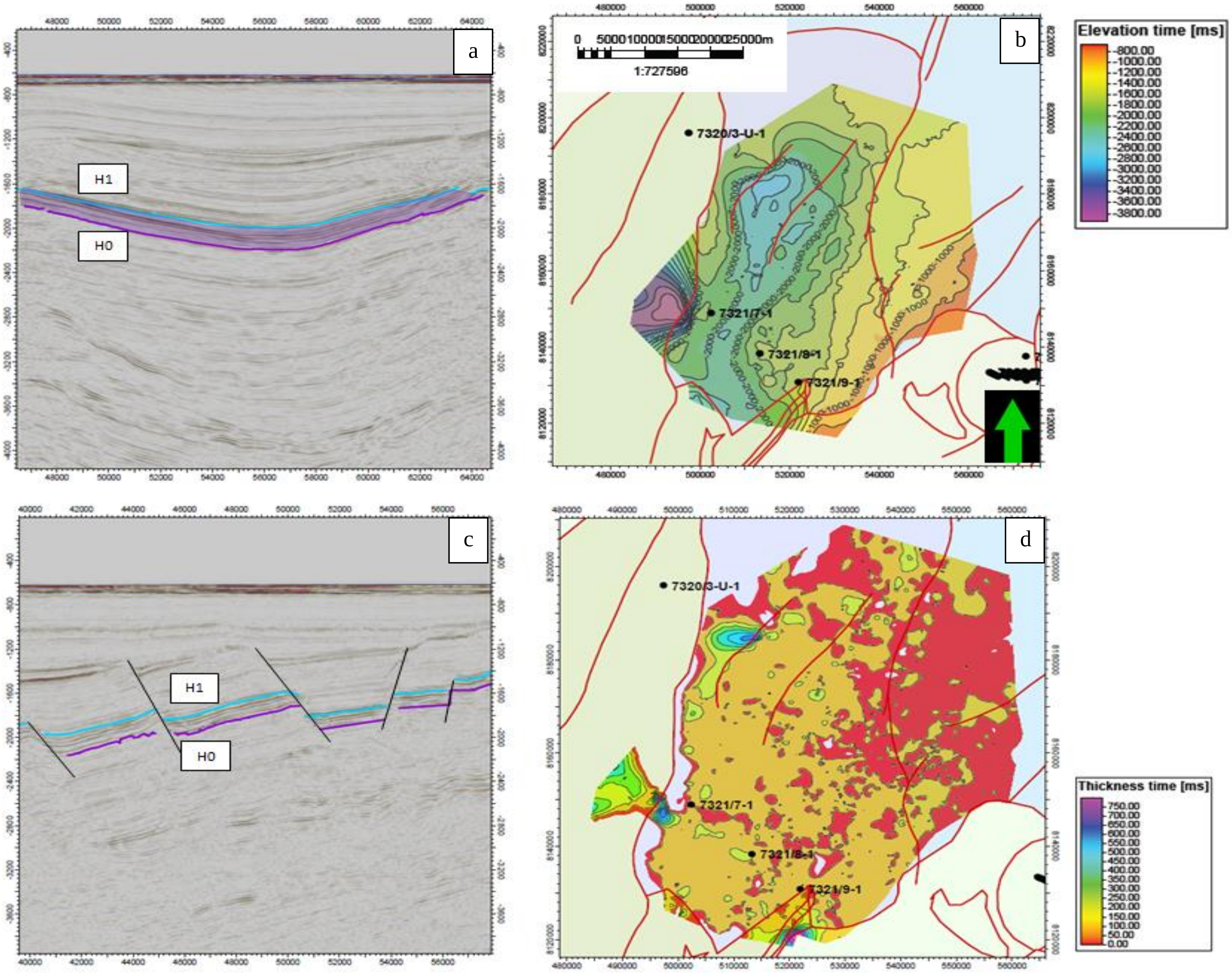


Figure 3-11: Sequence 1.1 of Jurassic. (a) Displaying the equal thickness of the sequence. (b) Showing the surface of sequence 1.1 H0, (c) displaying the tilted fault blocks, (d) time-thickness map.

Megasequence M.S.2

Megasequence (M.S.2) (Figure 3-8) is bounded at its base by the characteristic base Cretaceous surface (BCU, H1), and at the top by Intra Aptian surface (H5). This is the oldest and first megasequence in the Lower Cretaceous of the Fingerdjupet Subbasin.

The megasequence is best studied in the main part of the Fingerdjupet Subbasin because the megasequence seems to be thinning and pinching out onto the Loppa High in the southeast and is not easy to trace in the deepest parts of the Bjørnøya Basin in the southwest. The megasequence consists of the four sequences 2.1, 2.2, 2.3 and 2.4, all with different characteristics. The sequences will be presented and discussed separately.

Lower Cretaceous sequence 2.1

Description

The Lower Cretaceous sequence 2.1 is bounded at the base by the continuous BCU reflector described earlier and at the top by a weak positive reflector (H2). The upper part of the sequence (2.1b) tends to thicken towards the major faults in the central parts of the subbasin. The sequence 2.1a shows little or no signs of thickening towards the faults. The whole sequence 2.1 tends to thin towards the southeast to the Loppa High; this can be observed in figure 3-12(a-d). Wedge shaped deposits are observed in the whole area of research within sequence 2.1b.

The sequence 2.1 is best studied in the central parts of the Fingerdjupet Subbasin. As can be observed from the time-thickness map figure 3-12 the sequence has generally the same time-thickness throughout the whole area, with some small areas with increased thickness as mentioned above.

The sequence shows little or no signs of seismic facies changes throughout the area of research. However, small clinoforms are observed at the base of an uplifted area connected to the Leirdjupet Fault Complex. The clinoforms seems to downlap to a surface close to the interpreted Base Cretaceous surface. The reflector strength of the bounding reflectors and within the sequence seems to be somewhat the same.

Interpretation

Sequence 2.1 appears to have two internal sets of depositional systems, at least one which appears to be syn-tectonic and one which is not. The fact that the sequence seems to be thinning towards the Loppa High indicates that the accommodation space towards the high has been smaller than in the central parts of the basin, where the sequence is thicker. This observation is also in favor of the fact that faults have been active during the time interval when the sequence was formed, and that this created some areas with greater accommodation space than in other parts of the basin. From the well logs (figure 3-5) the sequence appears to have the same lithology in the whole sequence, regardless of the difference in depositional system. The difference in sequence 2.1a and 2.1b lies mostly in depositonal style and geometry.

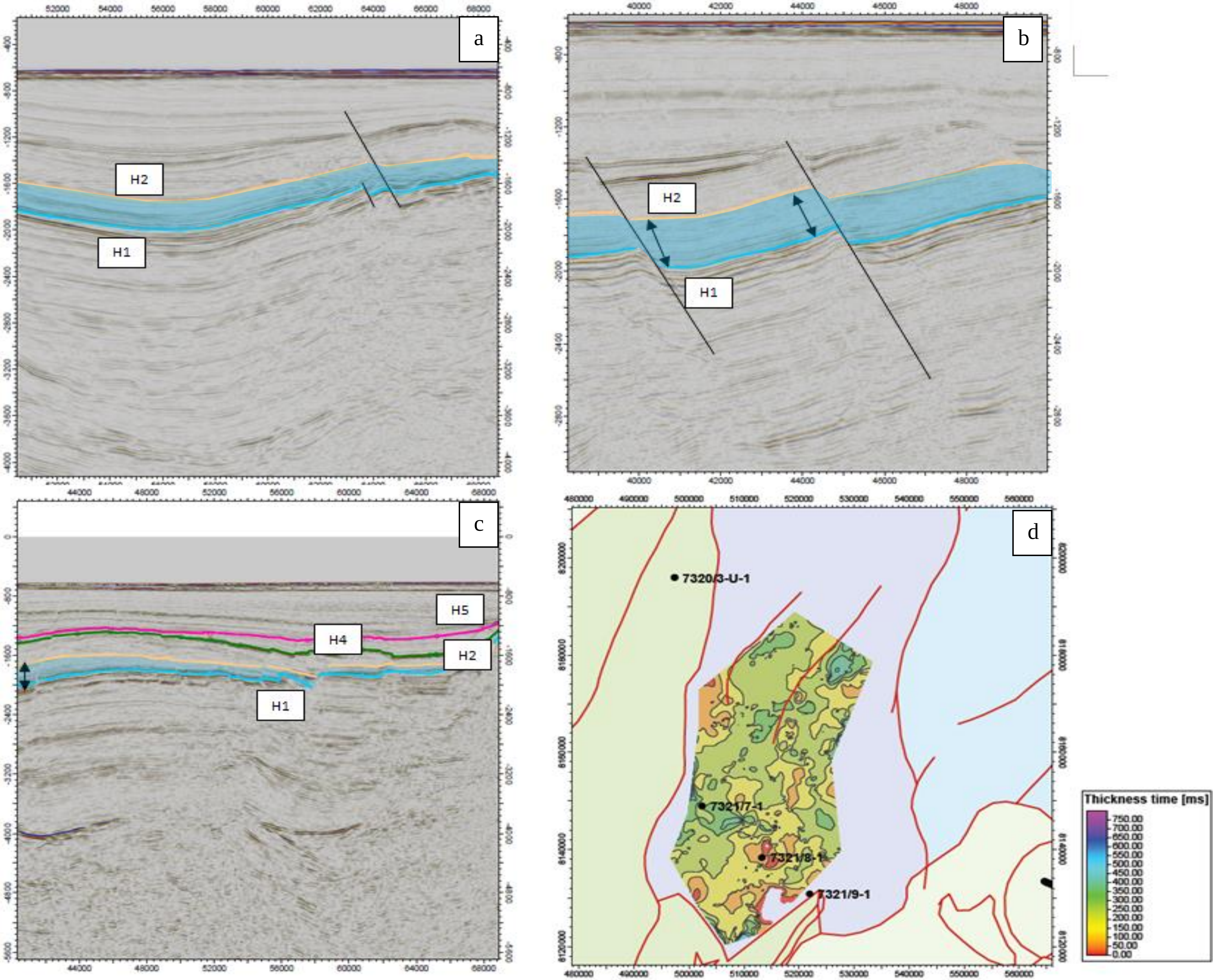


Figure 3-12: Sequence 2.1. (a) Displaying a typical picture of the sequence. (b) Thickness variation towards fault. (c) pinch-out towards the east and southeast. (d) Time-thickness maps.

Lower Cretaceous sequence 2.2

Description

This sequence has weak top and bottom reflectors; however, the base reflector is succeeded by a set of strata with downlapping clinoform reflections, so the surface is characterized as a downlap surface defined by oblique tangential reflections in the overlying sediment package. Both the top and base reflectors of this sequence are positive. The sequence itself seems to have at least one unit internally that is clearly wedge-shaped, and the whole sequence also seems to thicken towards the major faults. In a specific area the sequence thickens towards the top of a structure, revealing a convex geometry as a structural high. This internal structure can be seen in several lines (figure 3-13b). On the top of this structure, where the sequence thickens, reflectors above seem to lap onto this high. In areas close to the platform the reflectors within the sequence seem to change from dimmed and weak reflectors to be stronger and more pronounced, but still revealing the same trend as the reflector pattern in the remaining part of the package.

Interpretation

The fact that the Lower Cretaceous sequence 2.2 tends to thicken towards an area now being a structural high shows that the accommodation space was high in this area when the strata of the sequence were deposited, implying a former depo-center, followed by a small compression resulting in the thickness variation towards the structural high. This change in depo-center may imply that the basin was highly dynamic with several stress directions and controlling factors at this time. The fact that the reflector characteristics seem to be varying can be due to different textural properties of the sediments in the area; this could either be a result of erosion and sedimentation of some particular debris from adjacent platform areas, or a more complex differential compaction in the subbasin.

By studying the time-thickness map in figure 3-13 it becomes clear that there are great variations of thickness in the area. This could possibly be related to syn-tectonic deposition which is also indicated in the seismic sections interpreted. The clinoforms observed within this package seem to be deriving from the NNW, and the importance of these will be discussed further in chapter 4.

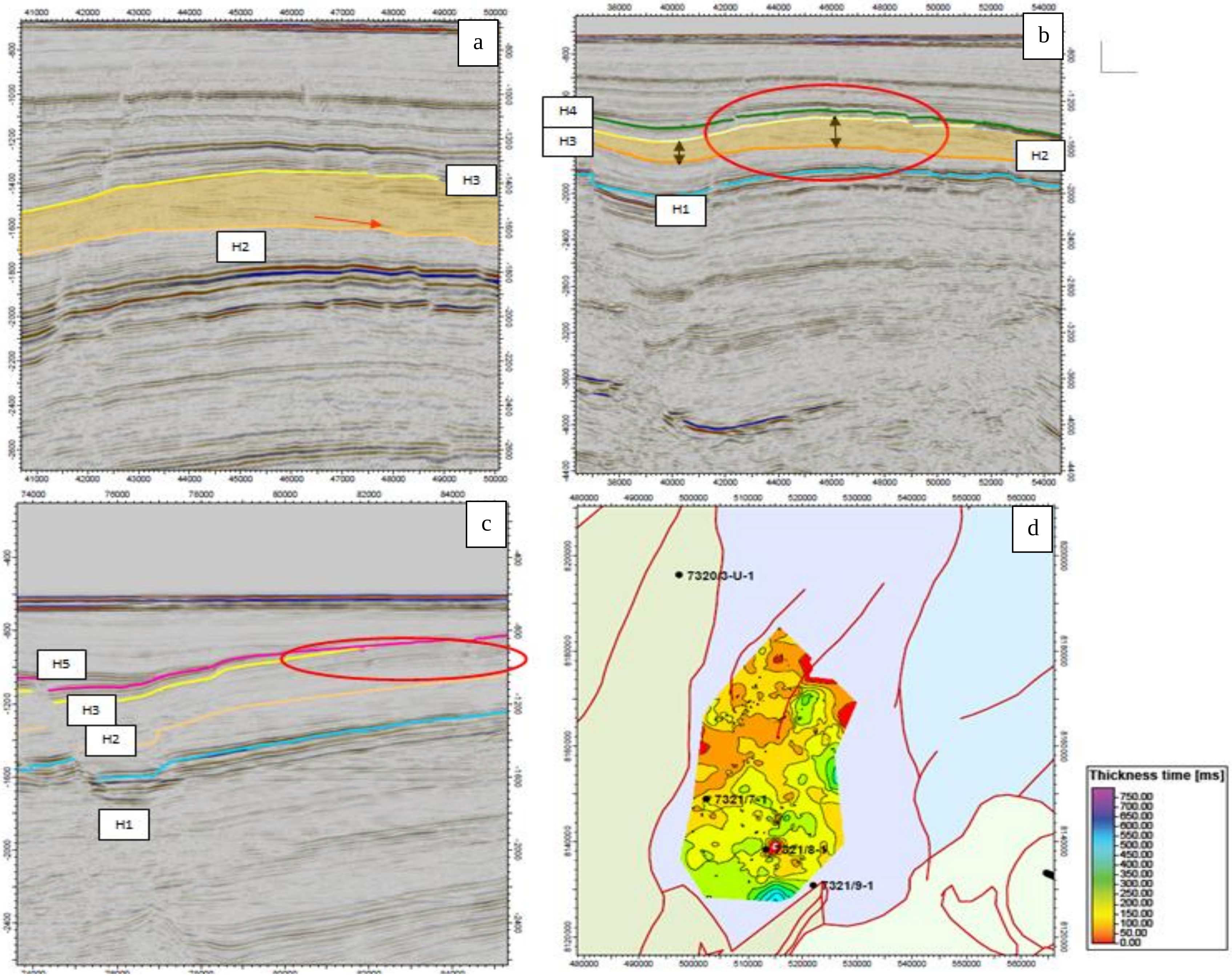


Figure 3-13: Sequence 2.2. (a) Clinoforms form the north. (b) Thickness variation towards a structural high. (c) Amplitude variations within the sequence. (d) Time-thickness map.

Lower Cretaceous sequence 2.3

Description

Sequence 2.3 is generally characterized as a wedged-shaped unit that is thickest at the main depo-center in the Fingerdjupet Subbasin and pinches out towards the basin margins. The sequence is relatively thin in the whole study area and can only be observed in the central part of the Fingerdjupet Subbasin. The base reflector is positive and not a high amplitude reflector. The top reflector is also a weak positive reflector.

In areas where the sequence 2.4 is not present the top boundary of sequence 2.3 is the reflector characterized as Intra Aptian (H5). By looking at figure 3-14 it becomes clear that the angle between the horizon 3 (H3) and horizon 4 (H4) is different, and H3 appears flat compared to H4. When studying the surface of H3 it shows small variations in elevation time, the surface also indicates that this sequence is only present in the central parts of the Fingerdjupet Subbasin. The thickness maps between H3 and H4 shows that the sequence is at its thickest in the south and gradually decreases northwards. To the east and the west the package seems to pinch-out. Drag features related to the faults within the basin are also observed within this sequence.

Interpretation

The fact that this sequence is wedge-shaped may indicate that the basin was differentially subsiding during deposition and creating differences in space available for sediments to accumulate. Thus the increase in thickness towards the central parts of the Fingerdjupet Subbasin gives an indication of that the accommodation was greater in this part of the basin at the period of deposition as compared to adjacent parts of the basin. The time-thickness map also gives an indication of that a depo-center was moving towards the south during this time period, implying that the main depo-center changed from being located in the northern and central parts towards the southern and central parts of the Fingerdjupet Subbasin (Figure 3-13d to 3-14d).

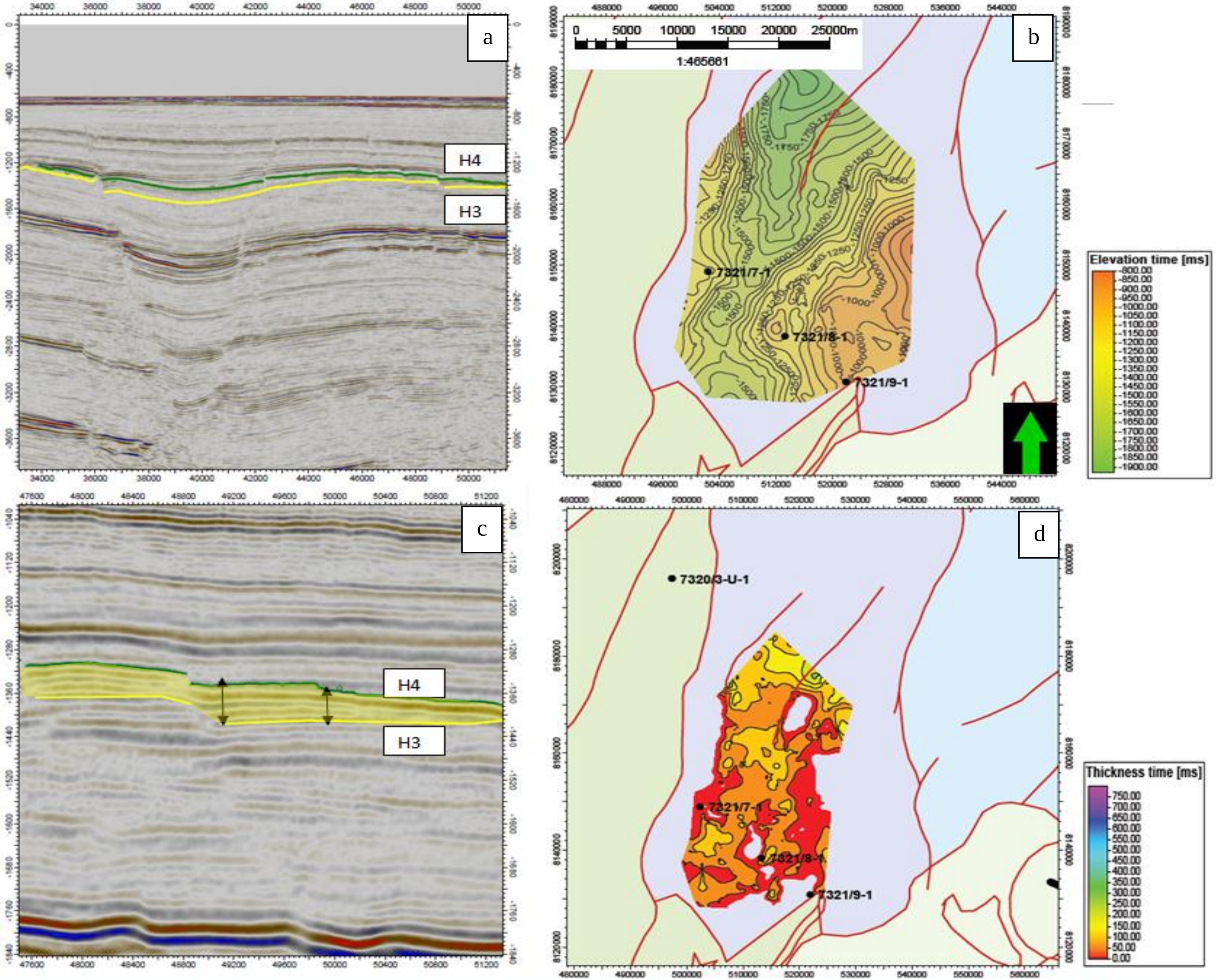


Figure 3-14: Sequence 2.3. (a) Thickness variation towards the depo-center. (b) Surface map of H3 (c) Pinch-out towards the east. (d) Time-thickness ma

Lower Cretaceous sequence 2.4

Description

The Lower Cretaceous sequence 2.4 is also one of the sequences which pinches out and is only found in the deepest part of the basin and in the hanging-wall of the faults located in the basin. It is not present in the whole study area but is generally observed towards the southern part of the Fingerdjupet Subbasin at the base of the Loppa High, and in the central part of the subbasin where the depo-center of the Fingerdjupet Subbasin had its largest lateral extent at this time (figure 3-15).

The base reflector is the positive reflector of the characteristic band mentioned in the sequence 2.3 displayed in fig 3-15, and the top boundary of the sequence is the reflector interpreted as the Intra Aptian reflector (H5) described in earlier chapters. The sequence tends to pinch out at structural highs and towards basin margins and it laps onto the Intra Aptian reflector (H5). The sequence is laterally most extensive in the area near the Loppa High and north in the central basin and thins out towards the north-east and the structural high that separates the Fingerdjupet Subbasin from the western part of the Bjørnøya Basin. In addition to the onlapping reflectors there are no internal structures observed in sequence 2.4. The strength of the base reflector seems to change through the study area. This can especially be observed in line 4 (figure 3-9a). Figure 3-15 displays that the largest depo-center of this sequence is located towards the Loppa High and as on-lapping units onto the structural high described above formed by basin inversion.

Interpretation

Since the sequence 2.4 occurs in the hanging walls of the basin faults and the main depo-centers of the Fingerdjupet Subbasin this indicates that the sequence is syn-tectonic, formed during an active stage of faulting and formation of accommodation in the central part of the basin. The wedge-shaped geometry of the sequence is the clearest sign of the syn-tectonic deposition. The pinching out of the sequence towards nearly all structural highs indicates that these highs were present when sequence 2.4 was deposited.

The change in reflector strength throughout the area can be a result of internal facies changes, including grain-size variations in the sediment-package of the sequence 2.4. It is reasonable to believe that the change in acoustic impedance observed in the seismic data could be due to textural differences in the sediments. As also mentioned above an explanation for this could be influx of some especial debris eroded from the platform areas in the SE, since the sequence appears to have its widest lateral extent at the base of the platform areas. Other explanations can be differential compaction or textural variations as a result of intrabasinal processes, as for example bioturbation or early diagenesis.

The time-thickness map of this sequence indicates that the depo-center that developed in the south at the base of the Loppa High is still present. The map also indicates that a new depo-center at this time started to evolve in the northern part of the Fingerdjupet Subbasin, towards the western margin bounded by the Leirdjupet Fault Complex. In the middle of the basin there seems to be little or no deposition of this sequence, which is supported by the observations from the seismic sections that the sequence is thinning on top of structural highs.

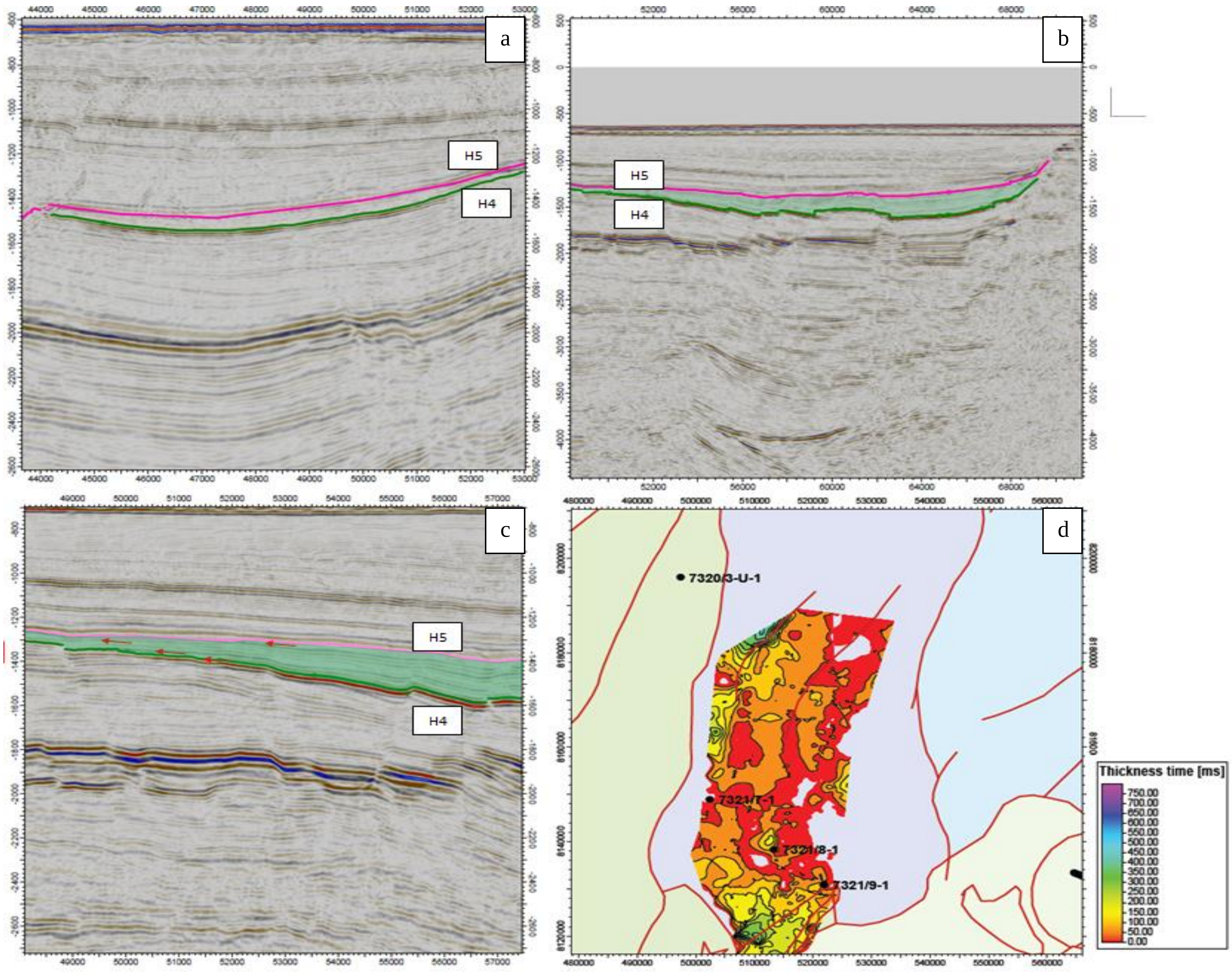


Figure 3-15: Sequence 2.4. (a) Thickness variation towards the depo-center. (b) Depocenter in the south towards the Loppa High. (c) onlap onto the structural high where sequence 2.2 shows a distinct thickening. (d) Time-thickness map

Megasequence M.S.3

The third and last megasequence is also Lower Cretaceous strata but it is above the Intra Aptian reflector. In the Barents Sea most of the Upper Cretaceous and Cenozoic strata are eroded and therefore not present, with exception of the deep basins in the SW Barents Sea. Paleogene sediments were accummulted in most of the area, and then later removed by erosion. Paleogene sediments are found in the deep basins in the SW Barents Sea (Faleide et al., 1993a, Faleide et al., 1993). If these units are correlated with the deep part of the Bjørnøya Basin in the west, there are more preserved strata from the Cretaceous, but still not reaching the Cenozoic.

Megasequence 3 consists of the three Lower Cretaceous sequences 3.1, 3.2 and 3.3, and reaches the Quaternary in the Fingerdjupet Subbasin.

Lower Cretaceous sequence 3.1

Description

Sequence 3.1 is bounded by the Intra Aptian surface at the base and a medium strong reflector at the top. This top reflector is the uppermost of a band of reflections. Some difference in strength of some reflections internally in the sequence 3.1 occurs, especially at the base reflector.

The sequence has its greatest thickness in the northern part of the Fingerdjupet Subbasin and pinches out towards the Loppa High and the Bjarmeland Platform in the south and the east, respectively. Strata being parallel with the horizon 6 (H6) onlap onto the reflector of Intra Aptian (H5) in areas where there are structural highs, faults or platform areas. This onlap can be observed in figure 3-16c.

The faults within the Fingerdjupet Subbasin (described in chapter 3.3.4 about Faults within Fingerdjupet Subbasin) that seem to stop at the base of this package are in some areas connected with a set of scattered reflections above with different orientations than that of the fault plane. The scattered reflections seem to have been initiated at the upper tip line of the already existing faults. These reflections can be observed in figure 3-16b

Interpretation

By observing the time-thickness map made for this sequence it becomes clear that the main depo-center again has shifted from the southern part of the basin back to the northern part of the Fingerdjupet Subbasin (Figure 3-16d). The fact that the sequence pinches out towards structural highs indicate their presence before deposition. The pinch-out of this sequence also indicates that the deposition took place in a tectonically active setting.

The scattered reflections that appears to emerge from the top of the faults located at the central parts of the basin could be interpreted as gas leakage from the existing fault-planes.

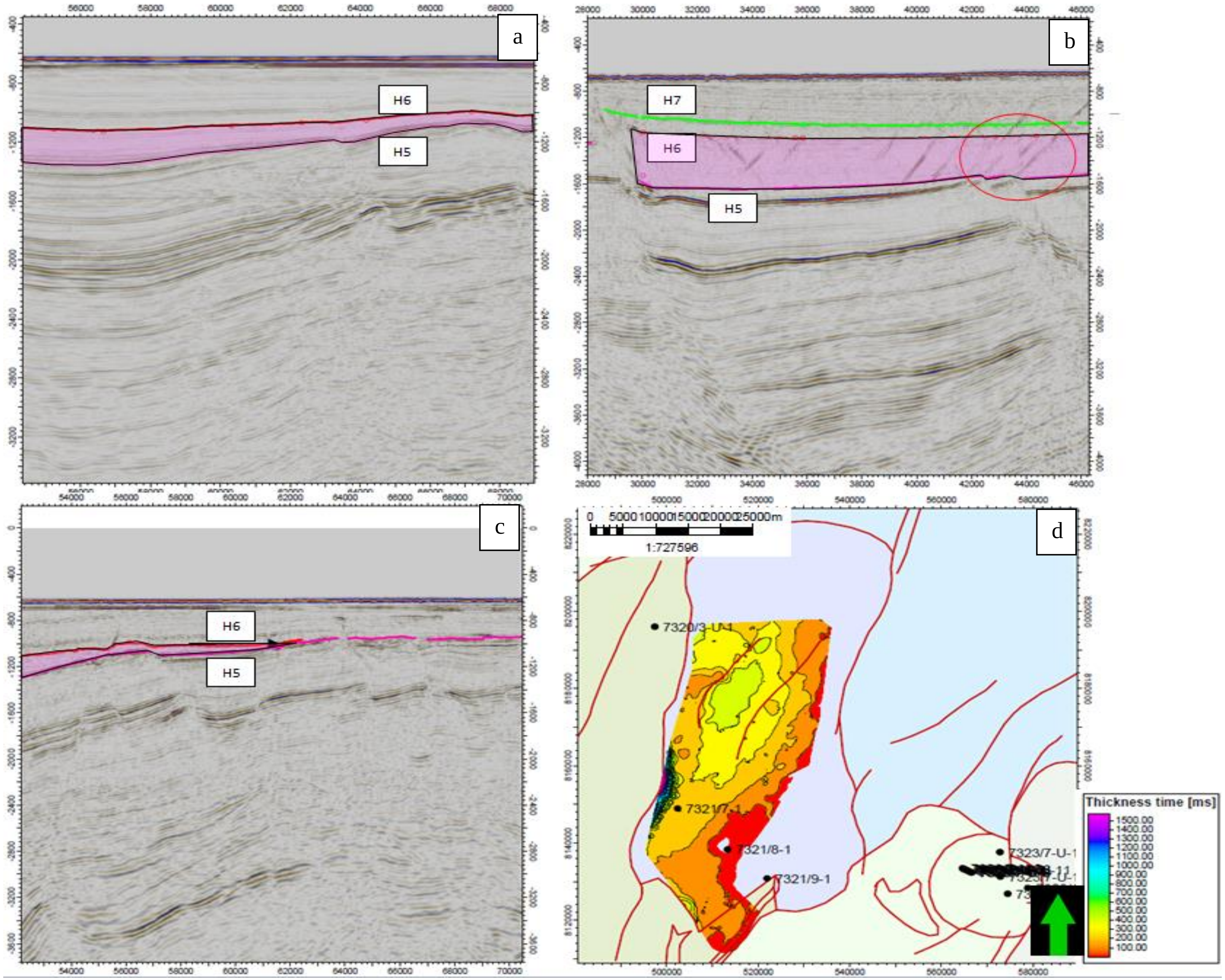


Figure 3-16: Sequence 3.1. (a) The depocenter in the northern part of the Fingerdjupet Subbasin and thinning towards a structural high. (b) Scattered reflections. (c) H5 acting as an onlap surface for the horizon H6. (d) Time-thickness map.

Lower Cretaceous sequence 3.2

Description

Sequence 3.2 is a very characteristic package with medium amplitude base and top reflectors. The upper reflector is the uppermost reflector of a distinct band of stronger reflections. The sequence is recognized as a consistent thin package with great lateral extent. Both the top and the base reflector are cut by a series of small faults throughout the entire study area. The faults have little or no offset, and no growth pattern has been recorded at the hanging-wall of the faults. The vertical extent of these faults is limited to only this sequence and does not seem to be connected to older fault patterns. The sequence seems to terminate towards the structural highs and onlap onto the Intra Aptian reflector both at the base and at the top.

The time-thickness map shows very constant thicknesses throughout the whole area of interest. The sequence seems to pinch out in the eastern part of the study area. This can be observed in figure 3-17d.

Interpretation

The constant thickness of this package indicates a deposition with little or no tectonic activity. However, the onlap onto structural highs indicates their presence before deposition. The frequent small faults in sequence 3.2 show that some extension has been acting on the sequence and that the package of sediments must have behaved physically brittle, as viewed from the fault pattern. These faults may have been formed just within sequence 3.2 shortly after deposition of the sequence, or they may have originated later by reactivation of older faults. However, the lack of connection between these small faults and older major faults in the basin supports the hypothesis that the faults have been initiated in this particular stratigraphic level, probably shortly after the deposition of the strata of sequence 3.2.

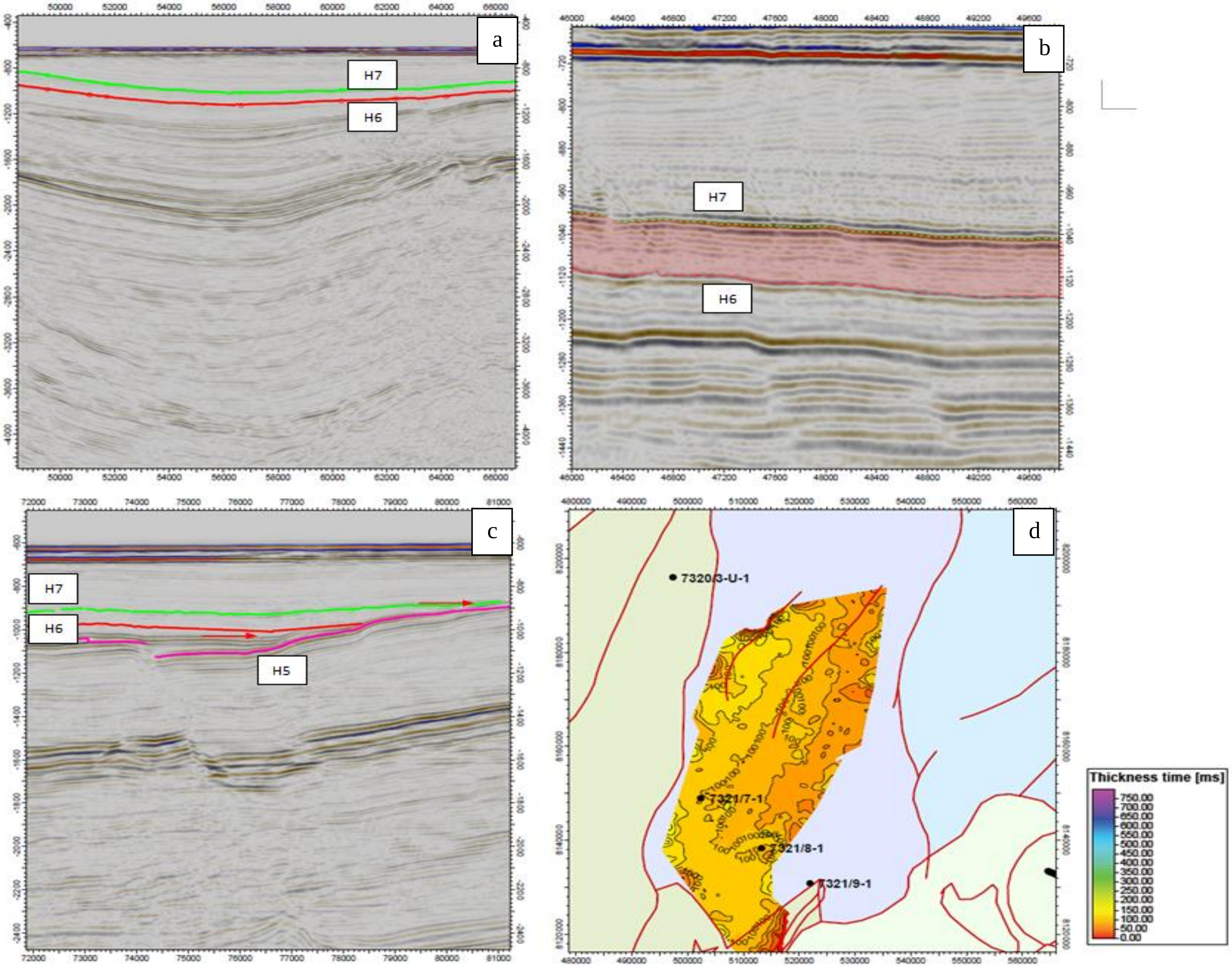


Figure 3-17: Sequence 3.2. (a) Typical geometry of the sequence. (b) The characteristic upper and lower boundary of the sequence. (c) Both the horizon H6 and H7 onlap onto H5. (d) Time-thickness map

Lower Cretaceous sequence 3.3

Description

The lower boundary of the sequence 3.3 is the band of reflections at the top of sequence 3.2, whereas the Quaternary constitutes the present upper erosional boundary. The thickness of this sediment package varies throughout the study area. The sequence is thickest in the southern part of the Fingerdjupet Subbasin, but also in the central parts of the basin there are thick deposits (Figure 3-18). The seismic facies of the sequence varies with change in reflection strength towards the Loppa High and is highly affected by small faulting with little or no offset at a given depth level near the base of the Loppa High. Some downlapping reflections are also observed within the sequence in this area. The main faults in the study area tend to end just above the base reflector of this sequence with some exceptions, so the sequence 3.3 is not highly affected by any faults of significant magnitude.

Interpretation

The sequence 3.3 is a sequence varying in thickness, seismic facies and the degree of tectonic influence. In some areas the sequence appears to be highly affected by small-scale tectonics and deposition, whereas in other areas the sequence appears unaffected by tectonic deformation. The thickness variations again show that the depo-center of the Fingerdjupet Subbasin has changed from being located in the northern parts of the basin to the southern part towards the Loppa High. The variation in seismic facies towards the Loppa High, with some reflections appearing stronger and more pronounced than others, can be a result of varying mineralogical and textural composition of material derived by erosion from the platform area, or be the result of differential compaction and early diagenesis, as mentioned for sequence 2.4.

The downlapping units observed give an indication of that there are sediments coming in from areas outside the basin, and this could also be the cause of the seismic facies changes observed in the same area. The faults that appear do not seem to link up to the major faults of the area and could therefore not be formed by reactivation of older faults. The fact that the faults appear mostly in the area with a change in the seismic facies could indicate that these sediments are more brittle than sediments in other parts of the sequence.

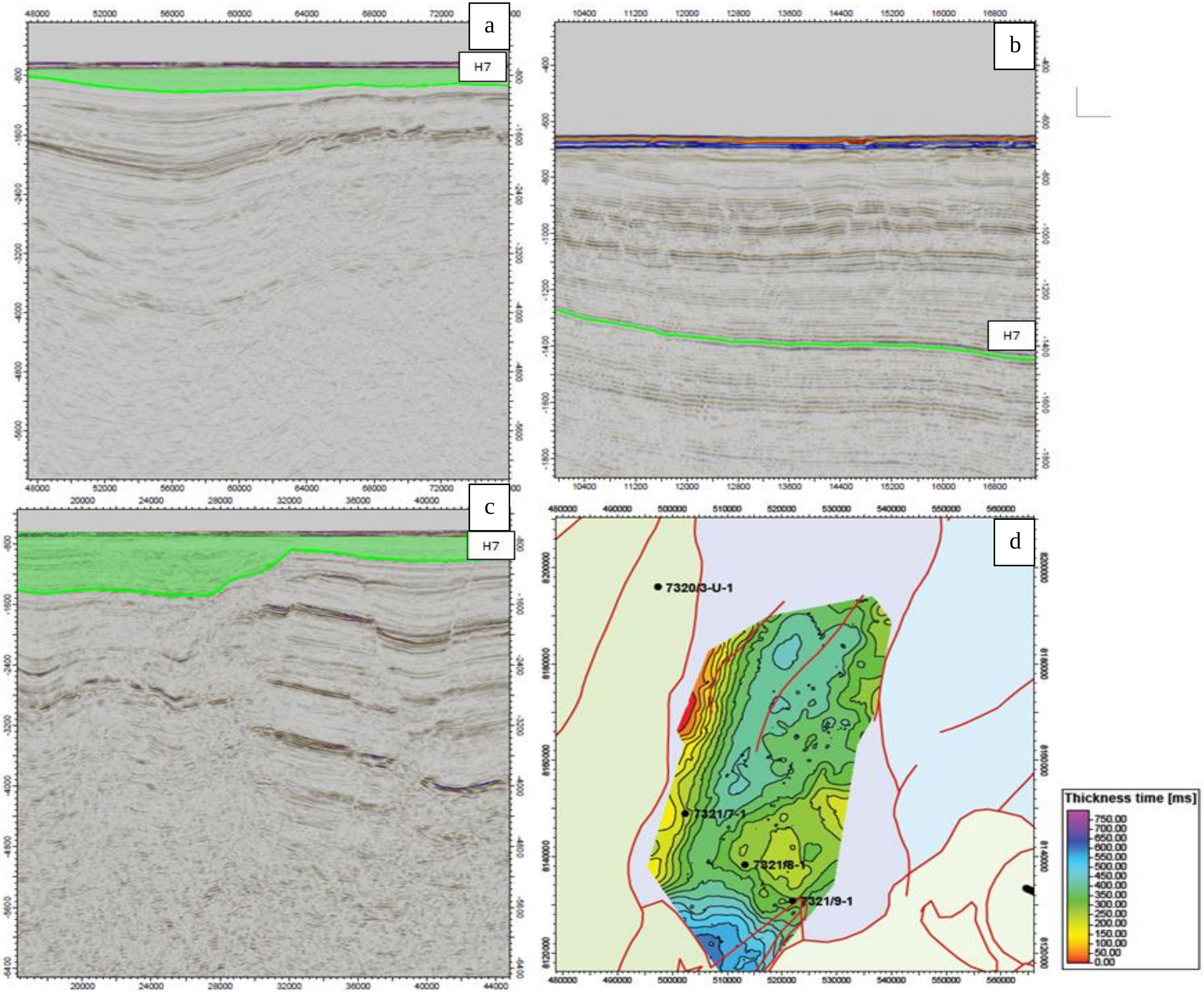


Figure 3-18: Sequence 3.3. (a) Typical geometry of the sequence. (b) Fracture pattern within the sequence. (c) Thickness variation of the sequence from the Fingerdjupet Subbasin down into the Bjørnøya Basin. (d) Time-thickness map.

3.4.3 3D Seismic interpretation

After having interpreted the 2D seismic lines with definitions of horizons and seismic stratigraphic sequences, TGS provided parts of a preliminary 3D cube (fast-track) from the northern part of the Fingerdjupet Subbasin (Figure 3-19). Based on the 3D data the Base Cretaceous Unconformity (H1) horizon was interpreted in great detail to make a surface map displaying the details of the fault network in the area. A dense map with interpretation every 10th line in an east-west and north-south direction was made. The resulting BCU surface (H1) is shown in figure 3-20.

The difference in morphology and details of the BCU surface (H1) made from the 3D cube and the same surface obtained from the 2D data is significant. These two sets of the BCU can be seen in figure 3-20. Due to constrain on time available for this Master thesis project, only the BCU (H1) was interpreted by using the 3D data.

Based on the detailed H1 surface created after interpretation was done of the 3D cube, a fault interpretation of the main faults in the Fingerdjupet Subbasin was made. These faults will be described in chapter 3.3.5 fault interpretation.

The 3D cube were also used to study in collaboration with Dimitriou (2014) if prograding units from the Barents Sea shelf are found in the Fingerdjupet Subbasin This will be discussed in chapter 4.

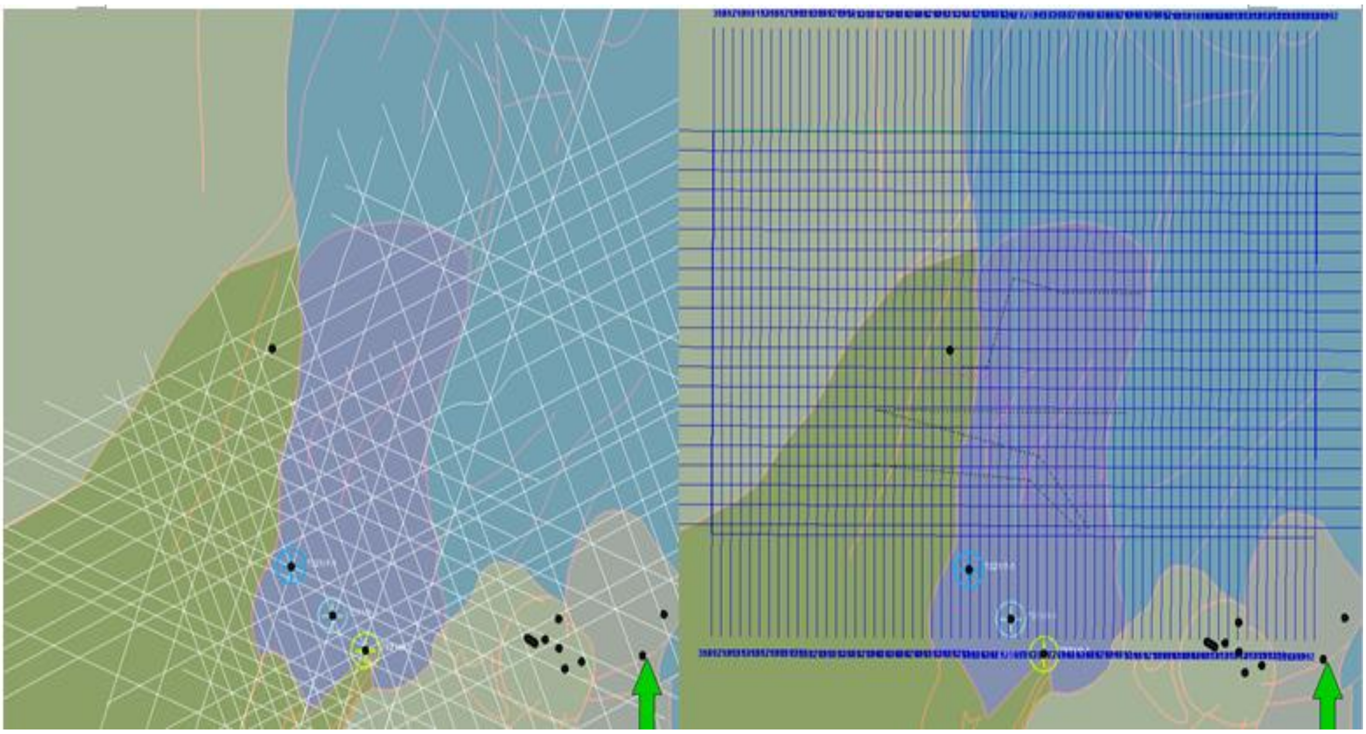


Figure 3-19: To the left the 2D seismic lines located in the Fingerdjupet Subbasin that was used for the interpretation. To the right the area of the 3D cube provided by TGS

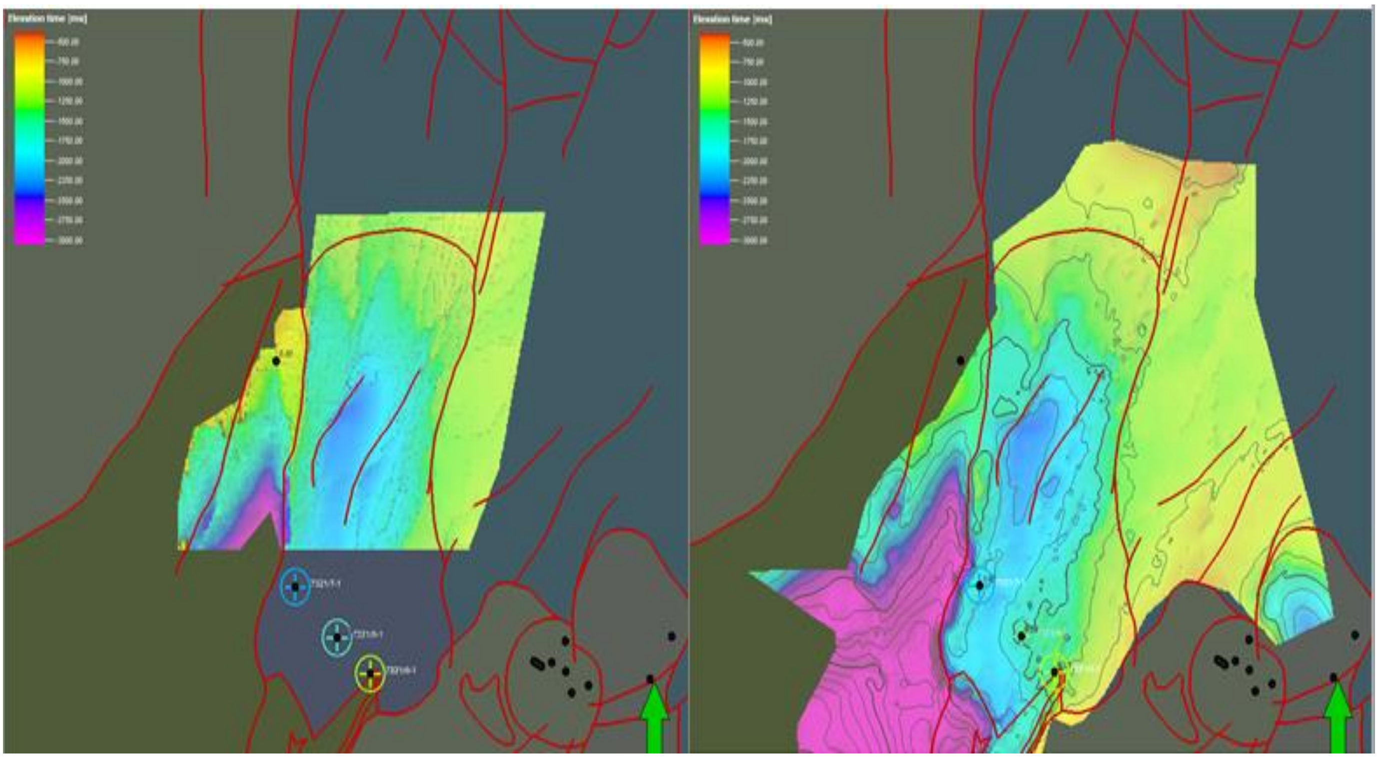


Figure 3-20: The BCU map made from the 2D data (left), and the 3D data (right).

3.4.4 Fault interpretation

The Fingerdjupet Subbasin is defined, as mentioned in chapter 2, by Gabrielsen et al. (1990) as the eastern part of the large Bjørnøya Basin. The Fingerdjupet Subbasin is to the west bounded by the Leirdjupet Fault Complex and to the south and east by the Loppa High and the Bjarmeland Platform, respectively (Figure 3-21).

Figure 3-21: Structural map of the study area. The bounding fault complexes to the Fingerdjupet Subbasin are observed (NPD, 2014).

Within the basin itself there are several major and minor faults. A map of fault traces projected on the BCU (H1) obtained from the 3D survey was made. This can be observed in figure 3-22. Before the 3D cube became available a set of 2D lines where manually interpreted with focus on the fault patterns. One of these lines is presented (figure 3-23) to determine the geometry at depth of some of the faults.

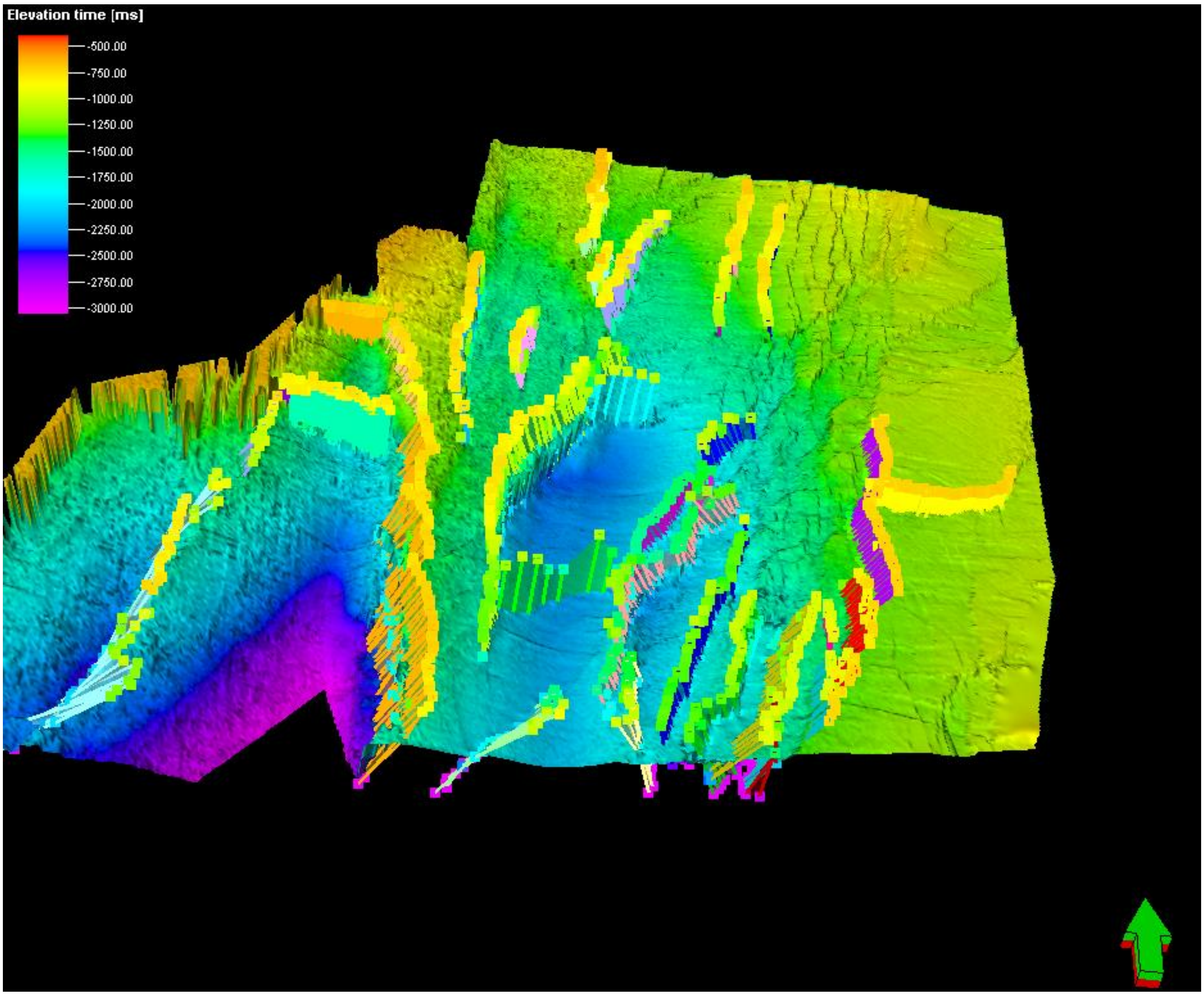


Figure 3-22: Interpreted faults projected on the near BCU horizon from the 3D data cube.

The faults, defining the boundaries of the Fingerdjupet Subbasin (Gabrielsen et al., 1990) and the other fault complexes of the study area will be described below, and afterwards some key faults within the basin will be given names and described.

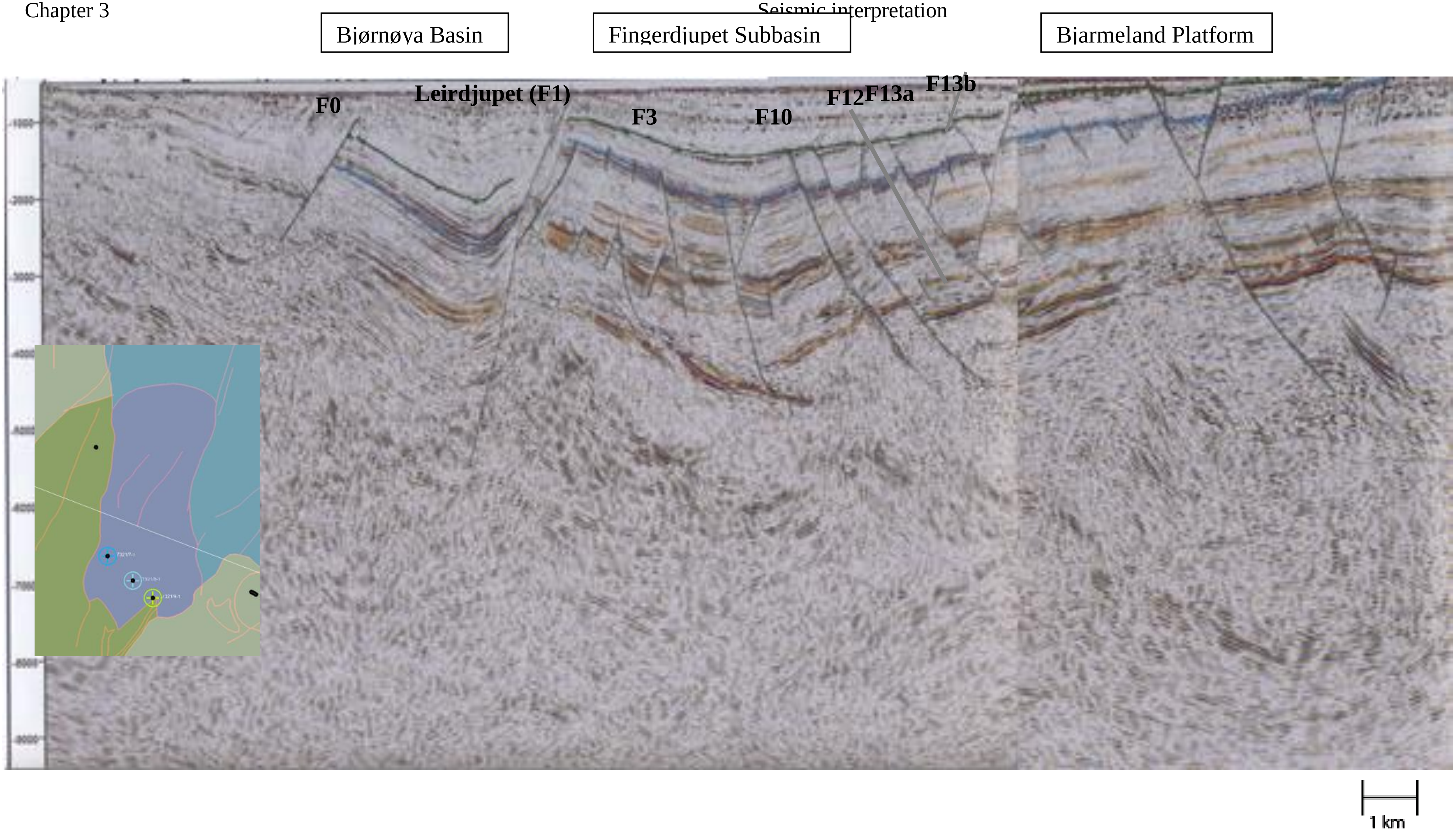


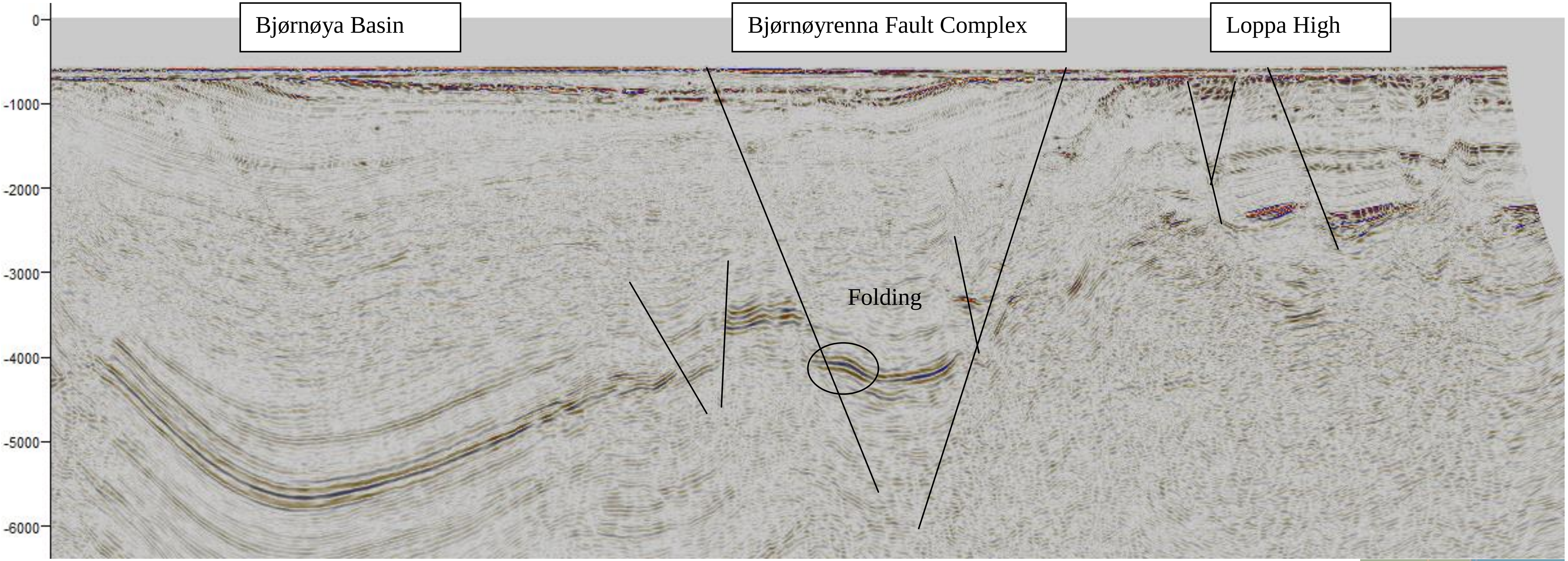
Figure 3-23: Seismic line displaying how the faults behave in the depth around the Fingerdjupet Subbasin. The faults seem to detach at a certain level. The bounding faults and the faults within the Fingerdjupet Subbasin appear to be reactivations of older faults (Permian?)

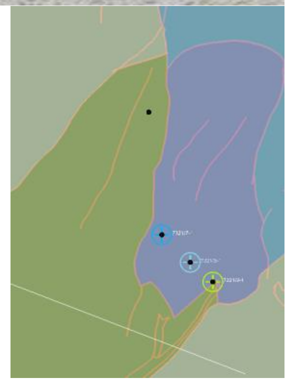
Bounding Fault Complexes

Northern part of the Bjørnøyrenna Fault Complex

Description

The southeastern boundary of the Fingerdjupet Subbasin is formed by the northeasternmost part of the Bjørnøyrenna Fault Complex. The lateral extent of the fault trace, measured perpendicularly to the main strike direction of the fault zone, is about 1 km, starting in the Fingerdjupet Subbasin and ending on the Loppa High; there are variations from the north to the south. Due to the erosion of the Loppa High the age of these faults are difficult to determine and also the amount of throw is difficult to determine. The throw of the faults seems to be varying with depth. The faults do not seem to have a preferred polarity and appear as a mixture of synthetic and antithetic faults. The Bjørnøyrenna Fault Complex is trending NE-SW and is dominated by normal faults with large throws. The throw of the fault complex as such however, seems to be decreasing towards the north, where the Fingerdjupet Subbasin is located. This fault complex also seems to have larger throws in the older strata around Base Cretaceous than the younger strata above Aptian. An example form the data of the Bjørnøyranna Fault Complex is seen in figrure 3-24. Folding structures are observed.





Figur 3-24: 2D seismic line displaying the northern part of the Bjørnøyrenna Fault Complex. Possition of the 2D line can be seen in the small picture attached as the white line. The background map of that figure is from NPD (2014).

Interpretation

The faults in the northeastern part of the Bjørnøyrenna Fault Complex show clear evidence of reactivation of the faults. The hypothesis of reactivation is based on the observations of throw differences in the seismic section, where the older strata can have experienced larger throws than the younger strata, and also wedge-shape in relation to the fault planes. Holdsworth et al. (1997) established a set of criteria of four groups of physical properties of faults in order to recognize reactivation of the faults. The four groups are stratigraphy, structural geology, geochronology and neotectonism. In this thesis the stratigraphical criteria have been used to recognize reactivation (figure 3-25).

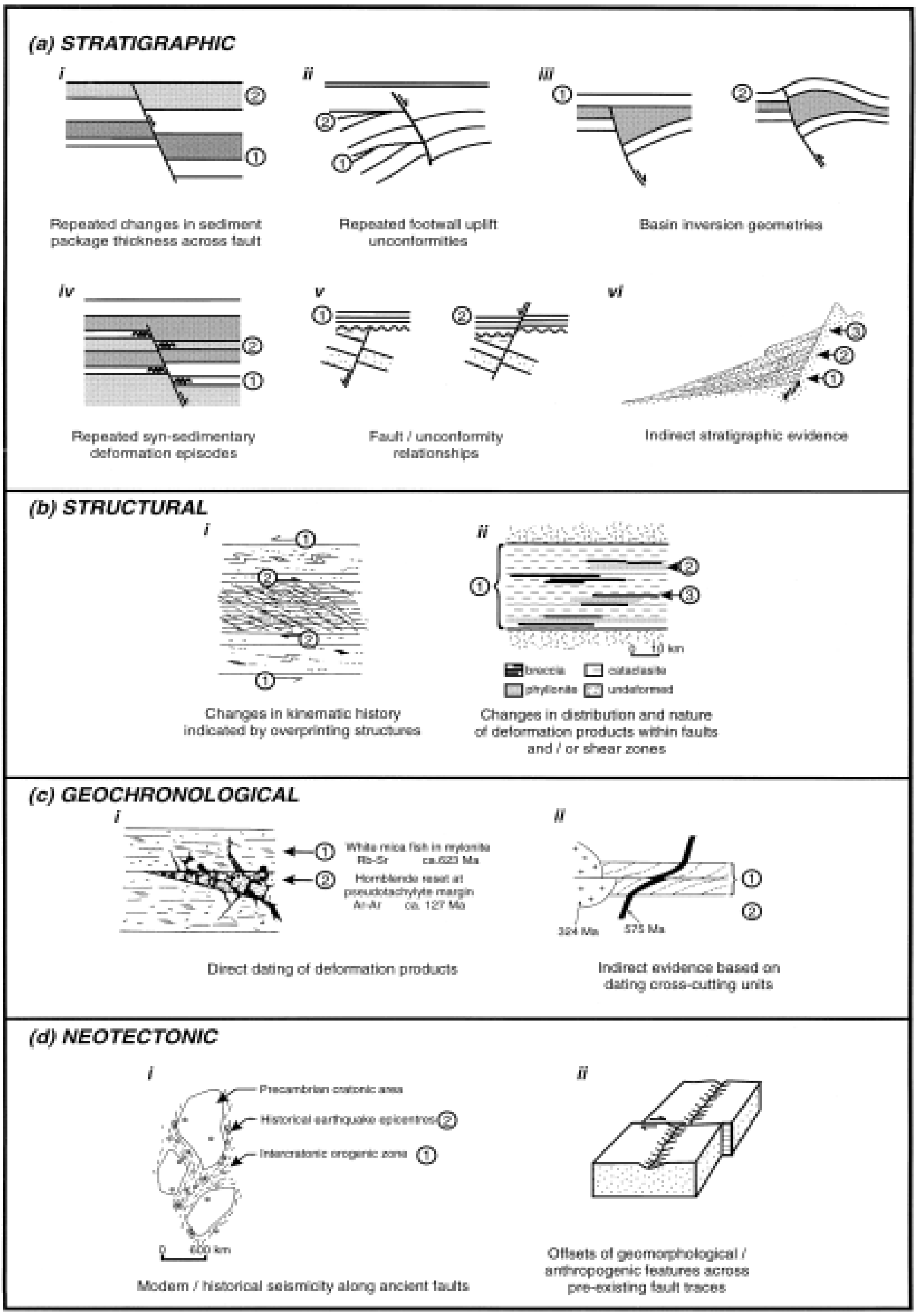


Figure 3-25: Stratigraphic criteria's to determine reactivation of faults within the study area (Holdsworth et al., 1997).

The fault zone between the Fingerdjupet Subbasin and the Bjarmeland Platform

Description

This Fingerdjupet Subbasin is towards the east bounded by a fault zone, separating the Subbasin form the Bjarmeland Platform (figure 3-27). This fault zone consists of NNE-SSW trending faults. The faults seem to be dipping towards the east, while at one point the dip direction changes and the faults seem to have a preferred dip direction towards the west. This could be interpreted as a horst and graben system with several faults.

Individual faults within the fault zone seem to be mostly synthetic, but with some exceptions. The throw of the faults seem to be largest in the oldest strata: however, the displacement is significant both in young and older strata. The age of displacement along these faults is hard to determine, since the fault planes appear to go all the way up to the seafloor; and as mentioned earlier, most of the Cretaceous strata have been eroded. The frequency of faults within the fault zone tends to increase towards the northern part of the Fingerdjupet Subbasin, and the throw of the faults also increases in the same direction. Towards the south more of the Cretaceous strata are preserved.

In the northern part of the fault zone along the eastern part of the Fingerdjupet Subbasin there is also a set of faults trending E-W. These faults appear to have smaller offsets than the NNE-SSW running faults. They can be associated to the feature described in sequence 3.1 with the scattered seismic reflection features that rise upwards from the tiplines of faults. These faults seem to be older than the NNE-SSW faults since the latter faults appear to terminate against the faults with E-W direction (figure 3-26), or they could offset the NNE-SSW trending faults. The specific age of these faults is just as the other fault pattern difficult to determine due to erosion.

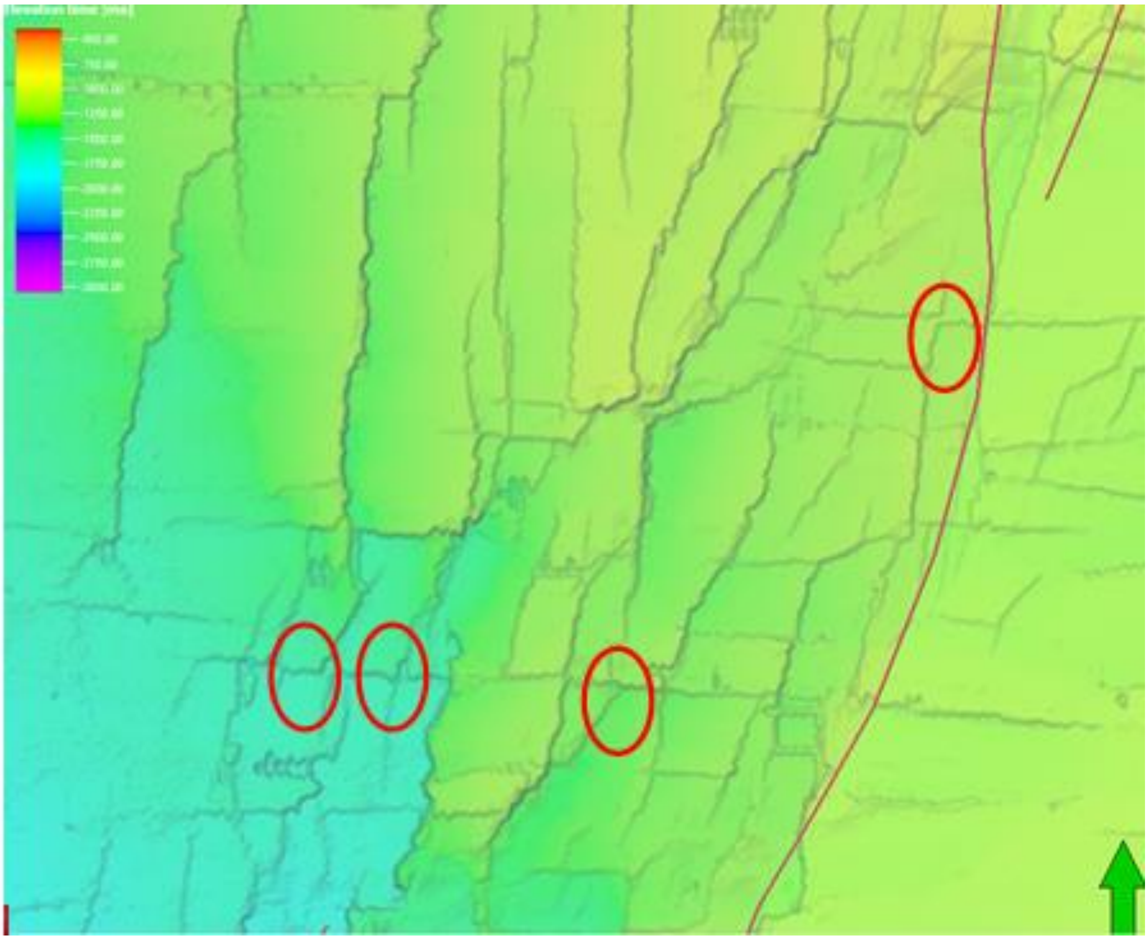


Figure 3-26: Fault patterns west of the Bjarmeland Platform and east of The Fingerdjupet Subbasin. The faults trending N-S appear to be terminated or offset by the faults that are trending E-W.

Interpretation

This fault zone between the Fingerdjupet Subbasin and the Bjarmeland Platform shows evidences of reactivation during several stages for the fault patterns observed. This interpretation is based on the difference in throw and observation of wedge-shape in relation to the faults through the Cretaceous strata. The fact that there are two sets of fault pattern with completely different directions also gives an indication of that there are at least two different stress regimes that have been in this part of the study area during the same period of time. The fact that the faulting is most extensive in the north may indicate that the stress has been greater in this area then in the southern part of the fault complex.

Leirdjupet Fault Complex

Description

As described earlier, the Leirdjupet Fault Complex is the fault complex that separates the Fingerdjupet Subbasin form the deep, western part of the Bjørnøya Basin. The Leirdjupet Fault Complex is characterized by one single fault in the south with large throw; towards the northern part it splits into several smaller faults with decreasing throw. The Leirdjupet Fault Complex trends N-S and consists mainly of normal faults. The faults of this fault complex also have different throws with depth, and the youngest tectonic phase of the Leirdjupet Fault Complex is not determined because of later uplift and erosion of the area. The polarity of the fault is synthetic faults. The Leirdjupet Fault Complex shows signs of transpressional stresses with small folding structures close to the master fault. Also a wedge-shaped in the hanging-wall of the Leirdjupet Fault Complex is observed. When moving northwards the fault throw gets smaller and the wedge can be correlated to be of Aptian age.

Interpretation

The Leirdjupet Fault Complex has clearly been active during several stages, and Gabrielsen et al. (1990) suggested that the main phases of movement was (Early?) Carboniferous, Mid Jurassic and Early Cretaceous but later studies of the area has proven that there are several important phases of rifting (Late Permian) in addition to what Gabrielsen et al. (1990) described, this including (Faleide et al., 1993, Gudlaugsson et al., 1998, Gabrielsen et al., 1997, Bjørnestad, 2012). The folding structures observed are documented by previous authors like (Bjørnestad, 2012, Gabrielsen et al., 1997).

Faults within the Fingerdjupet Subbasin

Within the Fingerdjupet Basin there are several major and minor faults that seem to have been active and influencing both the formation and configuration of the basin. These faults will be described and given name codes according to observations and interpretation of the 2D lines and the 3D data. Three arbitrary lines were generated to show the faults in the Fingerdjupet Subbasin. The position of the lines can be seen in figure 3-27 together with the fault codes.

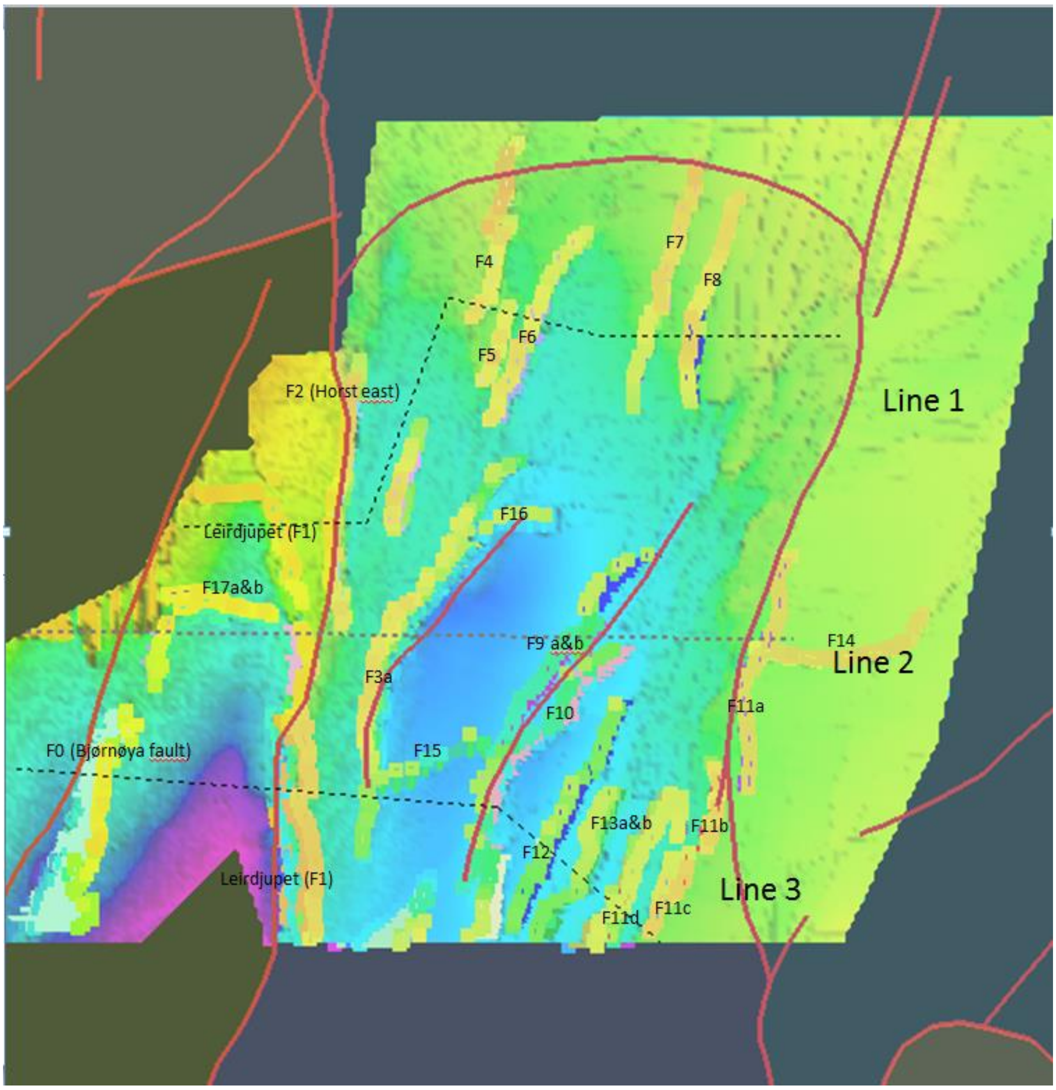


Figure 3-27: Position of the arbitrary lines, and the coding of the interpreted faults.

The faults have been numbered and named, ranging from F0 to F17, and synthetic and antithetic faults, and faults segments of one fault have been given additional names with letters a-d.

In table x a brief description of the chosen faults will be given.

Table 3-2: Table with description of all the faults interpreted in the Fingerdjupet Subbasin.

NAME	**TREND**	**DISPLACEMENT(ms)**	**HEAVE(m)**	**POLARITY**	**DIP**	**COMMENT**
F0	NNE-SSW	352,6	608,5	Synthetic	West	
F1	N-S	235,5*(line 1)*/436,8*(line2)*/769,3*(line 3)*	943,8	Synthetic	West	Bounding fault Decreases north
F2	N-S	407,7	302,9	Synthetic	East	Increases north
F3	NNE-SSW	478,2*(line 2)/*81,9*(line 3)*	70,1	Synthetic	East	
F4	NNE-SSW	101,7	110,6	Synthetic	East	
F5	NNE-SSW	59,8	34,9	Synthetic	East	
F6	NNE-SSW	114,9	51,3	Synthetic	East	
F7	NNE-SSW	56,9	63,4	Synthetic	East	
F8	NNE-SSW	128,5	31,6	Synthetic	East	
F9a	NNE-SSW	34,36	21,6	Synthetic	East	
F9b	NNE-SSW	71,0	17,4	Synthetic	East	
F10	NNE-SSW	143,2	138,6	Synthetic	East	
F11a	NNE-SSW	126,3	22,2	Synthetic	West	Bounding fault
F11b	NNE-SSW	163,4	101,3	Synthetic	West	Bounding fault
F11c	NNE-SSW	212,5	116,0	Synthetic	West	Bounding fault
F11d	NNE-SSW	45,6	50,6	Antithetic	East	Bounding fault
F12	NNE-SSW	85,8	75,2	Synthetic	East	
F13a	NNE-SSW	205,8	205,8	Synthetic	East	
F13b	NNE-SSW	46,8	115,2	Antitheic	West	
F14	E-W	28,6	20,7	Syntheic	South	
F15	E-W	29,4	20,7	Synthetic	South	
F16	E-W	125,2	186	Synthetic	South	
F17a	E-W	86,0	220,2	Synthetic	South	
17b	E-W	124,9	172,6	Synthetic	South	

Most of the faults in the area seem to have been active during several stages. The east-west faults, however, show a smaller difference in offset with depth than the NNE-SSW faults (Table 3-3). By looking at the three arbitrary lines made (figure 3-28), the cut-off of the seismic cube in some areas prevents the possibility to see where the base of the faults are, but some of the faults seems to start at a distinct level below a very characteristic set of reflectors at around 2500 ms to 3000 ms. The bounding faults and some of the faults within the Fingerdjupet Subbasin tend to be deeper and detach at a certain level, based on the detailed study of the 2D seismic lines a manual interpretation was done on the faults. The 2D line presented indicate that a lot of the faults within the Fingerdjupet Subbasin that are described above can be linked to old structural elements of Permian age, and that these faults detach at a certain level at between 4000ms and 4500ms (Figure 3-23).

What is also observed in the Fingerdjupet Subbasin related to the faults in the western part is small scale folding structures. These structures appear in relation to the faults existing, both within and the bounding faults, and are usually observed in the whole Early Cretaceous strata.

The heave and the displacement of the faults are measured, but this thesis work is not based on a displacement or heave analysis so the numbers are just measurements at one place of each of the faults in a seismic section. The displacement is measured to give an idea of the vertical size of the fault, and the heave is to indicate how much extension this area has underwent.

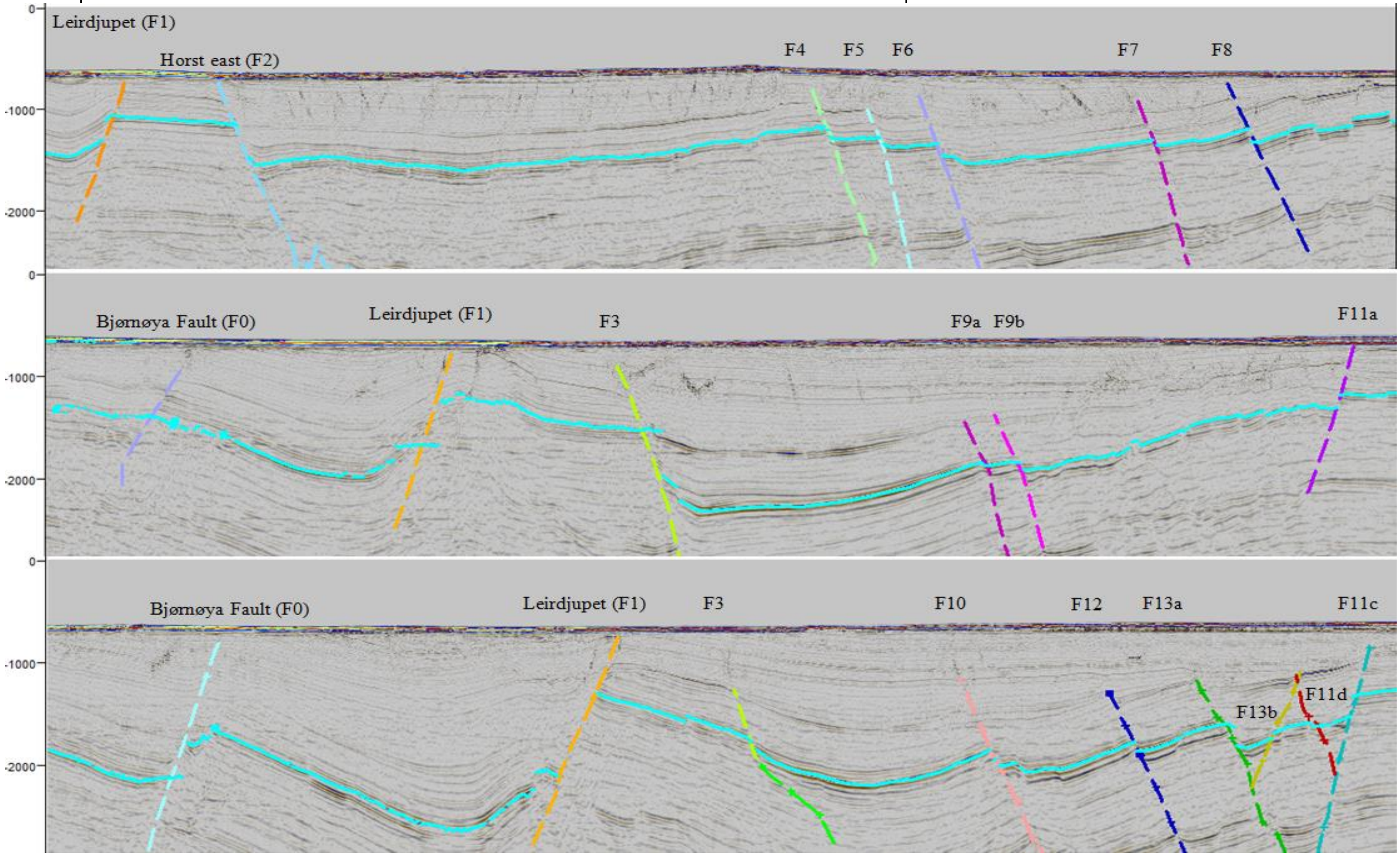


Figure 3-28: Three arbitrary lines through the 3D seismic data. The uppermost line represents line 1, the middle line represents line 2, and the lower seismic section represents line 3. The blue horizon represents near base Cretaceous.

4 Discussion

This chapter is a discussion of factors that have controlled formation and sediment infill of the Fingerdjupet Subbasin, based on results from the previous chapter. As pointed out in chapter 2, regional framework, the Fingerdjupet Subbasin was formed by tectonic activity in Early Cretaceous as part of the Bjørnøya Basin. This chapter will be divided into three main elements: 4.1 Principles of basin formation and basin infill geometry; 4.2 Infill history, and controlling factors of sedimentation in the Fingerdjupet Subbasin; and 4.3 The development of the Fingerdjupet Subbasin in a regional setting.

4.1 Principles of basin formation and basin infill geometry

Depositional basins are formed in a great variety of plate tectonic settings. The sedimentary facies and depositional geometry and sequence stratigraphy of basin infill successions are controlled by tectonics, eustacy and sediment supply, all factors combined in a three-dimensional distribution of rate in creation of accommodation (A) and rate in sedimentation (S). The depositional geometry is controlled by the ratio A/S, and how this changes in time and space (Allen and Allen, 1990).

Accommodation is the space available for sediments and is the sum of regional and tectonic subsidence, eustacy and compaction. Some of the mechanisms controlling the subsidence are crustal thinning, mantle-lithospheric thickening, sedimentary and volcanic loading, tectonic loading, subcrustal loading, asthenospheric flow and crustal densification (Ingersoll, 2012). According to the spatial distribution of accommodation and rate and type of sedimentation, the resulting depositional architecture may be aggradational, progradational or retrogradational. This can take place on various scales, from the scale of shoreface or delta well below seismic resolution to the scale of platforms and shelves with thickness well above seismic resolution (Helland-Hansen, 2010). The depositional architecture may be recognized by various internal reflection configurations of seismic stratigraphic sequences and reflection terminations at the sequence boundaries (Mitchum et al., 1977)

Mitchum et al. (1977) stated that the overall geometry of a seismic stratigraphic sequence can be like a sheet, sheet drape, wedge, bank, lens, mound, fan and various fill types of channels, troughs, basins and slope fronts. According to this classification and terminology the geometry of the sequences in the Fingerdjupet Subbasin (chapter 3) can be classified as sheet, sheet drape, wedge and lens.

Wedge-shaped deposition close to faults means that there has been deposition of sediments on the hanging wall of the fault at the time the fault was moving, creating a greater amount of accommodation space close to the fault, resulting in a depositional unit that looks like a wedge thickening towards the fault.

An aggradational unit implies a depositional unit that filled up the accommodation space made by faults or just by basin-wide subsidence, sediment loading and/or compaction. Aggradational units are defined by vertical stacking of seismic facies and may reveal onlap configuration on the basin margins.

A unit that has been deposited by vertical settling of fine particles out of suspension may in the seismic section be characterized by parallel reflections. The deposition of these types of sediments needs accommodation to be preseved, formed by tectonic subsidence or eustatic rise in sea level, but not necessarily specific depocenters formed by subsidence from tectonics or differential compaction.

A progradational unit implies that the water depth must have been significant at the onset of basin infill from one or several basin margins; there was accommodation space from the beginning of the sediment progradation. In the seismic data such a unit is observed by reflections downlapping onto a surface, forming clinoforms separating individual clinothems of the prograding unit. The topsets of the clinoforms are not always preserved or recognizable, and therefore the lower downlapping surface of the original progradational unit is easier to detect than its upper primary boundary.

The figure 4-1 below shows a simplified sketch of the depositional styles described above.

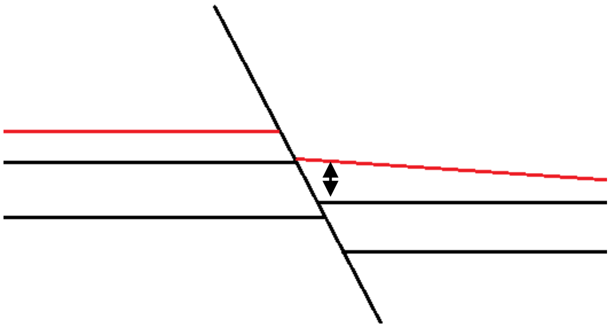
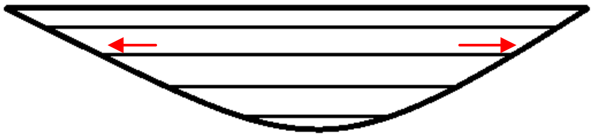
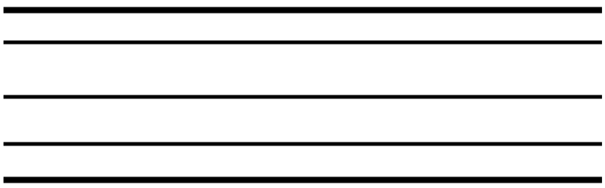
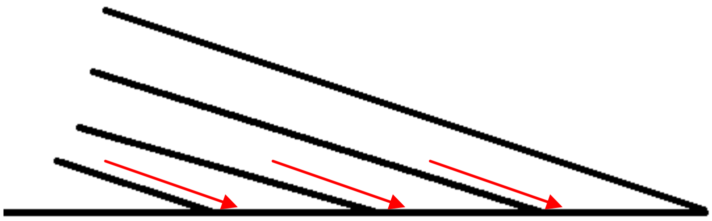
Wedge-shape	
Aggradation in basin with depocenter	
Suspension and aggradation in basin without any specific depocenter	
Progradation	

Figure 4-1: Simplified sketches of the depositional styles observed in the Fingerdjupet Subbasin.

4.2 Infill history and controlling factors of sedimentation in the Fingerdjupet Subbasin

The first step to establish the stratigraphic framework of the Fingerdjupet Subbasin was to identify and interpret depositional units based on the seismic data available. The seismic reflection pattern was used to interpret internal layering and characteristics of the individual units presented in chapter 3.3.2 Megasequences. On the basis of seismic facies and external form the eight seismic sequences were distinguished. The sequences of the Fingerdjupet Subbasin show long-term aggradational patterns, with some progradational units in distinctive sequences. The eight sequences will be discussed separately under the three sub-chapters 4.2.1 to 4.2.3, each subchapter discussing the three megasequences in which the sequences are organized.

4.2.1 Megasequence M.S.1

Sequence 1.1

The first sequence interpreted in the Fingerdjupet Subbasin has a relatively constant thickness throughout the whole study area (varies between about 50-150 ms) and thus reveals a sheet-like overall geometry. This is an indication of that the sequence was deposited prior to the event of tectonic extension that created subsidence and formation of the Fingerdjupet Subbasin as a depocenter of its own. The lack of wedge-shaped units close to faults, both the bounding fault complexes and the faults within the Fingerdjupet Subbasin, indicates that this was a calm period tectonically with regional subsidence in this part of the Barents Sea.

The fact that the sequence appears uniform at the time of deposition with little seismic facies variations suggests that the sediments were deposited by suspension in a basin with little or no relief, and that the faults did not play a significant role in establishing local accommodation at this time.

4.2.2 Megasequence M.S.2

Sequence 2.1

The oldest part of sequence 2.1 appears to be deposited under the same circumstances as sequence 1.1. However, further up in this sequence the internal reflection pattern seems to change from the relatively flat characteristics of the pre-tectonically controlled deposition of sequence 1.1 and the lowest part of sequence 2.1 (2.1a) to a wedge-shaped unit. This wedge-shaped unit reveals a distinctive thickening towards the central part of the Fingerdjupet Subbasin. This part of the Fingerdjupet Subbasin is thus recognized as the first depocenter of the subbasin. The change in sequence 2.1 from a relatively flat unit with mainly constant thickness to a sequence with lateral thickness variation and wedge geometry in the hangingwall of the faults indicates the onset of a localized subsidence and faulting. This stage represents the onset of the formation of the Fingerdjupet Subbasin. The subsidence pattern revealed by the geometry of sequence 2.1 may thus reflect the initiation of a new phase of crustal extension in this part of the western Barents Sea. The presence of wedge-shaped deposits in the hanging-wall of the faults within the Fingerdjupet Basin in the upper part of sequence 2.1(2.1b), indicates that the faults were moving and creating accommodation space for sediments to accumulate near the fault planes.

Since sequence 2.1 has different depositional style in the lower (2.1a) and upper part (2.1b), it is reasonable to believe that there has been a change in the depositional system. The lowermost part is aggradational, implying that a regional subsidence must have been present at the time of deposition of sequence 2.1a. The uppermost part of sequence 2.1 is also dominated by aggradational deposition pattern, but wedge-shape geometries related to the hangingwall of the faults in the Fingerdjupet Subbasin indicate that there has been an onset of a new extensional stress regime at this time (Early Barremian). This means that when sequence 2.1b was deposited there was first a phase of subsidence with no fault activity and somewhere within sequence 2.1b there has been a tectonic event that reactivated the faults present in the Fingerdjupet Subbasin. This interpretation fits well with that the Leirdjupet Fault Complex was active at this time, and that the footwall of the main fault was uplifted; the accommodation created could thus explain the small clinoforms observed at the base (2.1a) of the sequence.

By studying the upper and lower surface, and the time-thickness map of sequence 2.1, the location of the depocenter at this period (Early Barremian) is obvious. The depocenter is most prominent in the northern part of the Fingerdjupet Subbasin, but there is also a smaller depocenter located at the southern part near Loppa High. However, the depocenter observed in the south appears as a result of a later subsidence (Aptian sequence 2.4) in this part of the subbasin because the sediment-package seems to be thinner in this area than in the central parts of the northern depocenter. This thickness variation of sequence 2.1 (figure 3-12c) indicates that there was less accommodation available for sediments to fill in here in the south, and therefore, it is possible that this southern area started to subside later than in the north. However, the thickness distribution of sequence 2.1 is in favor of that the Fingerdjupet Subbasin in this early stage was one continuous depositional area and not separated in two basin lows.

Sequence 2.2

Based on the description of sequence 2.2 from the results chapter 3, this sequence is mainly an aggradational sequence. No wedge-shape is observed in relation to the faults of the Fingerdjupet Subbasin. However, at the base of this sequence a set of prograding units from the north appears as infill of the basin. The clinothems appear to be downlapping onto the bounding surface of this unit and show where the northern depo-center was located. The sequence does not appear to thicken towards the faults, giving an indication of that the tectonic activity recognized in sequence 2.1b was over. In this respect, the sequence appears to be a post-tectonic depositional unit, deposited while the Fingerdjupet Subbasin was still subsiding. If this subsidence is a result of the tectonic event described as having been active during depostion of sequence 2.1, or the result of crustal cooling of previous extensional activity is not possible to determine. It is probably a result of both cases. A regional subsidence could have contributed to this subsidence, and it will be discussed in chapter 4.3.

When identifying the depocenter of this unit by looking at thickness variations it becomes clear that what appears as a structural high in the seismic data set (figure 3-13b), could have been a previous sink for sediments. Sequence 2.2 appears to be thicker at the top of this structural high than in the rest of the Fingerdjupet Subbasin, thus giving room for the idea that this could be a basin inversion or that a transpressional force has been acting on the subbasin. This thickness change appears in the southern part of the Fingerdjupet Subbasin but further west of the foot of the Loppa High.

Sequence 2.3

Sequence 2.3 is one of the smallest sequences in terms of thickness and lateral extent, in the Fingerdjupet Subbasin. The sequence 2.3 appears as being a sequence where the deposition style is aggradational, due to the onlap of the sequence towards the basin margins. The horizontal extent of this sequence is smaller than the previous sequences and the onlaps are limited only to the first northern depocenter. This is a good indication of that the basin margins are becoming more defined and that the basin is narrowing down to a smaller area with a less extensive subsidence. The lack of major wedge-shaped deposits close to the faults indicates that there are little or no fault movements at the period of deposition. The depo-center is still located at the northern part of the Fingerdjupet Subbasin.

Sequence 2.4

Sequence 2.4 has many similarities to the previous sequence; however, this sequence is at its thickest and acts as an aggradational unit in the southern part of the Fingerdjupet Subbasin, near the Loppa High. This indicates that the depocenter within this time interval was in a process where it changed from the northern part of the Fingerdjupet Subbasin to the southernmost part. This interpretation is done based on the thickness differences within sequence 2.4. In the areas where the previous depocenter was located no thickness variation within this sequence is observed, compared to the southern part near Loppa High where onlaps are recorded. This indicates an aggradational depositional style and that the vertical extent is a lot larger than in the other parts of the basin. This change in depocenter can also be observed from the time-thickness map of sequence 2.4 (figure 3-15d)

Somewhere around the boundary between sequence 2.4 and 3.1 there is also a noticeable change in the thickness of the sequences towards the major fault within the Fingerdjupet Subbasin. This may be the indication of a new period of tectonic activity. This sequence represents an intra Aptian sequence.

4.2.3 Megasequence M.S.3

Sequence 3.1

Sequence 3.1 is also an aggradational unit. The main depocenter of this sequence has again shifted to the northern part of the Fingerdjupet Subbasin. The sequence 2.4 filled up the available accommodation space towards the southern part of the subbasin. The subsidence seems to have started again in the northern part as indicated by onlaps of sequence 3.1 towards the basin margins. The sequence seems to be subdivided into two parts, the lowermost (3.1a) being the aggradational unit deposited while the basin was still subsiding, with some wedge-shaped deposits, while the uppermost part seems to have been deposited during circumstances where the tectonically forced subsidence was all done (3.1b). The time-thickness map of this sequence (figure 3-16d) also shows that the majority of the sediments deposited are located in the northern part of the Fingerdjupet Subbasin while the southern depocenter is no longer acting as a sink for the sediments.

Some of the faults observed in the Fingerdjupet Subbasin also seem to end at the base of this sequence. The feature observed as a scatter of reflections that seem to emerge from the top of some of the faults in the area (chapter 3) could be interpreted as gas leakage from the existing faults. The subsidence after the intra Aptian reflector seems to be of a greater scale then the subsidence of the basin before this time, and is a result of the Intra Aptian (around H5) faulting. This statement is based on the thickness variations within the various sequences dominated by aggradation.

Sequence 3.2

Sequence 3.2 is again a sequence that has no evidence of large scale syn-sedimentary tectonic activity or deposition by subsidence driven by local tectonics. However, the sequence hosts many small faults that do not seem to be connected downwards to older faults. The frequent faults within this sequence might indicate that the sediments of the sequence were acting more brittle than the surrounding sediments during extensional stress. The sequence appears as a band of reflections, but it is interrupted by structural highs and therefore onlaps onto these. This is an indication of that some of the areas formed positive reliefs when this sequence was deposited. It is a unit which is most likely deposited by suspension.

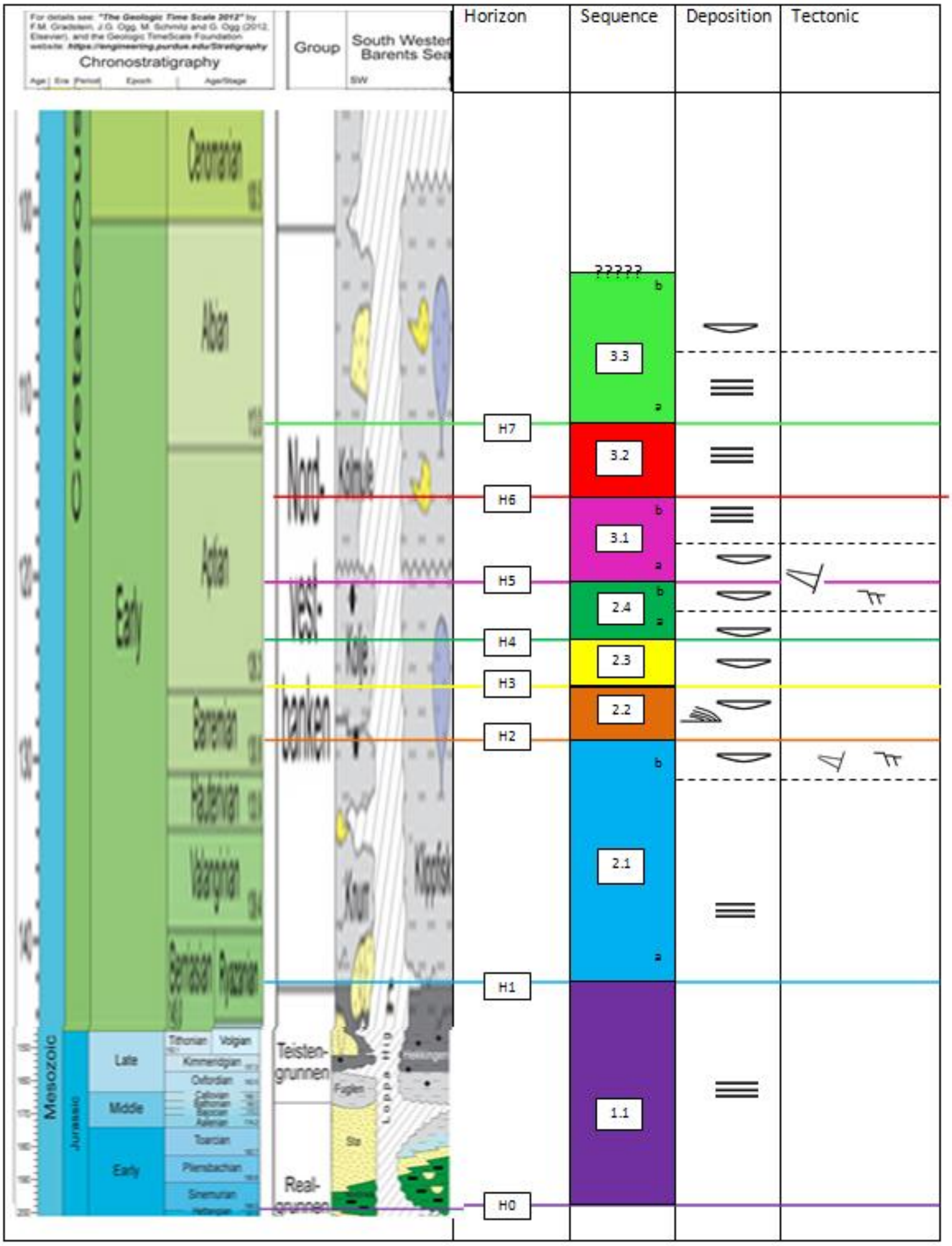
Sequence 3.3

The last of the eight sequences are the sequence going from the top of the sequence 3.2 and all the way up to the Quaternary. This sequence is also changing from, at the base (3.2a), an aggradational unit with indications of having been controlled by intrabasinal tectonic activity, to a relatively flat unit with no signs of tectonic activity (3.2b). The sequence has its greatest thickness towards the southern part of the Fingerdjupet Subbasin and the Loppa High, indicating yet another change in depocenter. The timethickness maps indicate the same, a small depocenter at the northern and central parts of the Fingerdjupet Subbasin, and a greater depocenter in the southern part.

4.2.4 Summary of sequence development

By studying the observations and the interpretations of the sequences it becomes clear that most of the Fingerdjupet Subbasin was filled in by aggradation except for sequence 2.2 which is a set of prograding units and sequences 1.1, 2.4b, 3.1 b, 3.2, and 3.3b where aggradation from suspension seems to have been dominating. There have been two important phases of fault movement, one within sequence 2.1b (Barremian?), and an event in sequences 2.4-3.1 (Aptian). The Fingerdjupet Subbasin has experienced stresses from several directions and the depocenters are probably controlled by the tectonic activity. A summary of the tectonic phases and depostional patterns can be seen in the updated key-figure (figure 4-2).

In the Fingerdjupet Subbasin there is also compression-related structures observed in several of the sequences. This importance of the compression will be discussed further in chapter 4.3. The prograding unit observed in sequence 2.2 will also be adressed in chapter 4.3. The possitioning of the horizons in relation to time are made based on the well tops. The figure 4-2 should be interpreted with caustion and no conclusion should be made directly from this figure based on the unsertainty of the age. The figure gives an indication of the main trends within each sequence and is a summary of the interpretation of the sequences in chapter 4.2 and the description in 3.4.2.



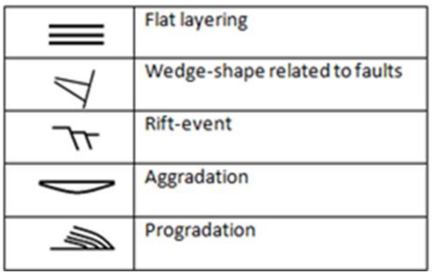


Figure 4-2: Summary of the tectonic phases and the deposition patterns observed in the Fingerdjupet Subbasin (NPD, 2014).

4.3 The development of the Fingerdjupet Subbasin in a regional setting

The records of seismic stratigraphy, structural framework and internal structural features (chapter 2 and 3) together with an analysis of the infill dynamics (chapter 4.2) make it evident that both small-scale and large-scale regional tectonic events have been acting on the Early Cretaceous Fingerdjupet Subbasin.

4.3.1 Late Jurassic

In the Jurassic discrete pulses of rifting affected the area between Norway and Greenland. In the Bathonian-Callovian there was a regional transgression, with following rifting and rapid subsidence between Norway and Greenland in the Late Kimmeridgian (Faleide et al., 1993a). This Middle to Late Jurassic rifting resulted in block-faulting in the east and the north. In the earliest Cretaceous subsidence took place and created the deep depocenters of the Tromsø, Harstad and Bjørnøya Basin (Breivik et al., 1998). At this point in time the Fingerdjupet Subbasin shows few signs of tectonic activity, the Jurassic sequence 1.1 appear to have been deposited on a relatively flat surface (chapter 4.2). This created a distinct division between the western and the eastern part of the Bjørnøya Basin, separated by the Leirdjupet Fault Complex.

The Hammerfest Basin shows signs of tectonic activity in the Late Jurassic and in the earliest Cretaceous (Berglund et al., 1986), whereas the Fingerdjupet Subbasin has its greatest amount of tectonic activity when the Hammerfest Basin was no longer tectonic active. This is related to the dynamics of the North-Atlantic rifting process. The rifting tried and failed several times before it was successful. One of the first attempts of breaking up Pangea in this northeastern Atlantic region gave rise to the Tromsø, Harstad and Bjørnøya Basins, without reaching the area of the Fingerdjupet Subbasin before Barremian-Aptian time.

4.3.2 Earliest Cretaceous

In the earliest Cretaceous the tectonic activity in the Hammerfest Basin ceased, and the extension appears to have moved further northwards, and may be represented by the first extensional event recorded in the Fingerdjupet Subbasin by the fault-related stratigraphy of sequence 2.1b (chapter 4.2). This extensional phase marks the onset of the subsidence and establishment of the Fingerdjupet Subbasin. By this extension and faulting the Fingerdjupet Subbasin was separated from the Bjarmeland Platform area, to which the pre-extensional area of the Fingerdjupet Subbasin had been belonging to. This is not consistent with what is described as the main phase of tectonic activity for the Fingerdjupet Subbasin in earlier publications, like (Gabrielsen et al., 1990), where the extension is described to have been in the Late Jurassic – Early Cretaceous. In accordance with the results presented in this thesis, it seems likely to place a more exacte timing of the event to Early Cretaceous, since the Jurassic sequence 2.1 appears to have few indications of fault-controlled deposition. However, it is important to mention that the Jurassic sequence is relatively small in thickness and that the seimsic resolution might be an issue when resolving the timing of the tectonic event.

HALIP

The rifting and initial breakup in the Artic Region and formation of the High Artic Large Igneous Province (HALIP) has also likely played an important role in the structural development of the Fingerdjupet Subbasin. The HALIP was initiated in the Early Cretaceous. The igneous rocks preserved in Franz Josef's Land, Svalbard, possibly in the North Greenland, and in the Canadian Artic represent a fraction of the total volume of the HALIP. The HALIP is thought to have affected the whole Artic Region (Maher Jr, 2001). Grogan et al. (1998) published the result of a preliminary mapping of the magmatic rocks in the Barents Sea Region. The establishment of the HALIP may have affected the continenta crust beneath the northern Barents Sea Region, at least as far south as the northernmost part of the Fingerdjupet Subbasin (figure 4-3).

Corfu et al. (2013) did a study on the age of the igneous rocks on Svalbard and Franz Josef's Land and was able to date the igneous rocks to be of Barremian age, with the rocks on Franz Josef's Land being younger then the sills studied on Svalbard. The formation of the large igneous province by deep-seated mantle processes may have led to the creation of a regional stress component in the continental plate of the Barents Sea region that has also affected the creation of the Fingerdjupet Subbasin (Maher Jr, 2001, Grogan et al., 1998).

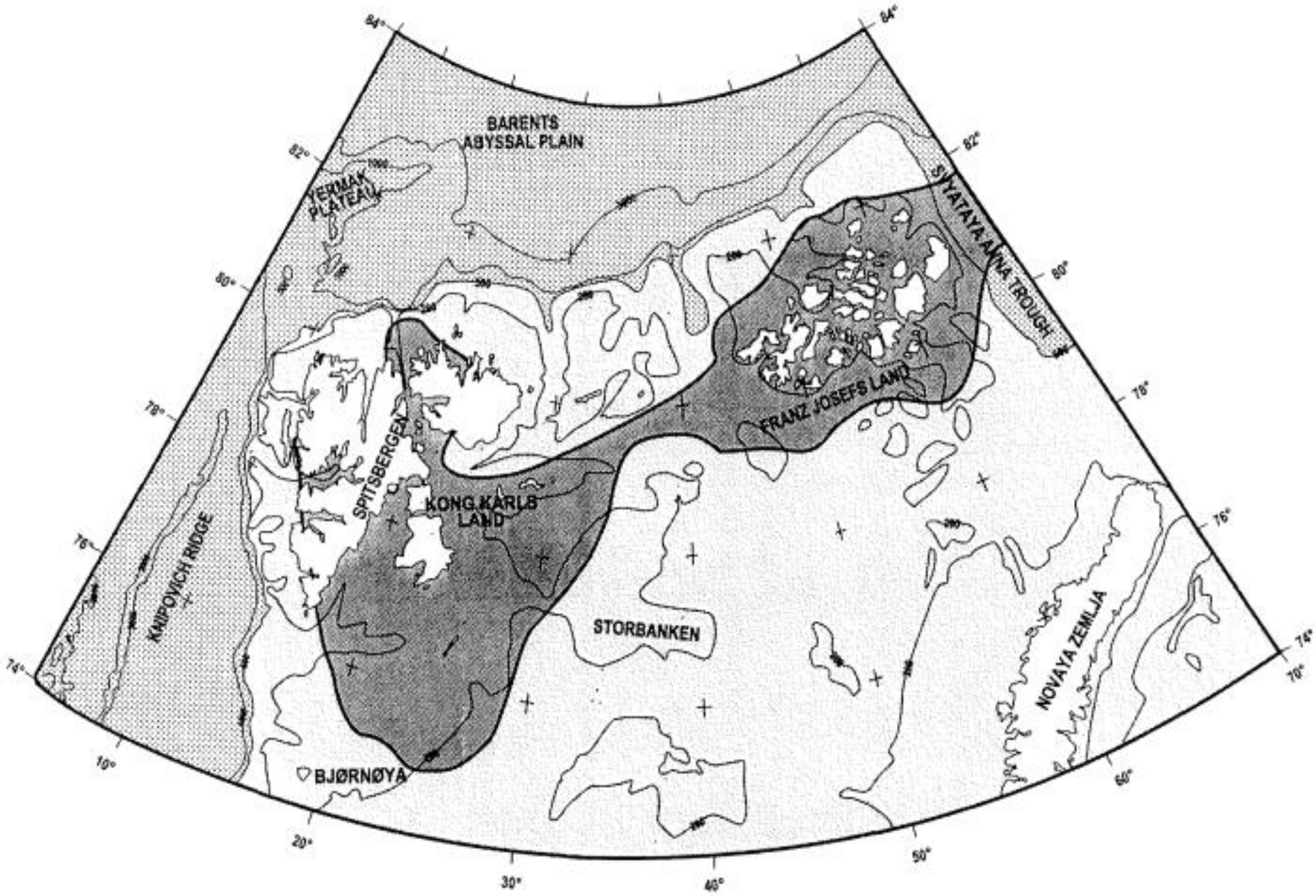


Figure 4-3: Figure displaying the extent of the igneous rocks within the Artic region (Grogan et al., 1998).

The HALIP was associated with a regional uplift in the Artic Region. The uplifted areas became a source for sediments which were transported by fluvial streams southwards. The formation of the regional unconformity beneath the Helvetiafjellet Formation in Spitsbergen may represent one of several incised valley systems at the southern flank of a structural uplift to the north in Barremian (Midtkandal and Nystuen, 2009). This uplift may have been related to a doming above the rising HALIP. Svalbard and adjacent areas to the east appear to have been acting mainly as bypass regions for sediments moving southwards. Marine accommodation still existed and was created in the Barents Sea Region. These basinal areas, as the Late Jurassic and earliest Early Cretaceous of the Fingerdjupet Subbasin and the Bjarmeland Platform (Dimitriou, 2014), received clay-rich suspension sediments before the arrival of prograding more coarser-grainedsediments from the eroded HALIP dome in the north.

Eustacy

The main infill of the Fingerdjupet Subbasin in the Cretaceous is shale. However, a condensed section in the Early Cretaceous is documented in the areas around the Fingerdjupet Subbasin. Århus et al. (1990) studied four shallow boreholes that were drilled in the Lower Cretaceous sections in the Barents Sea (figure 4-4). The four wells revealed a condensed section from Late Tithonian to Early Barremian represented as an approximately 5 meter thick unit of limestone with several cochina beds. Directly above this limestone unit dark shales represent deposits of a rather deep water system. This stratigraphy could be an indication of a platform area with deposition of carbonates with very moderate influx of siliciclastic debris, followed by influx of clay and silt deposition, obviously triggered by a sudden change in the depositional framework of the area. The change from shallow marine carbonates to deep water black shale represented the onset of a rapid regional subsidence.

By looking to the Fingerdjupet Subbasin this hypothesis appear to fit well by the fact that sequence 2.2 shows evidence of progradation and downlapping onto the surface separating sequence 2.2 and sequence 2.1. This indicates that the sea level must have been relatively high when sequence 2.2 was deposited, and that there was accommodation space for sediments to prograde into the basin. Whether or not the limestone unit described by Århus et al. (1990) are present in the Fingerdjupet Subbasin is not known since the resolution of the seismic and the well data is too low to detect this thin unit in the Fingerdjupet Subbasin. But it is reasonable to believe that these carbonate deposits had a wide regional extent, since a carbonate unit at this stratigraphic level is observed in all of the four boreholes (figure 4-4) and is likely to be found in sequence 2.1. One of the wells that these limestones are observed in (7320/3-U-1) is not far from the Fingerdjupet Subbasin. This would be a clear evidence of the regional subsidence in the Western Barents Sea.

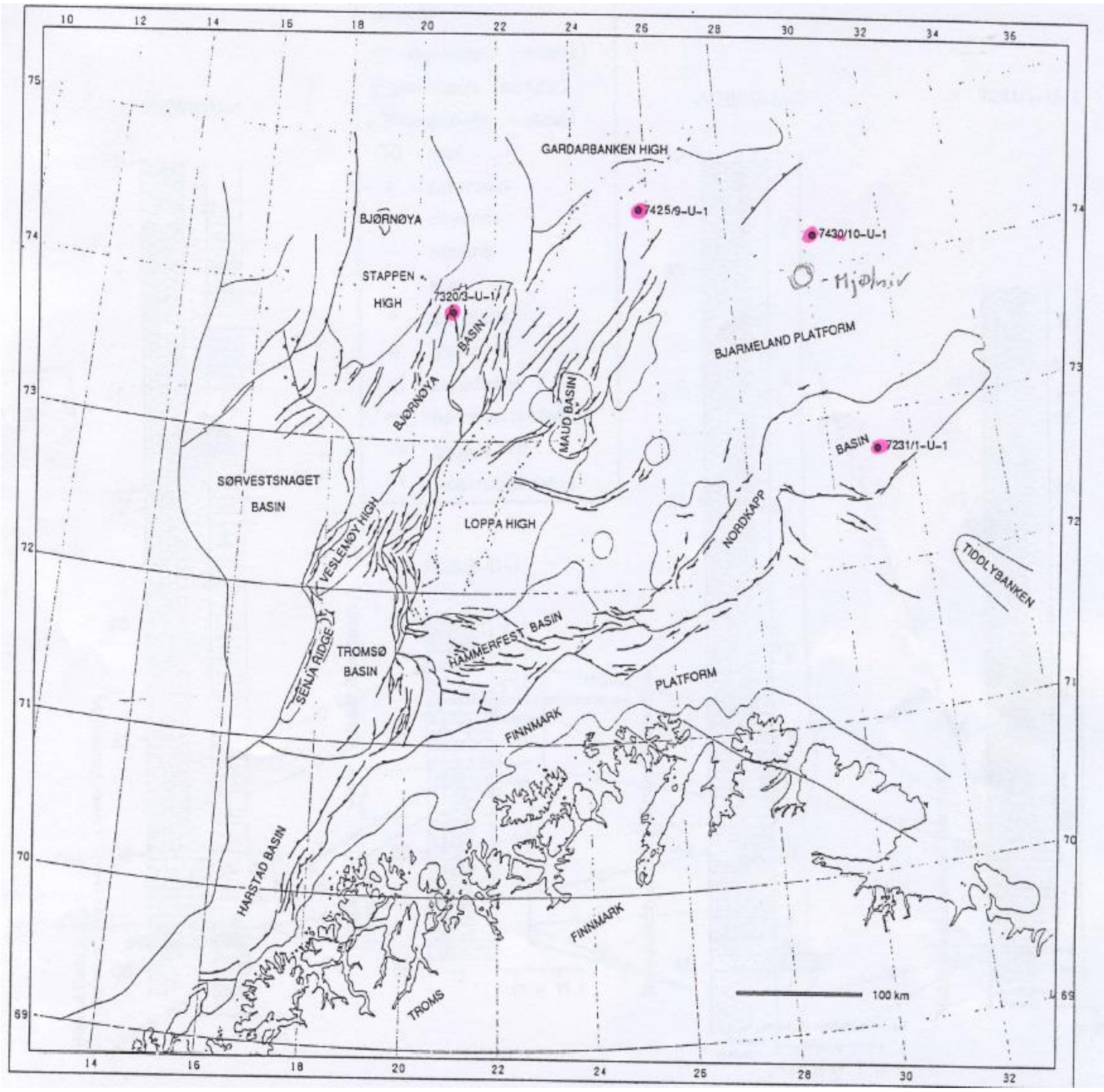


Figure 4-4: Wells that have limestone are marked with pink (Århus et al., 1990).

This brings up the discussion whether or not the interpreted succession of Knurr Formation in the Fingerdjupet wells should be underlain by a part of the Klippfisk Formation. Smelror et al. (1998) defined Early Cretaceous carbonates of the Barents Sea as the Klippfisk Formation. If these carbonates are present in the Fingerdjupet Subbasin, below shales referred to as the Knurr Formation, this will be in support of that the stable Bjarmeland Platform existed westward before Barremian time.

Progradational units from the north

The prograding units observed in the Fingerdjupet Subbasin, and which make up the sequence 2.2, are studied in greater detail by Dimitriou (2014). Dimitriou (2014) has carried out a study of seismic stratigraphic sequences with internal clinoforms in the Lower Cretaceous succession on the Bjarmeland Platform and recorded that the sequences had been advancing from north and northeast. These prograding units appear to downlap close to the Base Cretaceous Unconformity in the Bjarmeland Platform area. However, by tracing these units into the Fingerdjupet Subbasin it becomes clear that the sequence 2.1 pinches out towards the Bjarmeland Platform, leaving the sequences with internal clinoforms observed by Dimitriou (2014) to apparently be downlapping onto the BCU.

Since the Fingerdjupet Subbasin was formed in the Early Cretaceous the Cretaceous succession of the Barents Sea is far more complete in the Fingerdjupet Subbasin than in the platform areas, as demonstrated by sequence 2.1. The Fingerdjupet Subbasin would thus have had accommodation space for sediments derived from the north. The southwards migrating sediment flux in the northern Barents Sea area may correspond to the fluvial lower part of the Helvetiafjellet Formation that were transported from the northwest to the southeast in the Barremian (Midtkandal and Nystuen, 2009). Then this fluvial sediment load met the marine realm in the Barents Sea area, a deltaic or siliciclastic platform system started to prograde towards the south, progressively filled in lows of maximum accommodation. By such a source-to-sink system, it is reasonable to date the sequence 2.2 to Middle Barremian, since it would have taken some million years before clastic wedges arrived and accumulated in the Fingerdjupet Subbasin.

Recordings on Svalbard by Midtkandal and Nystuen (2009) show evidence of the uplift on the east cost of Svalbard near Rurikfjellet. In the Late Jurassic to the Early Cretaceous the environment changed from an open marine shelf to a regressive open marine shelf. A rapid change in the Barremian from regressive and open marine shelf to fluvial and paralic environments are a good indication for an uplift to the north or northwest of Svalbard; an uplift that may have been caused by doming connected to the initiation of the HALIP (Midtkandal and Nystuen, 2009). By reasoning, the HALIP area is thought to be the source of the sediments observed in the Fingerdjupet Subbasin as sequence 2.2. The Fingerdjupet

Subbasin kept on subsiding through the Barremian, and the accumulation of sediments was continuous.

Regional versus local subsidence

In the Early Cretaceous when the Fingerdjupet Subbasin appears to have been subsiding and separated from the Bjarmeland Platform in the east, a regional subsidence is recorded (Århus et al., 1990). This regional subsidence created accommodation space for the prograding units that is mapped out by Dimitriou (2014). Whether or not the Fingerdjupet Subbasin is a result of the regional subsidence only or the local subsidence created as a result of the North Atlantic rifting is not yet clear. Possibly, the subsidence recorded in the Fingerdjupet Subbasin is a result of the combination between the regional subsidence taking place at this time, and the extension that appears to have affected the Fingerdjupet Subbasin, and the areas north of the Fingerdjupet, and east of Svalbard. Since the condensed section is not above seismic resolution it is difficult to determine at which age the subsidence started, but it appears to have started before the first phase of fault movement. This can be resolved due to the thickness variations in sequence 2.1a whereas the wedge-shape in relation to the faults does not appear until sequence 2.1b. However, there have been pulses of tectonic activity in the Jurassic, and the subsidence observed in the Fingerdjupet Subbasin could be a result of the cooling after a Jurassic extension, or it could be that the regional subsidence had already started before the extension reached the Fingerdjupet Subbasin.

4.3.3 <u>Aptian</u>

In the Aptian a new phase of tectonic activity is recorded within the Fingerdjupet Subbasin (sequence 2.4b). The deep basins in the southwestern Barents Sea, as well as the Fingerdjupet Subbasin, were still subsiding, and the Leirdjupet Fault Complex was again activated (Faleide et al., 1993, Bjørnestad, 2012).

The extension in the NE Atlantic during several phases have affected the Barents Sea area, as well as areas like the volcanic Hatton-Rockall, Møre, Vøring, Faeroe, Lofoten-Vesterålen, and Vestbakken Margins in the European northwestern side but also its conjugates on the eastern side of Greenland (Tsikalas et al., 2012, Faleide et al., 1993). These phases of extension affected the Fingerdjupet Subbasin, and the tectonics observed in the Aptian could thus be a direct result of this extensional phase prior to the opening of the Norwegian-Greenland Sea. A similar event as the Aptian extension in the Fingerdjupet Subbasin has also been recorded onshore on East Greenland; later this rift phase has been identified in the Vøring Basin (Doré et al., 1999), Lofoten-Vesterålen Margin (Tsikalas et al., 2001), onshore Andøya (Dalland, 1981), and in the SW Barents Sea (Faleide et al., 1993). This extensional event could also be related to an extension and opening in the Artic Ocean.

The Fingerdjupet Subbasin shows at this period both a change in depocenter and a re-activation of both the bounding faults and the faults within the Fingerdjupet Subbasin. This could indicate that the total crustal stress field that was acting on the Fingerdjupet Subbasin at the same time was composite and set up by several dynamic components. The depocenter in the south which was developing at this time period (intra Aptian) is located at the base of the Loppa High. The western part of the Loppa high has been reactivated several times. Gabrielsen et al. (1990) stated that the activity of the western crest has been active at least four times since the Devonian, and in the Early Cretaceous it was an island. If the activity of the western crest of the Loppa High is activated, while the southernmost depocenter of the Fingerdjupet Subbasin is evolving, this tectonic activity might have played a role in the formation of the new depo-center. Sediments would have been eroded from the island, and the activation of the western crest could have affected the formation of the accommodation space. The subsidence in the west appears to stop at some point within the sequence 2.4 indicating that the subsidence stopped and the depocenter was filled in. The sequence 3.1 shows no signs of subsidence in the southern part of the Fingerdjupet Subbasin.

Leirdjupet and Bjørnøyrenna Fault Complexes

The Leirdjupet Fault Complex was also activated during the Early Cretaceous stage including Aptian, and experienced footwall uplift and erosion as indicated by a sedimentary unit onlapping the tilted fault block in the Bjørnøya Basin. This led the main fault flank of the footwall of the Leirdjupet Fault Complex close to Fingerdjupet Subbasin to be uplifted. It is reason to believe, based on observations in the Fingerdjupet Subbasin (sequence 2.1), that erosion on the top of the flank is found in the Fingerdjupet Subbasin which is acting as a sink at this period.

During the first phase of fault movement observed in the Fingerdjupet Subbasin (Near Base Cretaceous activity, sequence 2.1b), the Leirdjupet Fault Complex was not as active as before and in the later Aptian. During the Aptian phase however, the fault activity is observed in both the Fingerdjupet Subbasin and in the Leirdjupet Fault Complex. They both show signs of extension in the southern part and the observed wedge in the hangingwall of the master-fault in the Leirdjupet Fault Complex (figure 4-5) relates to the growth of the Leirdjupet Fault Complex in the south in the Aptian. The wedge is observed in the seismic data, and it has been described by other authors (Bjørnestad, 2012, Faleide et al., 1993).

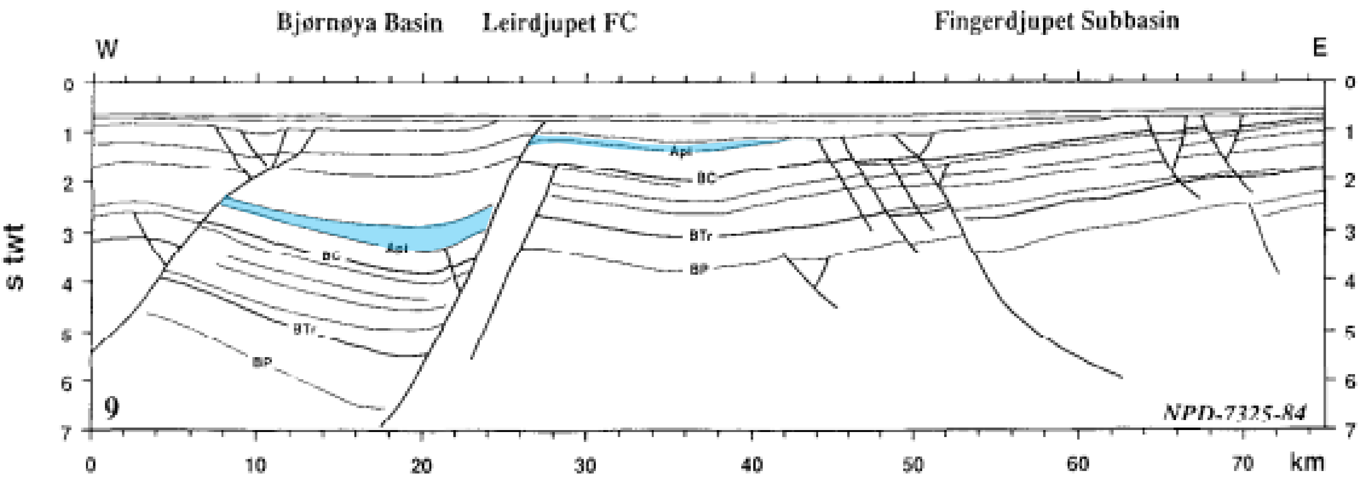


Figure 4-5: Wedgeshape geometry (Aptian) in the hangingwall of the masterfault of the Leirdjupet Fault Complex, and the correlation to the footwall uplifted area. Figure illustrating the fault movement in the Aptian (Faleide et al., 1993).

This difference in timing of activity within the first phase of tectonic activity is an indication that the extension that led to the formation of the Hammerfest Basin and that is observed in the Bjørnøya basin did not reach the Fingerdjupet Subbasin, and lost its energy towards the northwest. While the phase of extension that led to the formation of the Fingerdjupet Subbasin have continued through the Fingerdjupet Subbasin and then possibly north and east of Svalbard. Based on the throws of the Leirdjupet Fault Complex and the F2 (chapter 3.4.4) an interpretation of the change in throws towards the north could possibly prove the two separate extensional phases. By studying the throw it becomes evident that the throw of the Leirdjupet Fault Complex increases towards the north, while the F2 throw increases. This would be natural if there were two phases of extension, one which diminished towards the northwest (Leirdjupet) and one which propagated further northwards and east of the Leirdjupet Fault Complex.

Bjørnestad (2012) also recorded transpressional stress in relation to Leirdjupet Fault Complex. Small compressional structures are also observed within the Fingerdjupet Subbasin in relation to the faults, and are observed in most of the Early Cretaceous stratigraphy. The compression observed by Bjørnestad (2012) can be related to the contraction of which the Bjørnøyrenna Fault Complex underwent in the Late Cretaceous – Early Tertiary (Gabrielsen et al., 1997). Based on the work by Gabrielsen et al. (1997) the Bjørnøyrenna Fault Complex and the Bjørnøya Basin also experienced an inversion in the Hauterivian – Aptian, which it is reasonable to believe was a semi-regional event that would have affected the Leirdjupet Fault Complex as well as the Fingerdjupet Subbasin. These compressional phases would most likely have influenced the formation of the Fingerdjupet Subbasin in several ways. This could lead to a more extensive subsidence of the Fingerdjupet Subbasin, and also lead to folding and structural highs within the basin area. A structural high described earlier in chapter 3 and 4.2 (sequence 2.2) appears to have a greater thickness at the top of the structural high, and could be a result of the compression discussed above. This would prove that the compressional phase of the Hauterivian-Aptian affected the Fingerdjupet Subbasin and created what appears to be a folded sequence. It could also be a result of differential subsidence as a result of the compressional phase.

East/West faults

The two sets of fault patterns observed indicates that there have been two extensional directions affecting the Early Cretaceous strata. The throw and heave of the E-W faults are of generally smaller scale than the NNE-SSW trending faults. By studying seismic sections displaying the E-W fault it becomes clear that these faults are younger then the interpreted Intra Aptian horizon (H5), but their exact age is not possible to resolve since they appears to terminate against the base of the Quaternary. This fact that the E-W faults are affecting the Intra Aptian horizon (H5) and the strata above it (figure 4-6), prove the point that these faults must be younger then the N-S trending faults. Due to time limitations the relationship between the two fault-sets has not been studied in detail, but it is interesting to observe whether or not the E-W faults offsets the N-S faults and with how much. Since the E-W faults appear to be younger then the two phases of fault activity reckoned in this thesis further investigation should be focusing on the age of these faults, and the link to the regional geology. If the age of these faults are found it will contribute to a much greater understanding of what happened in the Barents Sea in the time interval where most of the sediments in the Barents Sea is not present.

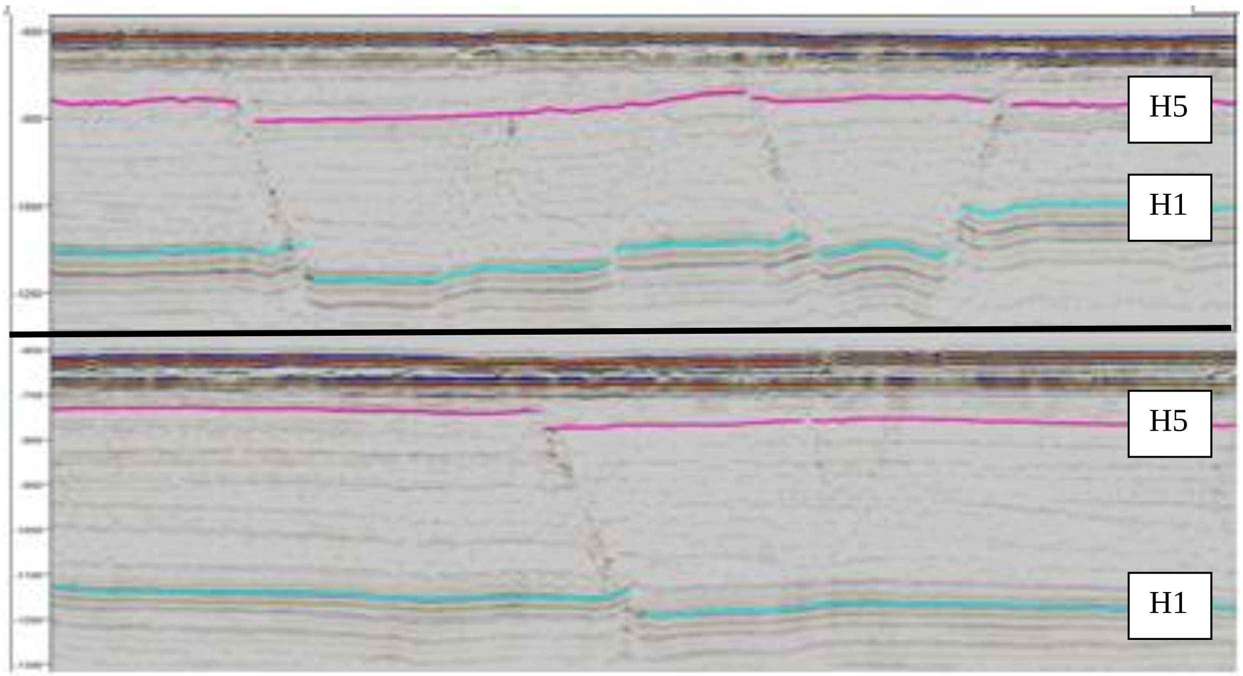


Figure 4-6: E-W faults in the seismic section affecting the stratigraphy above the Intra Aptian (H5).

5 Conclusion

The Fingerdjupet Subbasin has a complex history with a close interplay between tectonics and sedimentation. The geological history prior to the Early Cretaceous seems to be more closely linked with that of the Bjarmeland Platform than of the Bjørnøya Basin. In the Early Cretaceous the Bjarmeland Platform and the Fingerdjupet Subbasin however do not share the same geological history, whereas the Fingerdjupet Subbasin clearly experienced rifting that propagated northwards, and it subsided in response to this. Regional subsidence, also affecting the Bjarmeland Platform may have also contributed. The earliest Cretaceous extension, which is mainly related to the North Atlantic rift, is observed all the way over to the Hoop Fault Complex. This indicates that there must have been at least two stages of rifting in the SW Barents Sea with different directions in the time interval Late Jurassic-earliest Early Cretaceous. The first one in the Late Jurassic affected mainly the Tromsø, Harstad and Bjørnøya basins but caused also some rifting into the Hammerfest Basin. The second, which created the Fingerdjupet Subbasin in the Early Cretaceous, can be traced through the deep Tromsø, Harstad and Bjørnøya basins to the area covered by the Fingerdjupet Subbasin.

The Late Jurassic – Early Cretaceous evolution of the Fingerdjupet Subbasin can be summarized as below:

1. Late Jurassic shows little or no signs of tectonic activity and associated thickness variations.

2. Minor subsidence in the Berrasian – Hauterivian may be related to some extension in the Late Jurassic rift phase.

3. Early Cretaceous (Barremian?) extension related to the North Atlantic rifting, causing differential subsidence. In addition rapid regional subsidence event affected the Fingerdjupet Subbasin area.

4. Prograding units derived from the north in the Barremian. Source area for these sediments likely within a dome formed within the High Artic Igneous Province (HALIP)

5. Extensional phase within the Aptian related to the opening of the Norwegian – Greenland Sea.

6. Possible folding within the Aptian that could be related to the transpression recorded in the Bjørnøyrenna Fault Complex.

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