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Tectono-sedimentary characteristics of Upper Jurassic sedimentary rocks in the Fenja area, Norwegian Sea

by

Håvard Skipevåg

Bachelor Thesis

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I am grateful for all the help!

Abstract

This study focuses on enhancing the understanding of the relationship of normal fault and Upper Jurassic sandstone deposits in the Fenja area, situated within the Norwegian Sea. Utilizing data from three wells (6406/11-1 S, 6406/12-1 S and 6406/12-2) and a 3D seismic cube, the investigation aims to locate sandstone deposits and interpret the associated depositional systems.

The geological setting of the study area, characterized by its location in a marine depositional environment, presents a complex interaction of tectonic and sedimentary processes. Through structural and stratigraphic correlations, as well as seismic interpretation, sandstone deposits are recognized and correlated across wells, each exhibiting unique depositional characteristics.

In well 6406/11-1-S, Upper Jurassic formations are absent. In contrast, well 6406/12-1 S showcased Upper Jurassic sandstone in the Rogn Formation was deposited in a shoreface environment. Notably, well 6406/12-2 revealed sandstone deposits within the Rogn Formation, suggesting a submarine fan depositional system.

Seismic interpretation and geological mapping revealed two major boundary faults within the study area, influencing sedimentation patterns and depositional environments. This study contributes to the broader interpretation of the Norwegian Sea´s geological dynamics, bridging knowledge gaps and providing insights into the Upper Jurassic depositional environments and fault systems. The findings underscore the significance of integrated geological analysis for enhancing understanding of rift basin formations and informing future exploration efforts in Upper Jurassic oil and gas reservoirs.

Tectono-sedimentary characteristics of Upper Jurassic sedimentary rocks in the Fenja area, Norwegian Sea

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The University of Stavanger, 2024

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CHAPTER 1. INTRODUCTION

1.1. Literature review

A rift basin emerges as a distinctive geological phenomenon at divergent plate boundaries, where the Earth's lithosphere undergoes a profound transformation under the influence of tectonic forces. The lithosphere is subjected to stretching and thinning, which gives rise to linear depression or rifts within the crust. These rift basins predominantly manifest within continental crust, serving as tangible indicators of regions experiencing the dynamic processes of extensional tectonics (De Almeida, Janikian, Fragoso-Cesar, & Marconato, 2009).

Rift basins are intimately intertwined with regions undergoing extensional tectonics, often at the juncture of divergent plate boundaries where tectonic plates gradually drift apart. The resulting geological structures exhibit an elongated shape, harmoniously aligned with the prevailing direction of tectonic extension, and are distinguished by narrow depressions with steep-sided boundaries known as fault scarps (De Almeida, Janikian, Fragoso-Cesar, & Marconato, 2009). As a major part of the Norwegian Continental Shelf (the NCS), the North Sea is an example of a rift basin that underwent both Paleozoic (Permo-Triassic) and Mesozoic (Late Jurassic to Early Cretaceous) extensional events (Figure 1).

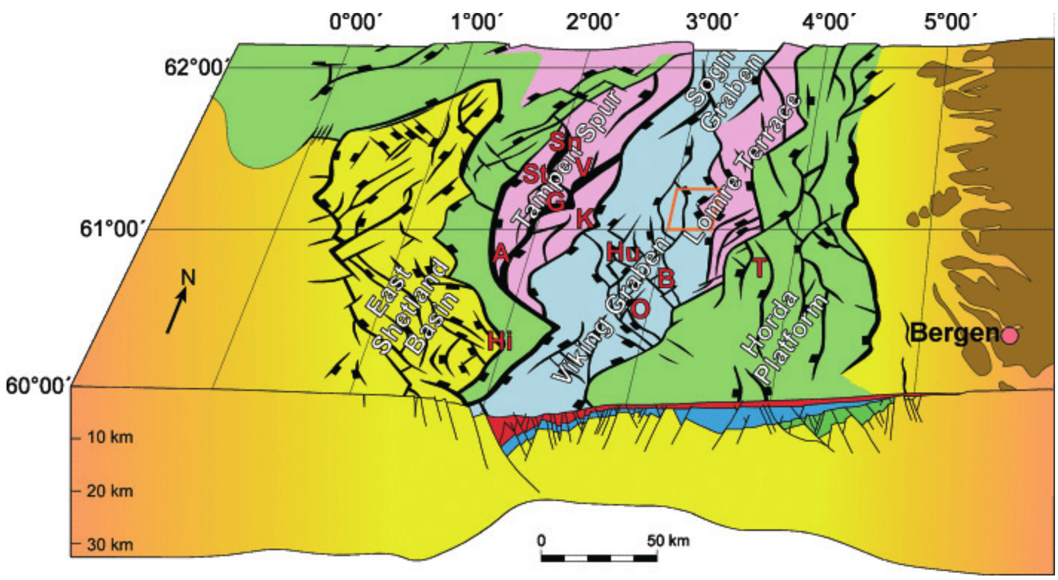


Figure 1: An example of a Mesozoic rift basin in the North Sea

In the North Sea, the Late Jurassic to Early Cretaceous extension led to reactivation of existing Paleozoic faults and the creation of normal faults (Zhong & Escalona, 2020). This Upper Jurassic rift basin is featured by the deposition of shallow marine shoreface to submarine fans that were actively controlled by the complex interplay of multiple fault systems, which was termed as syn-rift deposition. The pattern of syn-rift deposition is primarily determined by fault activity. The rotation of fault blocks results in erosion in emerged areas, which became the sources of reworked sediments. In addition, drainages that act as the passages for sediments are influenced by fault activity. Driven by gravity, coarse grained sediments may incise existing bedrocks and transport towards deeper part of the rift basin (Zhong et al., 2020). Upper Jurassic sandstone is an important reservoir rocks of discovered oil and gas fields on the NCS. These sandstone reservoirs are commonly capped by an organic rich shale formation, or the Kimmeridgian shale. Previous research has proposed a number of depositional models to reveal how fault activity controlled the style of syn-rift deposition. As a major geological contact across the NCS, the basal Cretaceous Unconformity, or the BCU, marked the cease of the Late Jurassic to Early Cretaceous syn-rift deposition.

1.2. Study area

This study focuses on the Fenja area in the Norwegian Sea. The area encompasses parts of the Halten Terrace, Frøya high and the Rås basin (Færseth, 2021). The Fenja oilfield is located in the southeastern part of the Study area (Figure 2). This field is a large oilfield that was discovered in 2014 (Sokkeldirektoratet, 2024). It is located in the Norwegian Sea 120 km north of Kristiansund and 36 km southwest of the Njord field. The Fenja field is currently under production of oil and the production is done by water and gas injections. The field has a water depth at 325 meters and the oil reservoir is at the age of the Late Jurassic (Sokkeldirektoratet, 2023). The reservoirs contain oil and gas in sandstone of the Melke Formation, and oil in Upper Jurassic sandstone in the Rogn Formation. These reservoirs were reported to be deposited in a fan system at a depth of 3200-3500 metres, and had variable reservoir properties. However, there is little information available for the public about the structural impact on sandstone deposition.

1.3. Aim of study

By using subsurface borehole and seismic data from public database, DISKOS, this thesis aims to gain better understanding of how the Upper Jurassic sandstone deposits were influenced by structures. To achieve the goal, the following breakdown tasks will be carried out, which are well correlation to locate the sandstone deposits on selected boreholes, horizon and fault interpretation to understand the structural styles and major stratigraphic boundaries, fault throw analysis of the major bounding fault, seismic attribute to reveal the distribution of Upper Jurassic sandstone, and construction of a depositional model. In a word, this thesis will try to close in the knowledge gap and offer an improved interpretation around the Fenja oilfield area.

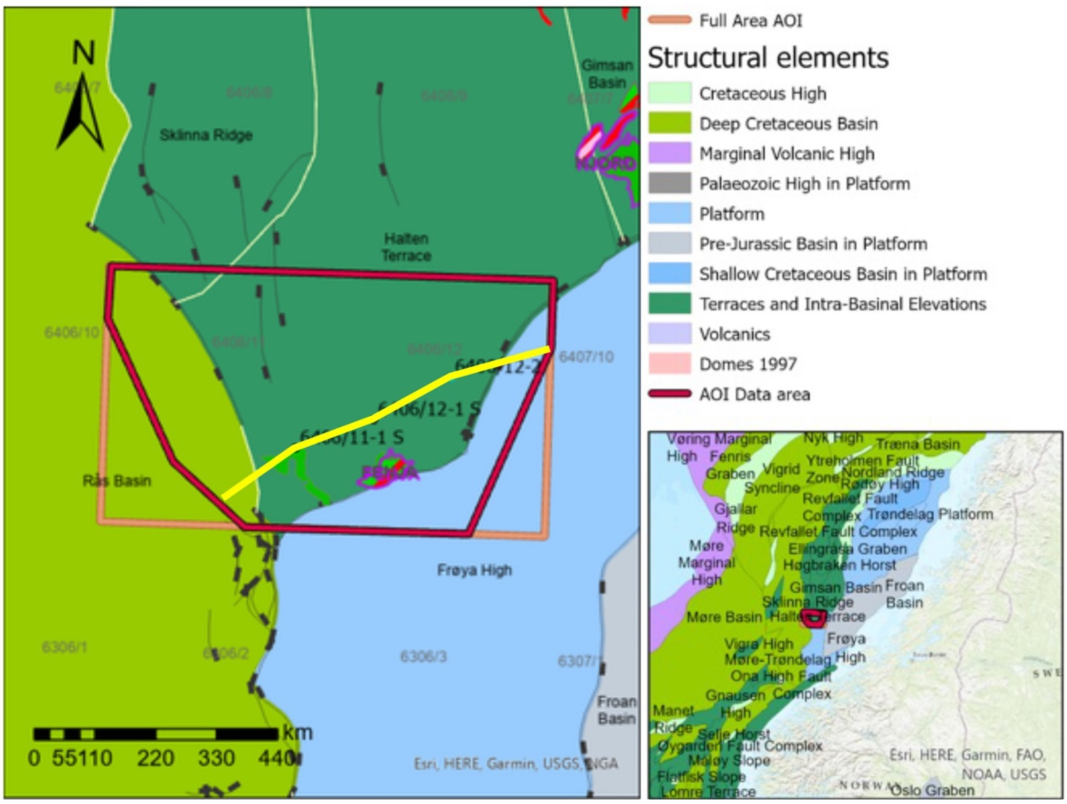


Figure 2: Location map of study area showing major structural elements

CHAPTER 2. GEOLOGICAL BACKGROUND

2.1. Three types of marine deposition systems

As mentioned in the previous chapter, the study area is located in the Norwegian Sea. In a marine depositional environment, sandstone deposits are commonly deposited in three different types of deposition systems, which are marine delta, shoreface, and submarine fans.

2.1.1. Marine Delta

A marine delta is characterized as a distinct shoreline protrusion, comprised of subaqueous and subaerial coastal accumulations of river-derived sediments adjacent to the source stream. These deposits are often secondarily shaped by waves, currents, or tides (Syvitski, et al., 2022). There are three main types of deltas classified by the processes that control the build-up of sandstone: wave-dominated, tide-dominated, and fluvial dominated deltas. In a wave-dominated delta, the movement of waves controls a delta's size and shape. Besides, a fan delta, can be a coastal prism of sediments derived from an alluvial-fan feeder system. It is deposited mainly or entirely subaqueously at the interface between the active fan and a standing body of water (Nemec and Steel, 1988).

2.1.2. Shoreface

The shoreface is the nearshore zone of the inner continental shelf, bounded landward by the mean low-water line. It extends seaward to where the influence of wave action on cross-shore sediment transport is, on average, minor compared to other influences (Smith, 1995). The shoreface is traditionally divided into three sub-facies from seaward to landward: the lower, middle, and upper shoreface. However, the boundaries between these zones and between the lower shoreface and the offshore are not always clearly defined. Shoreface deposition is near shore regions of the continental shelf where beach sand is deposited, weathered, rounded and sorted. This often forms with pronounced basin wards fining (Pemberton et al., 2012).

2.1.3. SUBMARINE FAN

Submarine fans are underwater geological structures associated with large-scale sediment deposition. A submarine fan is a section of the seafloor where land-derived sediments have accumulated, resembling a low cone with its apex located at the lower mouth of a submarine canyon incised into a continental slope (The editors of Encyclopaedia Britannica, 2024). The world's largest submarine fan, known as the Bengal Fan, has a length of 3000 km, a width of 1430 km, and a sediment thickness of 16.5 km. The Bengal Fan virtually occupies the entire length of the Bay of Bengal, and covers an area of 2800–3000 km^2 (Shanmugam, 2019). Turbidites, which predominantly occur in channels and lobes (or sheet sands), constitute the major portion of submarine-fan sequences. Thinning- and thickening-upward trends suggest channel and lobe deposition, respectively (Shanmugam, 1990).

2.2. Tectonic background of the Norwegian Sea

The Norwegian Sea is an offshore sedimentary basin developed in a continental margin, stretching from approximately 62° to 69°30´N. Its tectonic history is featured by three major events (Directorate, 2024):

1. The closure of the Iapetus Ocean during the Caledonian Orogeny which spans from Late Silurian to Early Devonian.
2. Successive episodes of extensional deformation from Late Devonian to Paleocene, culminating in the separation of Greenland and Eurasia.
3. Ongoing seafloor spreading in the North Atlantic between Greenland and Eurasia since the Earliest Eocene.

As the eastern margin of the study area, the Trøndelag Platform is closely linked to regional tectonic processes involving the Caledonian Orogeny and subsequent plate tectonic reorganizations, multiphase rifting, continental drift, and glaciations (Bunkholt et al., 2024). This platform encompasses essential structural elements such as the Nordland Ridge, Helgeland Basin, Vega High, Ylvingen Fault Zone, Froan Basin and Frøya High (Directorate, 2024).

For the study area itself, its tectonic history can be classified into three phases: (1) the rifting phase during the Carboniferous, Permian, and Triassic; (2) the creation of the N-S trending basin in the Jurassic and Cretaceous; and (3) the uplift of the Norwegian mainland during the Cenozoic.

2.2.1. Carboniferous, Permian, and Triassic Rifting Phase

During the Carboniferous, Permian, and Triassic period, significant geological activity shaped the landscape. Rifting processes led to the formation of N-S to NE-SW trending rotated fault blocks on the Halten Terrace and sections of the Trøndelag Platform in the late Permian to early Triassic era. Subsequently, a substantial continental Triassic succession was deposited.

Exploration in the Helgeland Basin has uncovered Triassic deposits reaching thicknesses of up to 2500 meters, comprising grey and red beds, with two Middle Triassic evaporite intervals measuring up to 400 meters thick. These evaporite layers served as detachment levels for later extensional faults. The deposition of these extensive sequence was driven but pronounced subsidence within a fluvial sabkha environment. This tectonic event likely followed earlier rifting activities during the Carboniferous and Permian periods (Directorate, 2024).

2.2.2. Jurassic and Cretaceous N-S Basin Stretching

During the Early and Middle Jurassic periods, the Trøndelag platform and the Halten/Dønna Terrace formed part of a vast N-S trending subsiding basin, which was filled with sediment from a deltaic to fluvial depositional system. Sediment influx from various directions occurred over time. Thickness variations in Jurassic sediments reveal a thinner deposition towards the Nordland Ridge, while thickness increases are observed over the Vega High and the Helgeland Basin. From the Middle Jurassic onwards, escalating through the Late Jurassic to the Early Cretaceous, the Norwegian Sea underwent significant tectonic activity marked by extension, faulting, and thinning of the upper crust (Directorate, 2024).

The Halten and Dønna Terrace experienced downward faulting relative to the Trøndelag Platform, while the Vøring Basin subsided further west in comparison to the terrace areas. This extensional phase involved the activation of both large-scale basement faults and listric faults, penetrating into the Triassic salt. By the Middle Jurassic, the Nordland Ridge and the Frøya High were uplifted, whereas the Helgeland Basin area underwent subsidence. Later, inversion occurred in the Vega High, with faulting persisting along major faults well into the Cretaceous period (Directorate, 2024).

The Froan Basin transitioned from a shallow marine in the Late Jurassic to being overlain by thin, condensed Cretaceous sediments. Conversely, the Helgeland Basin area continued to subside, accumulation Cretaceous sediments reaching thicknesses of up to 1500 meters. During the Late Cretaceous, rapid subsidence occurred west of the Nordland Ridge due to increased rifting, while structural highs and the Lofoten-Vesterålen area experienced uplift (Directorate, 2024).

2.2.3. CENOZOIC UPLIFT

During the Paleocene, the uplift of the Norwegian mainland prompted the outward advancement of clastic sediments from Scandinavia into the Norwegian Sea. Notably, sandy deposits, occasionally exhibit favorable reservoir properties, have been documented north of the Nordland Ridge and within the Møre Basin. This progradation persisted into the Eocene period. Concurrently, the separation between Greenland and Eurasia initiated ocean floor spreading in the Earliest Eocene, evident in the widespread deposition of tuffs and tuffaceous sediments regionally. Lava flows and basaltic dike complexes were emplaced in the Vøring and Møre marginal highs during this period. Subsequently, sediment influx from Scandinavia diminished during the Oligocene and Miocene epochs. The deltaic Molo Formation boasts commendable reservoir sands, albeit lacking a seal towards the seafloor. Noteworthy uplift of the Nordland Ridge occurred in late Cenozoic era. In the Pliocene and Pleistocene, additional uplift and glaciations induced erosion and the deposition of substantial sedimentary wedges onto the mid-Norwegian shelf (Directorate, 2024).

2.3. Stratigraphy of the Norwegian Sea

The lithostratigraphic chart of the Norwegian Sea illustrates the lateral variation of preserved Mesozoic to Cenozoic sediments from the Trøndelag Platform, Halten Terrace, Vøring Basin, Møre Basin, to Møre Coastal Area (Figure 3). The Fenja study area is part of the Halten Terrace.

The Jurassic formations in the study area include the Åre, Tilje, Ror, and Tofte formations in the Lower Jurassic, the Not, Garn, and Melke formations in the Middle Jurassic, and the Spekk and Rogn formations in the Upper Jurassic. The Ror, Not, Melke, and Spekk formations are dominated by claystone. Especially the Spekk Formation, it is dominated by organic-rick shale. By contrast, the Åre, Tilje, Tofte, Ile, Garn, and Rogn formations are sandstone dominated. The Jurassic formations are overlain by Lower Cretaceous Lange, Lyr, and Nise formations.

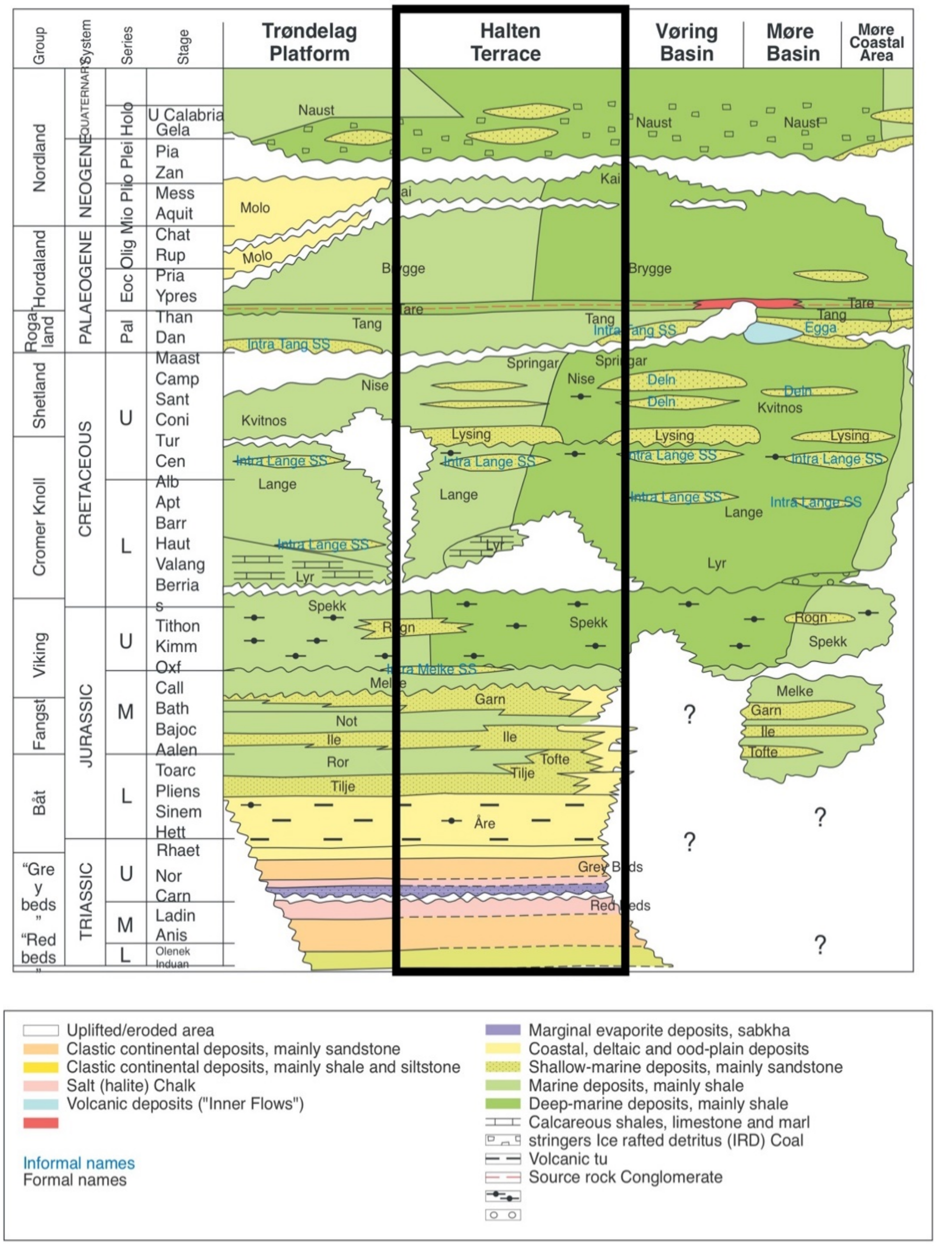


Figure 3: Lithology of the Norwegian Sea. The study area in Halten Terrace is highlighted. Modified after NPD (2024).

CHAPTER 3. DATA AND METHODS

3.1. Data

The borehole data is offered by three exploration wells, 6406/11-1 S to the west, 6406/12-2 to the east, and 6406/12-1 S in the middle (Figure 2). The basic information, logs, and well reports are derived from NPD´s public webpage.

A 668 km^2 post-stack 3D seismic cube, ST9302 in two-way-time (TWT) domain from the DISKOS database, is used for seismic interpretation. The cube comprises 1726 inlines with a step of 37.5 m, 2947 crosslines with a step of 12.5 m, and TWT range up to 6000 ms.

3.2. Methods

3.2.1. WELL LOG CORRELATION

The well logs that are used in the study include gamma ray (GR), deep- (RD) and shallow resistivity (RS), density (DEN), and neutron porosity (NPHI). The lithology of the Jurassic clastic rocks is mainly interpreted from the GR log, which helps to locate the sandstone from the claystone. Major stratigraphic boundaries of geological formations are determined by drastic variation of lithology from one to another.

Well correlation can be used to understand geological formations, mapping geological features, checking the geological features of a reservoir, regional geological studies, and so on. It is an essential tool to determine where the sandstone is located and thereby understand the deposition of sandstone deposits. Both structural and stratigraphic correlations are performed to interpret lithostratigraphic variations within the subsurface based on well log data.

3.2.2. SEISMIC WELL TIE

A seismic well tie integrates seismic data with well logs to correlate seismic information with subsurface geology, enhancing seismic interpretation accuracy. This process aids in calibrating seismic data, converting depths, interpreting geological features, and optimizing drilling operations. Specifically, it facilitates depth conversion and the interpretation of geological structures like faults and unconformities, supporting comprehensive geological analysis and exploration planning.

3.2.3. Seismic interpretation

Seismic interpretation is a method used to create a snapshot of the subsurface that one can use to define faults, formations, and unconformities. This makes it possible to see the geological changes as well as the amount of deposition that occurred over different time periods.

In this study, the Petrel software developed by Schlumberger company is used. This software has a user-friendly interface that makes both well and seismic data visible.

Both faults and horizons of key formations are interpreted (Figure 4 and Figure 5).

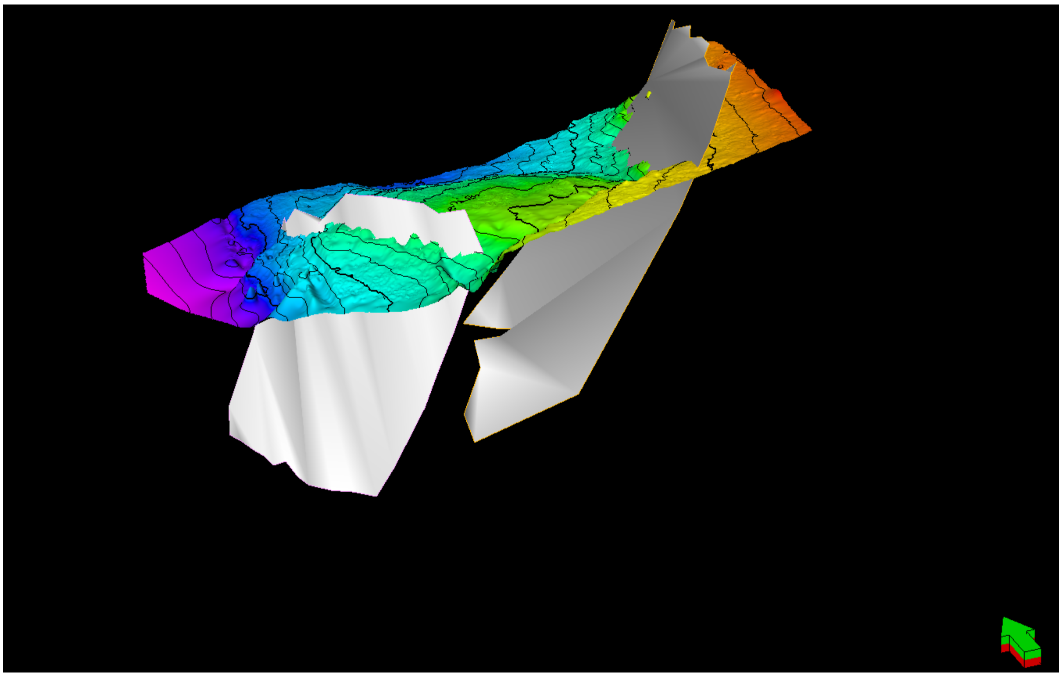


Figure 4: figure of the BCU showing the major faults

These geological elements serve as the basics of geological mapping, time to depth conversion with defined velocity model, and seismic attribute analysis.

3.2.4. Mapping of faults

Fault mapping is crucial for understanding the overall picture of the study area. Seismic discontinuities and structural patterns are key indicators that allow one to locate and characterize these faults. In general, a fault can be interpreted along align seismic discontinuities such as broken, bended, and splitting reflectors. Drastic changes in seismic amplitudes and phases are other indicators that present the possible existence of geological faults.

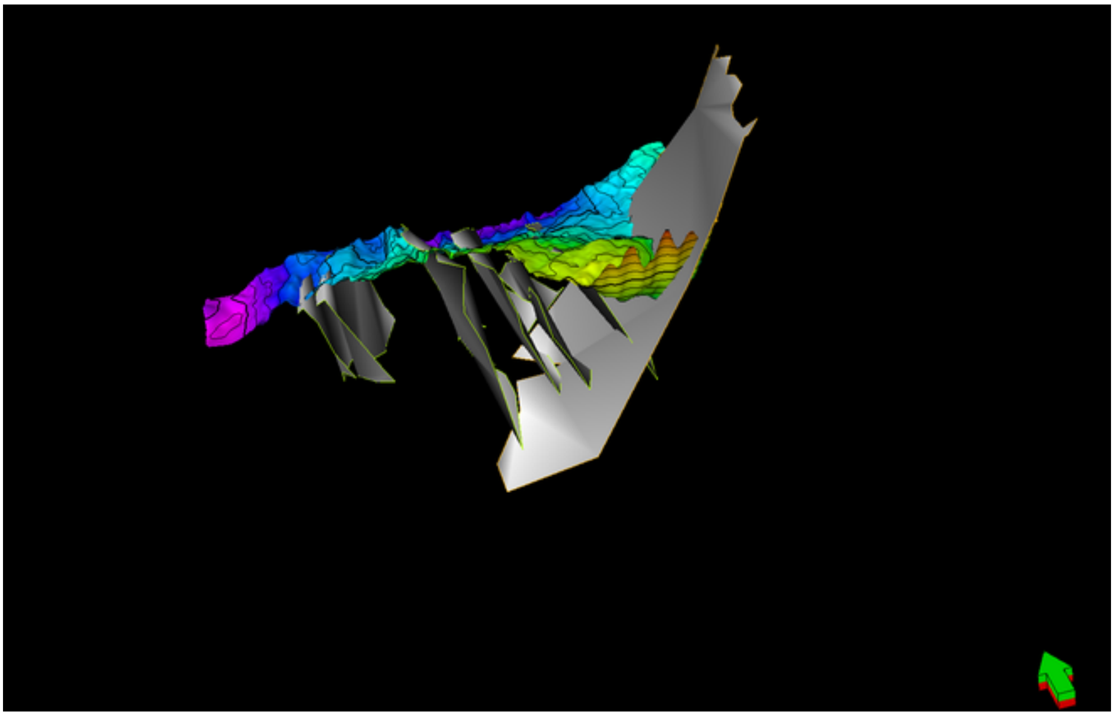


Figure 5: Figure of Formation A with the major faults and the minor faults

3.2.5. Mapping of Horizons

In the Norwegian Sea, one of the most important horizons is the BCU (Sodir, 2024). The BCU is the primary horizon that is interpreted in this study. On seismic profiles, the BCU is featured by a continuous reflector of strong amplitudes and medium frequency. These features make it easy to track over the entire study area. Therefore, automatic tracking is applied during the interpretation of the BCU horizon. For those areas with poorer BCU continuity, for example, along the major faults or at some structural slopes, manual tracking was performed. Besides, horizons along the tops of Rogn and Melke formations are interpreted. The Melke horizon is treated as the base of the Upper Jurassic. Structural maps in TWT are created for the BCU, Rogn, and Melke horizons.

3.2.6. Interval velocity model

In order to present the actual subsurface Upper Jurassic structures, the TWT maps of the BCU, Rogn, and Melke need to be converted to depth domain. To achieve it, this study defined an interval velocity model based on well tops. This velocity model allowed seismic depth conversion by honoring both well top information and interpreted structural trends from TWT structural maps. The thickness map of Upper Jurassic in depth domain is therefore generated by using the BCU structural map subtracted by the Melke structural map.

3.2.7. Seismic Attribute Analysis with RMS amplitude

Seismic attribute analysis is vital in seismic interpretation as it offers supplementary information regarding subsurface properties that extend beyond the direct observations from seismic data. The selection of attributes is contingent upon the geological and geophysical purposes of the interpretation.

The root mean square (RMS) amplitude attribute provides a visual representation of the average power of a signal across different regions or areas. It calculates the square root mean of the squares of the amplitudes of the signal within a certain time interval. The higher the acoustic impedance values, the higher the RMS amplitude. The high values of RMS amplitudes may also be related to high porous sandstone, which are potential hydrocarbon reservoirs.

CHAPTER 4. GEOLOGICAL INTERPRETATION

4.1. Well log interpretation and correlation

4.1.1. WELL LOG INTERPRETATION

The stratigraphic correlation in Figure 6 shows the well logs of the Jurassic-Cretaceous intervals.

4.1.1.1. Well 6406/11-1 S

The 6406/11-1 S well encountered strata from the Lower-Middle Jurassic Åre, Tilje, Ror, Tofte, Not, and Melke formations. Upper Jurassic formations are absent. Jurassic formations are directly overlain by Lower Cretaceous Lyr Formation. The absence between the Jurassic and Cretaceous indicates the presence of the BCU.

The Ile and Tilje formations show overall lower GR values, which are around 40 API. By contrast, the rest Jurassic formations show higher gamma ray values. The Ile and Tilje formations are interpreted to be sandstone dominated. Moreover, the Ile Formation shows lower density in the upper most and lowermost parts.

4.1.1.2. Well 6406/12-1 S

The 6406/12-1 S well encountered Middle Jurassic Melke Formation and Upper Jurassic Spekk and Rogn formations. These formations are directly overlain by Lower Cretaceous Lyr Formation. According to the stratigraphic chart, the Rogn Formation is supposed to be capped by the upper part of the Spekk Formation instead of Lyr Formation (Figure 3). Therefore, the BCU is suggested on top of the Rogn Formation.

The GR values of the Rogn Formation is low, with average value around 40 API. By contrast, the Spekk Formation is featured by high GR values that even reached 170 API. The GR log of the Rogn Formation presents an overall funnel shape, with GR values decrease upwards. The Neutron porosity log shows overall higher values in the Rogn formation. Consequently, the Rogn Formation is interpreted to be sandstone dominated, possibly deposited in a coastal-shoreface environment. There are a few intervals in the Melke Formation show relevantly low GR values. The thickness of these intervals is thin, which is usually less than 5 meters.

4.1.1.3. Well 6406/12-2

The 6406/12-2 well also encountered Middle Jurassic Melke Formation and Upper Jurassic Spekk and Rogn formations. Compared to the 6406/12-1 S well, both Rogn and Spekk formations appeared twice, which indicates that these two formations are interlayering to each other. Not like the previous two wells, the Jurassic formations in this well are capped by the Lower Cretaceous Lange Formation, instead of the Lyr Formation. The absence of the Lyr Formation indicates that the BCU was developed between the Spekk and Lange formations.

The GR values of the Spekk Formation is very high, up to 250 API. By contrast, the Rogn Formation present lower GR values. The GR log in lower Rogn unit presents an overall bell shape, with increasing GR values upwards. The DEN log shows an increase in density when it reaches from the Spekk Formation to the Rogn Formation. The deep resistivity log values significantly increased in the Rogn Formation for the first time, with a highest value of around 80 Ohmm. Based on above features, the Rogn Formation in the 6406/12-2 well is interpreted to be sandstone dominated filled with hydrocarbon, possibly deposited in a submarine fan system.

Note that the correlation of the Spekk and Rogn formations between 6406/12-1 S and 6406/12-2 wells are crossing each other (Figure 6). This is a bug caused by Petrel software when a formation has repeated tops.

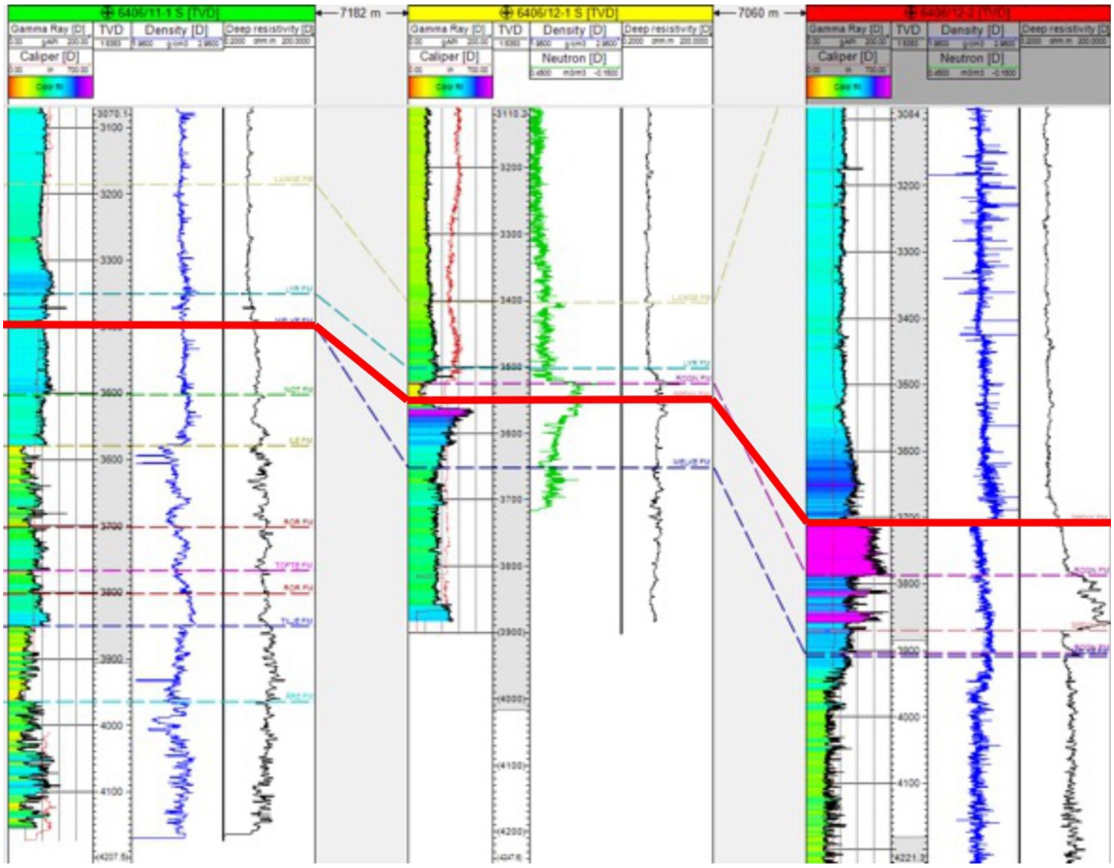


Figure 6: Well log correlation of selected wells in the Fenja field area. Red line is the BCU

4.1.2. Well log correlation

The structural correlation in Figure 6 shows that the buried depth of the top of the Jurassic is increasing from the 6406/11-1 S well (3400m) in the west, via the 6406/12-1 S well (3550m), to the 6406/12-2 well (3780m) in the east. The Melke Formation shows the same trend of buried depth, with 3400 meters in well 6406/11-1 S, 3650 meters in well 6406/12-1 S, and 3900 meters in well 6406/12-2. This eastward deepening of Jurassic formations suggests that the Jurassic strata were possibly tilted. The absent Upper Jurassic in the west indicates that the 6406/11-1 S well was possibly drilled in a structural high.

A stratigraphic correlation panel is made by flattened to the Melke Formation, as shown in Figure 7. The thickness of Upper Jurassic formations shows an overall trend of thickening towards the east, with 0 m in the 6406/11-1 S well, 100 m in the 6406/12-1 S well, and 200 m in the 6406/12-2 well. Both the Spekk and Rogn formations are notably thick in the 6406/12-2 well. This kind of thickness variation trend is common in a rift system, which contains wedge-shaped growth strata in the hanging wall blocks of syn-depositional faults.

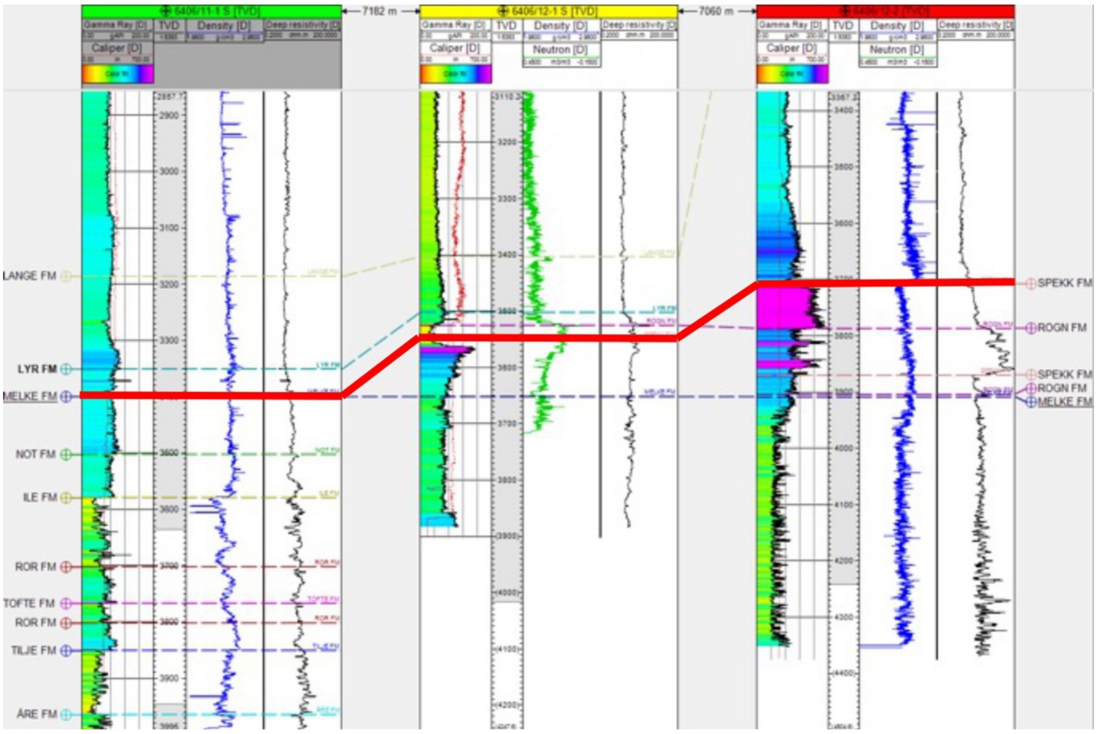


Figure 7: Stratigraphic correlation of selected wells, flattened to the Melke Formation. Red line is the BCU

4.2. Seismic Interpretations

4.2.1. SYNTHETIC SEISMIC-WELL TIE

The synthetic seismogram in Figure 8 shows a satisfactory tie between time and depth domain (Zhong, Escalona, & Augustsson, 2020). In general, the Ricker Wavelet is 25 HZ, with the BCU (red line in Figure 8) as a strong amplitude in a through.

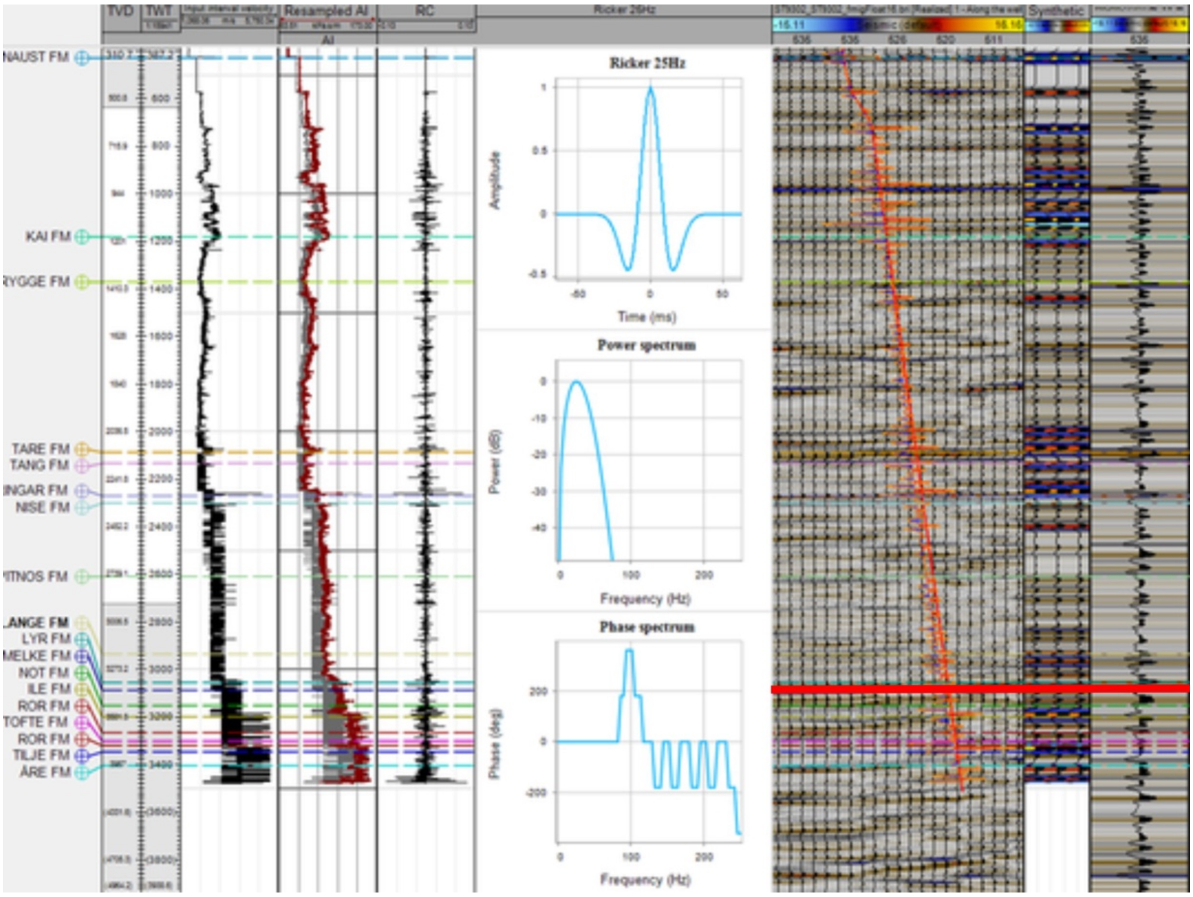


Figure 8: Synthetic seismic with the BCU marked in red

4.2.2. Regional seismic line

The full sandstone interpretation from the well logs is shown in Figure 9.

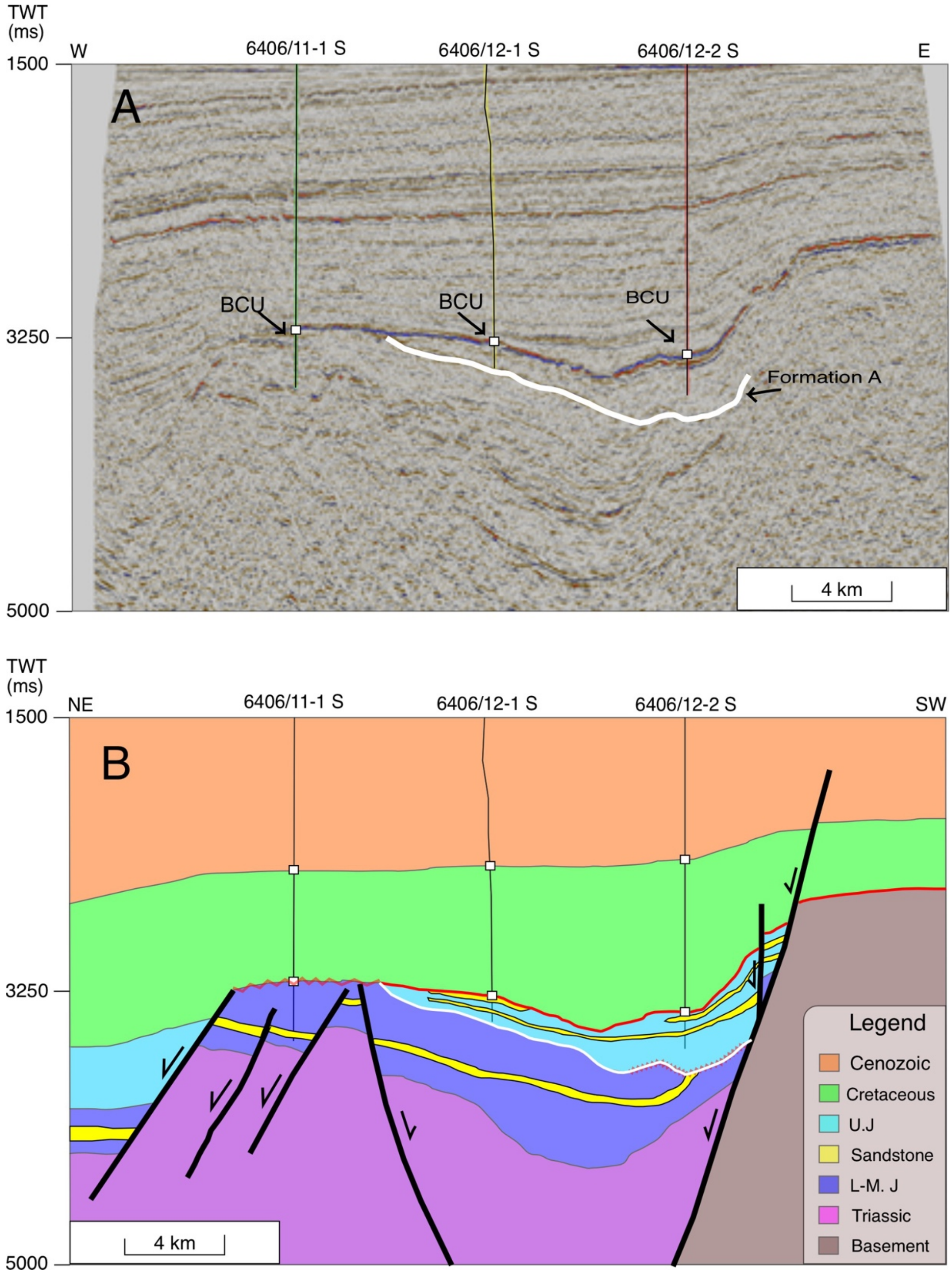


Figure 9: Interpretation of the Fenja Study area. This crossline is shown as a yellow line in Figure 2: location map of study area showing major structural elements in the study area

The interpretation of the regional seismic line shows the BCU together with six faults. There are two major faults visible, which is the one furthest east and the one furthest west. The strong reflector called formation A, visible in Figure 9 A, is truncated by the BCU between well 6406/11-1 S and 6406/12-1 S. The strata below formation A is tilted, while the strata between the BCU and formation A is deposited as a wedge shape.

The above-mentioned observations show block rotations of the Jurassic strata, and the wedge shape is a sign of syn-rift deposition. This combined with the well log interpretation and correlation is made to show the relationship between the faults and the Upper Jurassic sandstone units.

4.2.3. STRUCTURAL MAP OF THE BASE CRETACEOUS UNCONFORMITY (BCU)

The structural map, Figure 10, shows the BCU with the major faults.

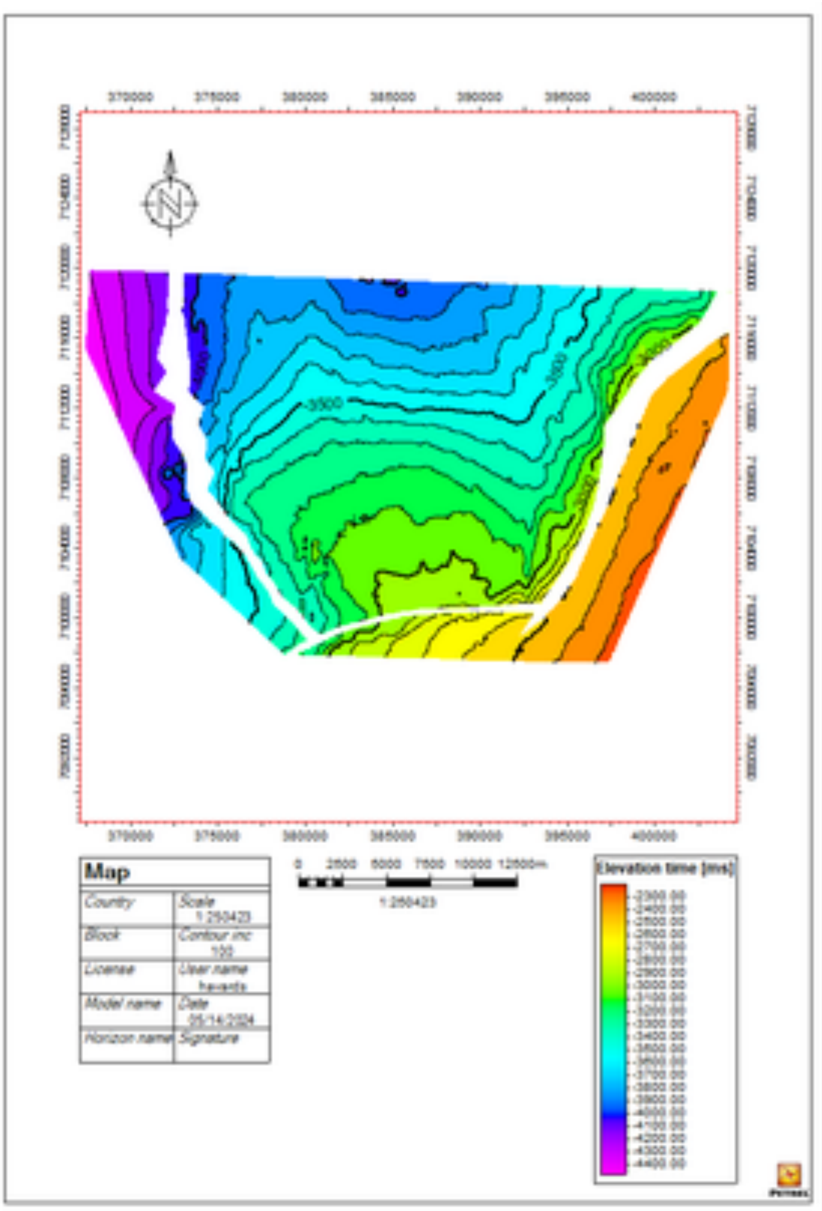


Figure 10: Structural map of the BCU across the study area, showing the major fault that crossed the surface of the BCU

4.2.4. STRUCTURAL MAP OF FORMATION A

Figure 11 shows the structural map of the reference formation which is located below the BCU. This formation together with the BCU, shown in Figure 10, is used to create the RMS amplitude map, Figure 13, that will help to interpret the depositional location and environment for the sandstone.

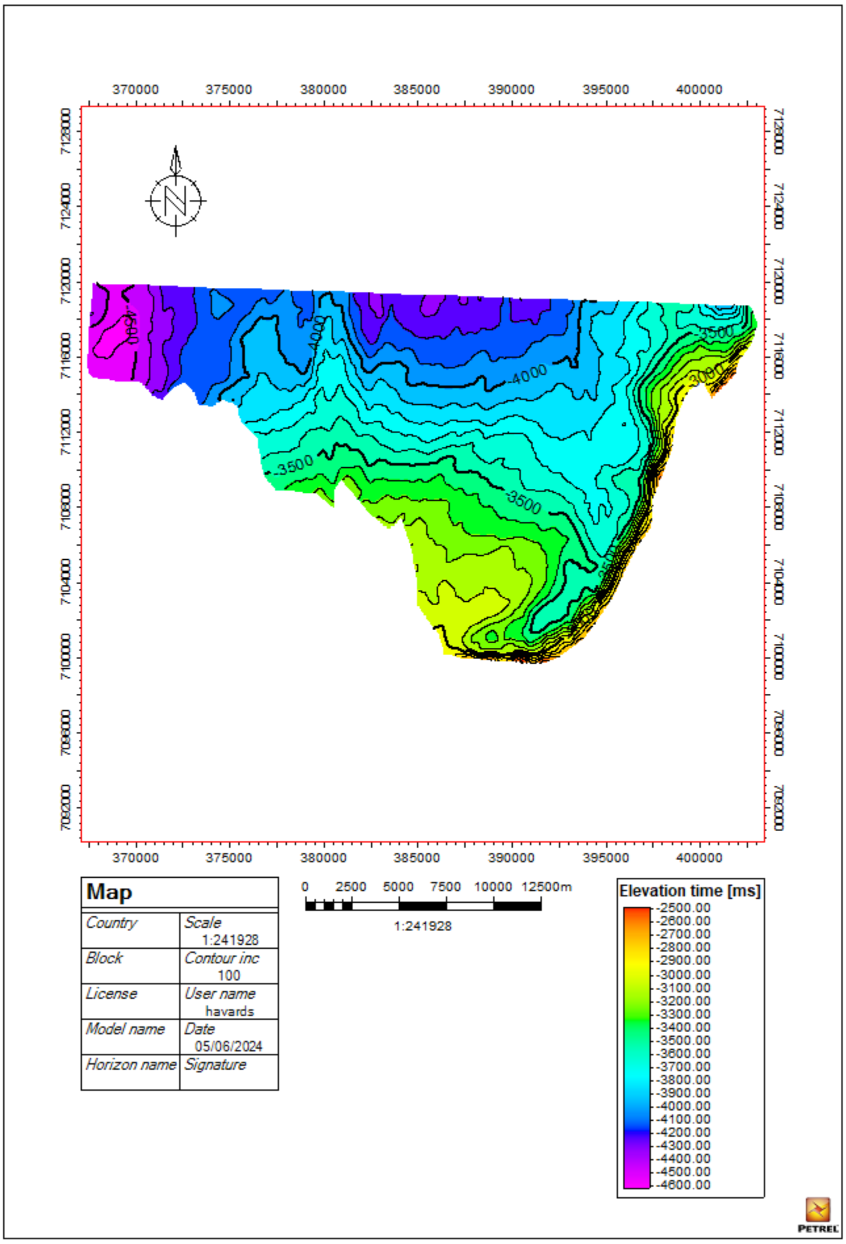
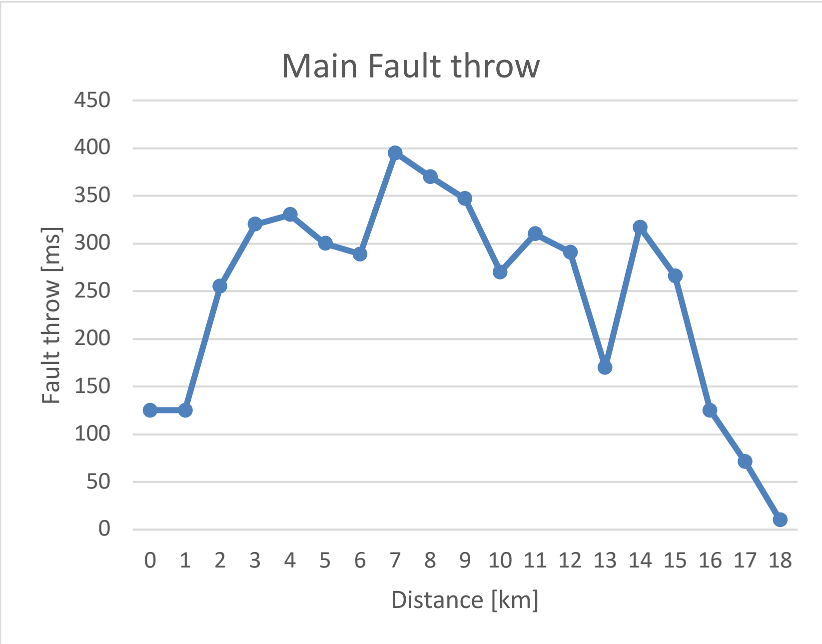


Figure 11: Structural map of formation A below the BCU

4.2.5. FAULT THROW

Figure 12 shows the distribution of fault throw of the eastern boundary fault along the BCU. The fault throw goes from 10ms to 395ms. The throw graph has three peaks, which hints to three previous fault segments. One that peaks at 4 km, one at 8km and the last peaks at 15km. Due to stretching of the strata, the segments would grow and eventually link.

Fault interaction and linkage might pose a significant role in controlling the deposition.



Distance [km]	Throw [ms]
0	125
1	125
2	255
3	320
4	330
5	300
6	289
7	395
8	370
9	347
10	270
11	310
12	291
13	170
14	317
15	266
16	125
17	71
18	10

Figure 12: Distribution of fault throw across the base cretaceous unconformity

4.2.6. RMS AMPLITUDE MAP

This RMS amplitude map is between the base cretaceous unconformity and the reference formation below, shown in Figure 13. The high value of the amplitude is shown in a grey/white color, while the low values are shown as red/green color.

In the RMS amplitude map, there is four areas that have a high RMS amplitude value. Figure 1

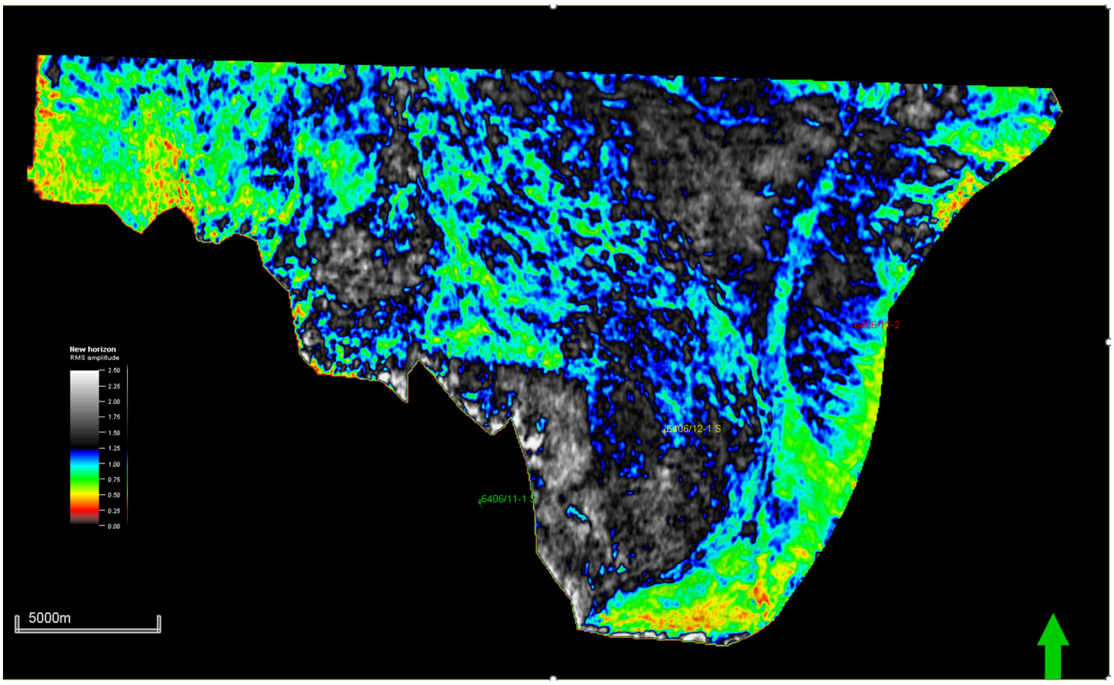


Figure 13: RMS amplitude map between BCU and Formation A

CHAPTER 5. DISCUSSION

5.1. FAULTING OF STUDY AREA

The active faulting in this study area, faults shown in Figure 9 were active during different periods. The lesser faults were active during the Late to Middle Jurassic, while the main fault were active during the Cenozoic. The reason for the interpretation that the main fault was active during the Cenozoic is due to the fault having displaced the formations from the Cenozoic and through to the Triassic. The reason behind the interpretation of the lesser faults is that they have rifted from Lower to Middle Jurassic and well into the Triassic.

The faulting can either have happened during one rifting episode, or multiple faulting phases. Since this area is affected by rifting, then it supports the idea that the rifting took place over different episodes.

The sandstone deposits in the different wells vary in amount of sandstone, the formations containing sandstone as well as the depositional environment that have deposited the sandstone. The sandstone in well 6406/11-1 S, Ile and Tilje, have been deposited during the Lower-Middle Jurassic. The sandstone in 6406/12-1 S, Rogn and Melke formation, and the sandstone in 6406/12-2 has been deposited in the Upper Jurassic. The depositional environment of this study area is a marine depositional environment, this is due to it being in the Norwegian Sea.

5.2. SANDSTONE DEPOSITION IN 6406/11-1 S

The sandstone in well 6406/11-1 S has likely been deposited as a shoreface depositional environment. This interpretation is supported by the flasser bedding with variation of claystone and sandstone in the Ile and Tilje formations. Flasser bedding is created in area where there is deposition of sand which is carried by waves, water currents or tides. The flasser bedding showed up as alternating layering of sandstone and claystone in the well log and showed up as high and low amplitude in the seismic. The altering gamma ray value for sandstone and claystone is shown in Figure 14.

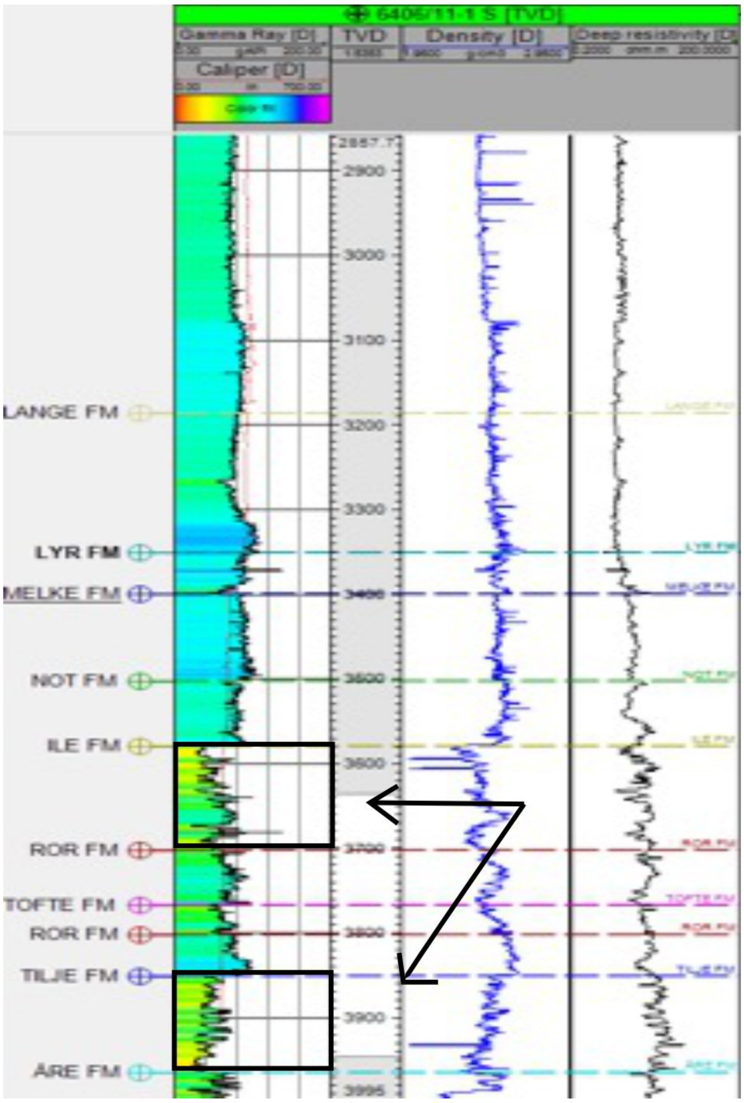


Figure 14: Well log of 6406/11-1 S showing the sandstone and claystone varying in Ile and Tilje

5.3. Sandstone deposition in 6406/12-1 S

The sandstone in well 6406/12-1 S has likely been deposited as a fan in a shoreface environment. The sandstone has likely been coming from an island that have been eroded by the sea, and the mass been deposited as the fan. This interpretation comes from the seismic, Figure 9, where it is visible that the area has been eroded by the BCU, and the sandstone is located West from where the Upper Jurassic is completely eroded away.

5.4. Sandstone deposition in 6406/12-2

The repetition of formation Rogn and Spekk in well 6406/12-2 could be caused by a couple of different methods. The first idea was that it was a reverse fault, causing the well to go through the same formations twice.

This reverse fault would then have to come after the deposition of these formations and would move the hanging wall upwards. The fault would need to be small, since there is no repetition of the formations above and below the Spekk formation.

The further the interpretation of the field got, the more unlikely this idea seemed. The second idea is much more logical and makes more sense based on the seismic and well log.

The sandstone in well 6406/12-2, Rogn and Melke, have likely been deposited as a sub-marine fan, where the sandstone deposits have been molded and affected by the waves and currents in the ocean. The reason for the formations Rogn and Spekk showing up twice in the well log is because the waves and currents caused the sandstone deposits to stick out in two places, which this well is going through. Since the depositions of the Rogn sandstone happened at the same time as Spekk claystone formation, then the sandstone was surrounded by claystone. This caused the Spekk formation to show up twice as well. The total interpretation of the well log correlation is shown in Figure 15.

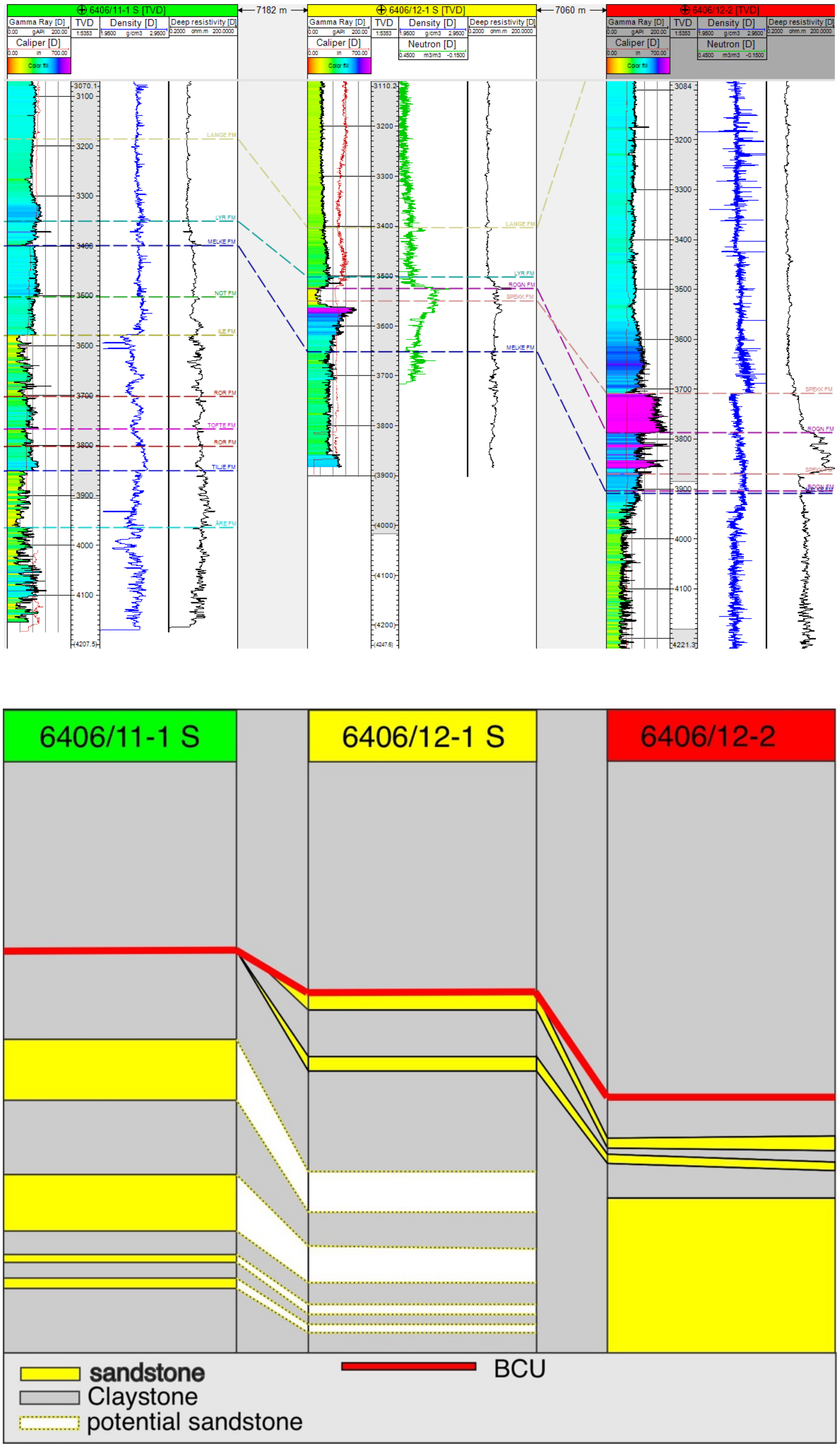


Figure 15: Complete interpretation of sandstone locations in a structural correlation.

5.5. Sandstone deposition from the RMS amplitude map

Figure 16 shows the interpretation of the sandstone deposition on the RMS amplitude map shown earlier in Figure 13. The area is cut off at the east by the main fault and is cut off at the south-west by an unconformity which most likely is erosion. This fault throw distribution is shown earlier in Figure 12. The RMS amplitude map in Figure 16 has four different sandstone depositions in different areas, and the interpretation is that the sandstone has been deposited from the direction of the yellow arrows.

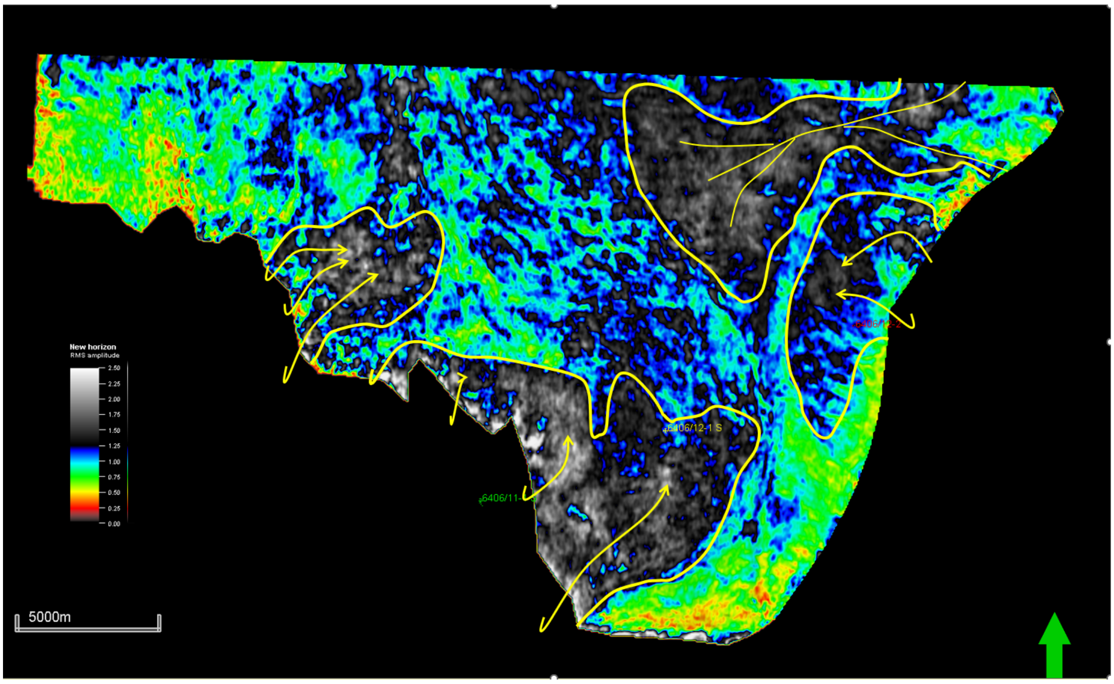


Figure 16: RMS amplitude map with sandstone interpretation

5.6. Final interpretation of sandstone deposition in the RMS amplitude map

The full interpretation of the sandstone deposition is shown in Figure 17. This shows four different sandstone deposits, SST 1-4. SST 1 might be deposited at a shoreface depositional area. Since SST 2 has been deposited in a similar area as SST 1, then this is also deposited in a shoreface depositional system. SST 4 has been deposited as a sub-marine fan, due to its shape and the distance the sandstone has traveled from its source. Due to the linkage of the three smaller faults into the major fault, one can assume that the SST 3 and 4 are on different sides of one of the smaller faults, and has thus been deposited on each side of the fault. This means that SST 3 and 4 has been deposited from the same source. This leads to the assumption that SST 3 is also a sub-marine fan.

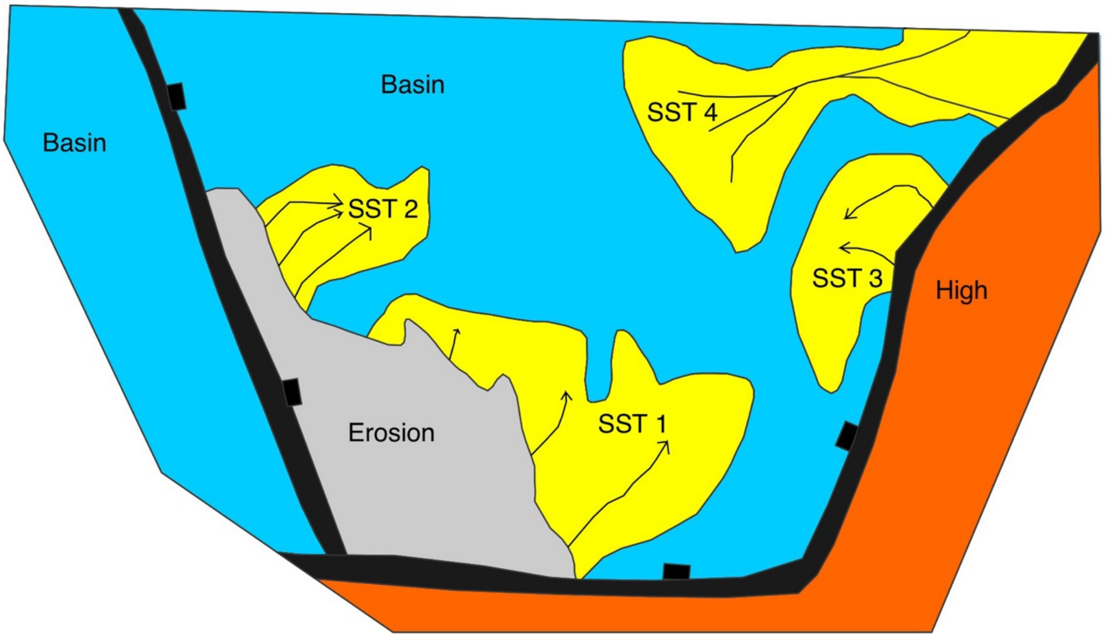


Figure 17: Full interpretation of sandstone deposits

CHAPTER 6. CONCLUSION

In conclusion, this study has provided valuable insights into the sandstone deposits of the Fenja area within the Norwegian Sea's continental shelf. By analyzing data from three wells equipped with seismic data and well logs, various depositional environments and structural characteristics have been identified and interpreted.
The study area's geological setting, situated within a marine depositional environment, reflects a complex interaction of tectonic processes and sedimentary deposition. Through structural and stratigraphic correlations, as well as seismic interpretation, sandstone deposits were located across the wells, each exhibiting distinct depositional characteristics.

Well 6406/11-1 S revealed sandstone deposition suggesting a shoreface environment in the Tilje and Ile formations, while well 6406/12-1 S showcased sandstone that could be deposited as a sub-marine fan within the Rogn and Melke formations. Moreover, well 6406/12-2 suggested a marine delta depositional environment or a sub-marine fan within the Rogn and Melke formations.

Fault mapping identified one major fault within the study area, influencing sedimentation patterns and depositional environments. The findings contribute to a deeper understanding of the Norwegian Sea's geological dynamics, particularly the Jurassic-era depositional environments and tectonic activities.

This integrated geological analysis is crucial for informing future exploration efforts in offshore oil and gas reserves, bridging knowledge gaps and enhancing understanding of rift basin formations. By clarifying the complexities of sandstone deposition and structural characteristics, this study paves the way for more targeted exploration strategies and resource management in the Norwegian Sea.

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