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Petroleum System Analysis in Skrugard Area, SW Barents Sea

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Abstract

In 2011, Skrugard discovery (well 7220/8-1) made an explorational breakthrough in the south- western Barents Sea. Earlier this year, Havis discovery (well 7220/7-1) was found in the same area. Both two discoveries are in the production license PL 532. However, there are many dry wells (7219/9-1, 7219/8-1S) in the same area before these two discoveries. The objective of this master thesis is to figure out why there found commercial hydrocarbon in Skrugard and Havis rather than other areas close to them, furthermore contribute to a better understanding of the petroleum system in the south-western Barents Sea.

Key words: South-western Barents Sea, Petroleum system, Skrugard, Harvis

Contents

1. Introduction

1.1 Introduction of Barents Sea

Barents Sea is located north part of Europe, which is the greatest shelf area surrounding the Arctic Ocean (Fig. 1). Physiographically, the Barents Sea is the region bracketed by the north Norwegian and Russian coasts, the Novaya Zemlya, Franz Josef Land and Svalbard archipelagos, and the eastern margin of the deep Atlantic Ocean (Dore, 1995). The area of Barents is 1.4 million km^3 with an average water depth of 230 m.

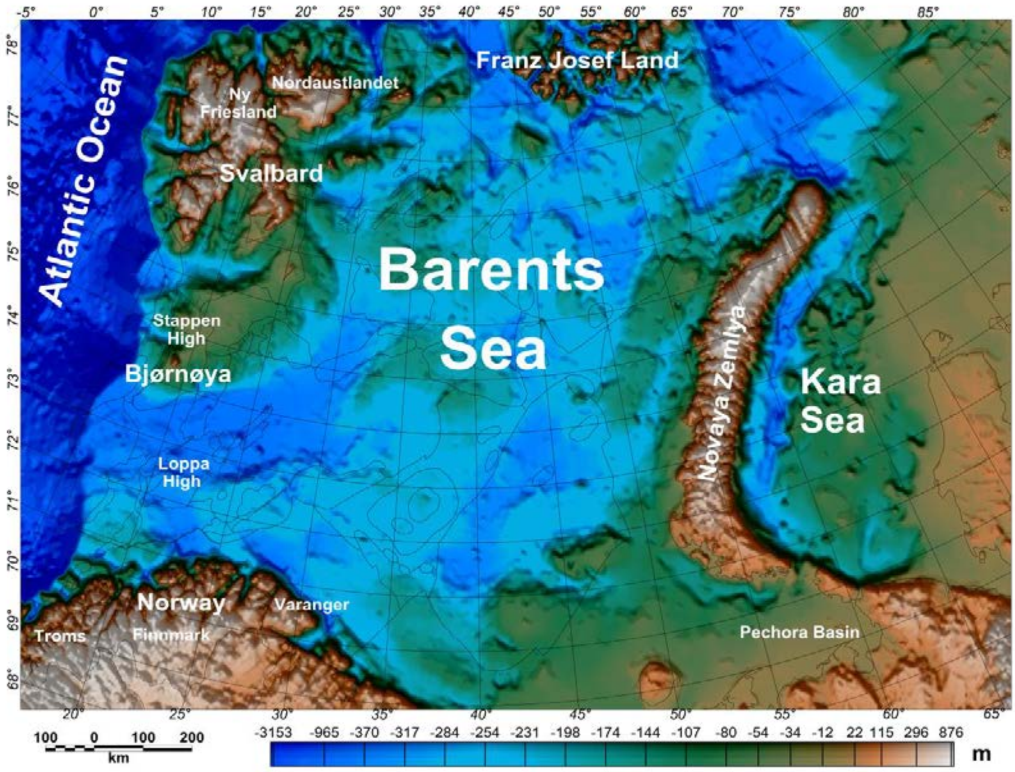

Fig. 1 Geography of Barents Sea

There are Cenozoic passive margins in the west and north parts of the Barents Sea. The eastern continental shelves are long-wavelength basins structures, while western continental shelves are narrower rift basins structures (Cécile, 2009).

In Norwegian waters, there are proven resources of 260-300 billion cubic meters of gas and minor oil, with most reserves being in Jurassic, and to a lesser extent Triassic sandstones (Stilwell, 2012).

Because of rich potential petroleum, the border problem of Barents Sea is disputed 40 years between Norway and Russia. However, they signed an Arctic border agreement in 2010 and made the agreement of the Barents Sea border (Fig. 2).

Fig. 2 Agreed border in Barents Sea

1.2 Exploration Status

Norway began to do exploration activities in the Barents Sea in 1979, when the first license was awarded in this area. The first well was drilled in 1980, and gas was discovered in Jurassic sandstones in the Alke field. In the following decade, more wells were drilled and thousands of hydrocarbons were discovered in the Barents Sea. In 1989, the Priraslomnoje structure on the Pechora Block was drilled and the oil was proved in Lower Permian to Carboniferous carbonates.

Historically, development of the Barents Sea area is disappointing. Almost 90 exploration wells were drilled in Barents Sea south, most of them have failed to prove significant hydrocarbons, and some discoveries are considered to be non-commercial or only marginally commercial. Another reason for its slow development is its mainly gas-prone system, most discoveries are gas and rare oil (Fig. 3). Some discoveries have been made, exciting prospects are to be found, and a number of possible prospects are under discussion.

In 2011, Skrugard discovery (well 7220/8-1) made an explorational breakthrough in the south- western Barents Sea. Earlier this year, Havis discovery (well 7220/7-1) was found in the same area. These two discoveries are in the same Production License (PL

532), which is operated by Statoil, ENI and Pedro. Skrugard is located on the west flank of Loppahøyden (Polheim sub-platform), a steeply sloping with narrow, rotated fault blocks towards Bjørnøyabassenget.

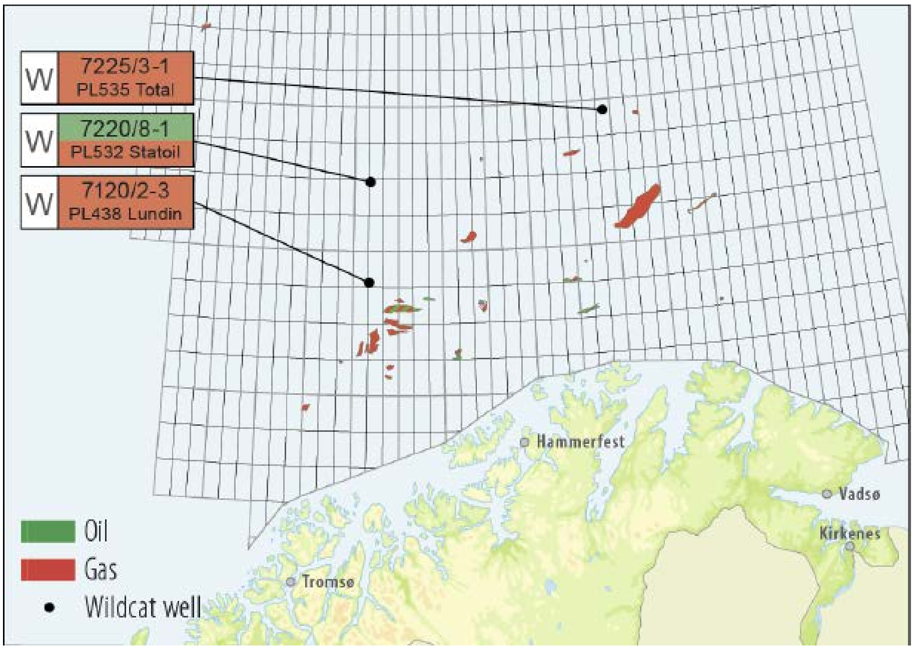

Fig. 3 Discoveries in Barents Sea

There have been drilled 95 exploration wells in the Norwegian part of the Barents Sea, but there are only three commercial oil discoveries (Goliat, Havis and Skrugard) and one large gas discovery (Snøhvit). The success of exploration rate is very low in this area. In the Barents Sea west margin, there have been drilled less than 15 exploration wells so far, which distributed in 40,000 km2 area. Comparing to this, there have been drilled 1150 wells in 170,000 km^2 area in North Sea. Well density is very low in Barents Sea, so it is a very frontier area now.

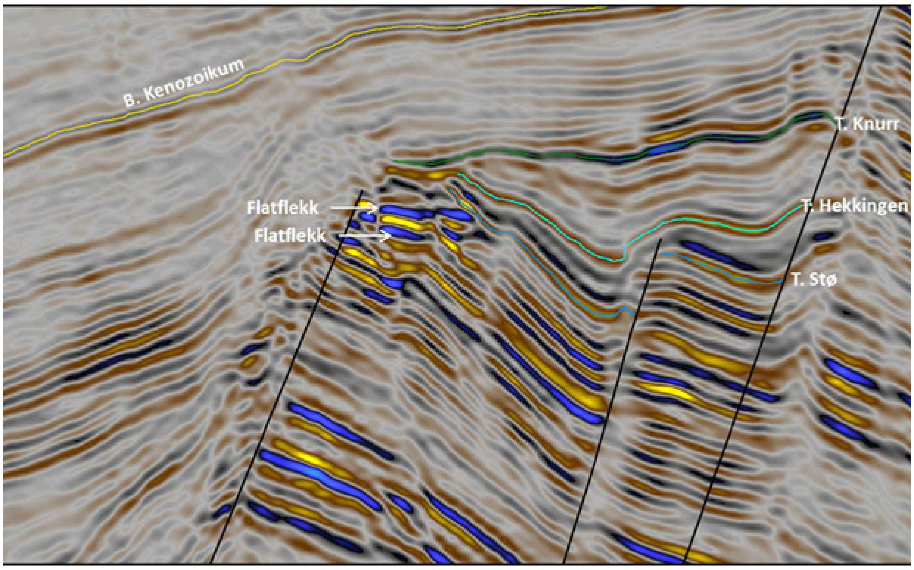

Fig. 4 Double flat spot was found in Skrugard

1.3 Geological Evolution

The Barents Sea consists of a complex of platform areas and basins, formed by two major continental collisions. The first collision event, the Caledonian orogeny (mountain-building episode), culminated approximately 400 million years ago. This collision made the Laurentian plate and the Baltic plate connected into the Laurasian continent. The second collision was created by a further collision between the Laurasian continent and Western Siberia, ended approximately 240 million years ago. This collision created the eastern margin of the Barents Sea (Dore, 1995).

The Barents Sea area has undergone several phases of tectonic and sedimentation. There are five widely recognizable phases of basin in the area:

i) Devonian - Middle Carboniferous

ii) Middle Carboniferous to Permian

iii) Triassic - Jurassic

iv) Late Jurassic to Early Cretaceous

v) Tertiary Deformation

1.4 South-western Barents Sea

In the western Barents Sea, the continental margin extends about 1000 km in NNW direction. It was comprised by three major structures: a southern sheared margin along the Senja Fracture Zone; a central volcanic rift segment; a northern, sheared and subsequently rifted margin along the Hornsund Fault Zone (Ryseth et al. 2003).

The evolution of the southern sheared margin is closely linked to the opening of the Norwegian - Greenland Sea (Skogseid et al. 2000). There are three main tectonic phases: 1) continent- continent transform prior to crustal break-up, 2) ocean- continent transform as the Atlantic spreading ridge propagated northwards along the shear zone, 3) a passive continental margin with no shear movement as the spreading ridge shifted still further to the north (Vågnes et al. 1997). This margin separates the Lofoten Basin, which contain mainly Neogene sediments (Ryseth et al. 2003).

The southwest Barents Sea area includes the Bjørnøya basin, Sørvestsnaget basin, Tromsø basin and Harstad basin, which is a province of particularly deep Cretaceous and Cenozoic basins. Sørvestsnaget basin, Bjørnøya basin and Tromsø basins have equal rates of Early Cretaceous subsidence.The Sørvestsnaget Basin subsequently showing more pronounced Late Cretaceous and Cenozoic subsidence than the Tromsø- and Bjørnøya basins (Breivik et al. 1998).

The south-western Barents Sea is divided into three distinct regions (Gabrielsen et al., 1990; Faleide et al., 1993) (Fig. 5).

1. The Svalbard Platform, a stable platform since Late Paleozoic covered with a relatively flat underlying sequence of Upper Paleozoic and Mesozoic, mainly Triassic sediments.

2. The Basin Province, characterized by number of sub basins and highs with increasing structural relief westward between Svalbard Platform and Norwegian Coast. The sediments deposited in these basins are Jurassic – Cretaceous while the western side of the basin is dominated by Paleocene – Eocene Sediments.

3. The western margin, divided into three main segments (a) a southern sheared margin along the Senja Fracture Zone (SFZ); (b) a central rifted complex south-west of Bjørnøya associated with volcanism (Vestbakken Volcanic Province); and (c) a northern, initially sheared and later rifted margin along the Hornsund Fault Zone (HFZ). The continent-ocean transition occurs over a narrow zone along the line of Early Tertiary breakup and the margin is overlain by a thick Upper Cenozoic sedimentary wedge.

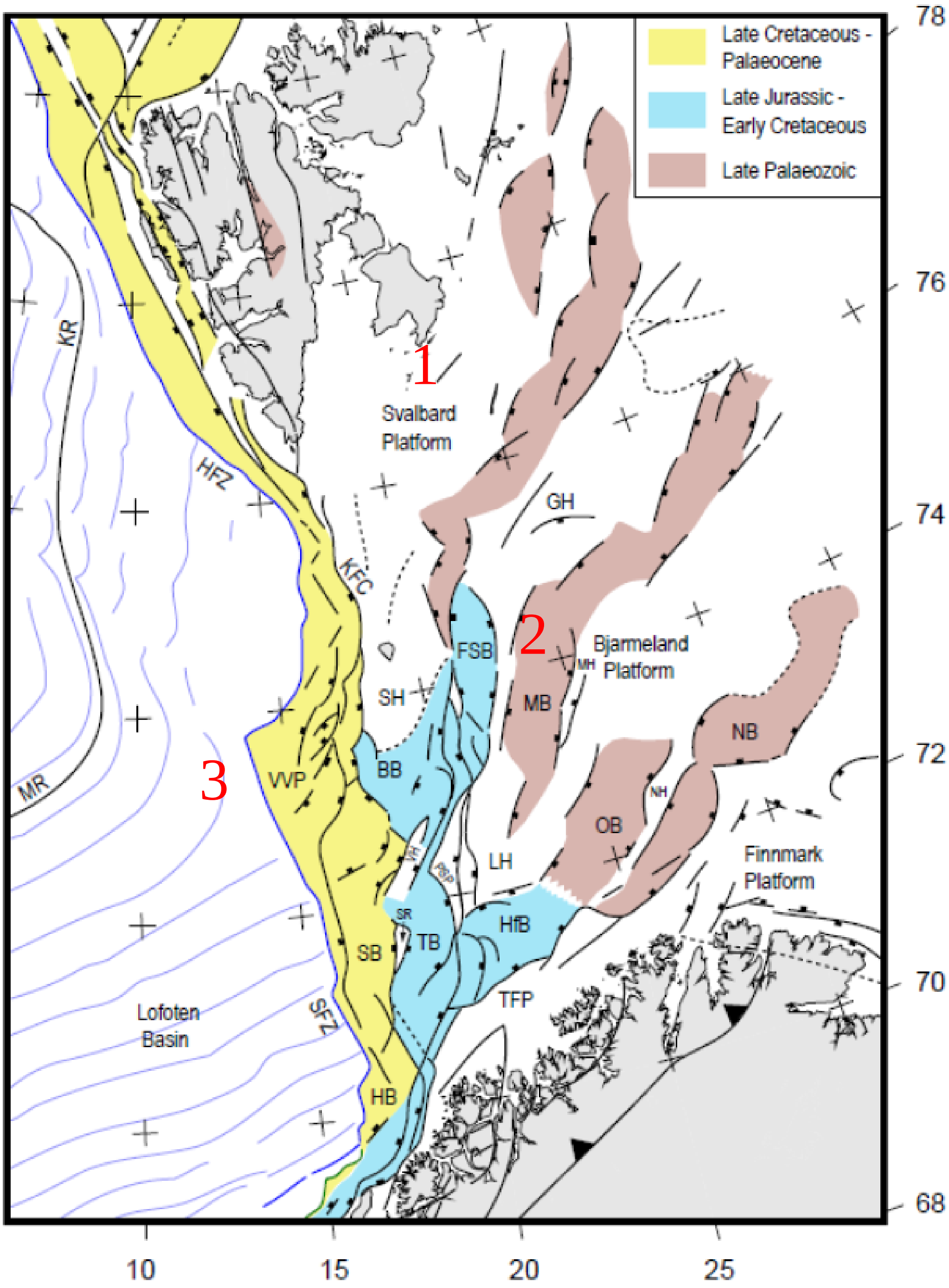

Fig. 5 Main structural elements in the western Barents Sea and adjacent areas (modified from Faleide et al., 2010). Numbers 1-3 shows location of three geological provinces.

BB = Bjørnøya Basin, FSB = Fingerdjupet Sub-basin, GH = Gardarbanken High, HB = Harstad Basin, HfB = Hammerfest Basin, HFZ = Hornsund Fault Zone, KFC=Knølegga Fault Complex, KR = Knipovich Ridge, LH = Loppa High. MB = Maud Basin MH = Mercurius High, MR = Mohns Ridge, NB = Nordkapp Basin, NH = Nordsel High, OB = Ottar Basin, PSP = Polheim Sub-platform, SB = Sørvestsnaget Basin, SFZ = Senja Fracture Zone, SH = Stappen High, SR = Senja Ridge, TB = Tromsø Basin, TFP = Troms-Finnmark Platform, VH = Veslemøy High, VVP = Vestbakken Volcanic Province.

1.5 Structure Elements

The study area is located across the Loppa High (including Polhem Sub-platform) and Bjørnøya Basin (Fig. 6). In order to figure out the analysis and discuss the petroleum system in this area, the adjacent structural elements should be described here. The Skrugard fault is one of the parts of the Bjørnøyrenna Fault Complex, and it will be considered as one of the aspects in affecting Skrugard oil province.

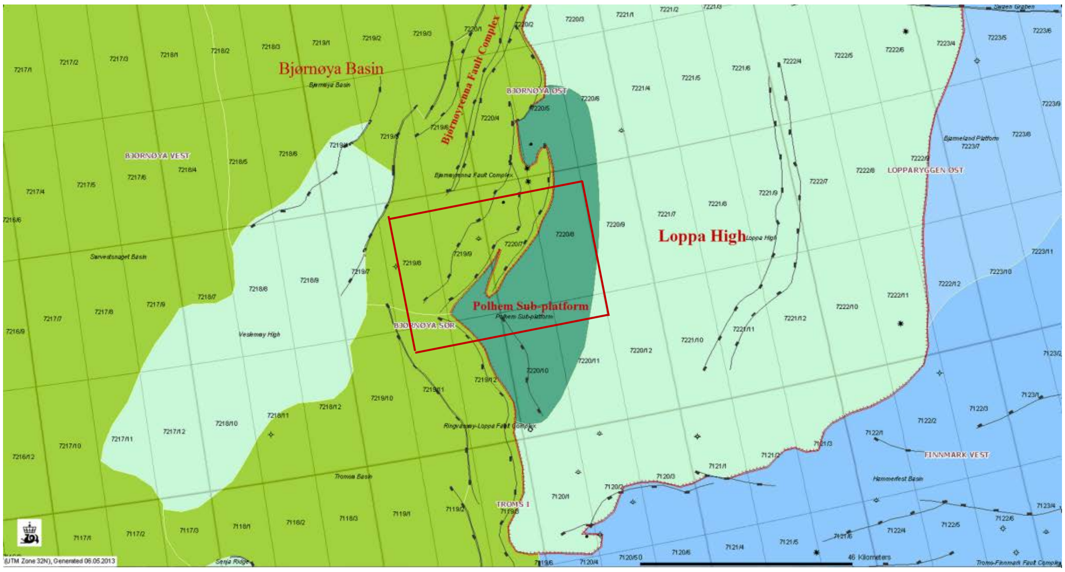

Fig. 6 The location of the structural elements adjacent to the study area (red outline)

1.5.1 Loppa High

The eastern study area is located on Loppa High, which is an elongated, structural high in the south-western Barents Sea. To the south, the Southern Loppa High Complex called Asterias Fault Complex is referred to the boundary between the Loppa High and Hammerfest Basin. The NNE-SSW rotated fault blocks called Ringvassøy-Loppa Fault Complex, which separates the Loppa high and Tromsø Basin in the west. The Bjørnøyrenna Fault Complex is referred to the boundary between the Loppa High and Bjørnøya Basin in the northwest (Berglund et al. 1986). There is a major salt structure called Svalis Dome in the north-eastern limit of the high, and it is associated with a rim syncline. The Loppa High is associated with positive Gravity anomalies from 0-70mGal, and magnetic anomalies from 100- 900nT. The anomalies are caused by a relatively shallow metamorphic basement from Caledonian age underlying the western part of the high (Barrére et al., 2009; Gabrielsen et al., 1990).

The Loppa High has been repeated as a high at least four times since Dovonian time. The high now is formed by the Late Jurassic to Early Cretaceous and Late

Cretaceous-Tertiary tectonism period. This area has undergone several uplifts, subsidence, tilting and erosional events including tensional and compressional regimes, that resulting in the complex tectonic pattern of the Loppa High. The first generation of the high is Carboniferous time, and the strike-slip tectonics influenced the area. Mesozoic extensions were followed by Permo-Carboniferous E-W extension, and the deep lying Paleozoic reflectors give the evidence of vertical displacement in the Loppa High area. Late Permian and Early Triassic extension resulted in tilting and erosion of the crestal parts of the Loppa High, and it is the time when was the first major uplift happened. Selis Ridge, formed during this period, was a narrow N-S trending ridge situated in the western part of present day Loppa High. The Loppa High area was still positive structural feature until Early to Mid-Triassic time. During this period, pre-Triassic E-W extension faults changed to compression faults forming the NNE-trending faults (Stemmerik et al., 1995). The High turned into a deposition center from Late Triassic to Mid Jurassic period (Larssen et al., 2005). In Late Jurassic to Cretaceous time, extension related to the Late Kimmerian event lead to happen uplifted and erosion again, generating NE-SW and NW-SE faults in Loppa High. A Mesozoic fault pattern which has two shear planes with compression and tension features shows the strike-slip tectonics. In Early Tertiary time, the Loppa High was part of the shallow Barents Sea shelf and it was unlifted and erided again in Neogen period (Wood et al., 1989). In Late Tertiary, the uplift resulted in the erosion of covered Palaeogene shale.

The structurally complex Loppa High area indicates considerable petroleum potential. Three exploration wells (7120/1-1, 7120/2-1 and 7121/1-1) drilled on the Loppa High, and all the wells are penetrating the Upper Palaeozoic succession.

1.5.2 Polhem Sub-platform

Polhem Sub-platform is located between the Loppa High to the east and the Bjørnøyrenna Fault Complex and Ringvassøy-Loppa Fault Complex to the west, where it forms the block-faulted area. There formed a positive, tectonically active element of Loppa High during Late Paleozoic times. In the Early to Middle Triassic it was downfaulted relative to the crest of Loppa High. The platform is heavily deformed by faulting starting in Permian, and increasing in Triassic and became listric normal faults during Jurassic to Early Cretaceous period. The listric normal faults had a detachment surface deeper than the base of the Triassic. The Jurassic rocks have been eroded from the platform. During the creation of the Ringvassøy-Loppa Fault Complex the sub-platform slid westward and formed the structural pattern of rotated fault blocks (Gabrielsen et al. 1990). The Jason Fault Complex separated the Polhem Sub-platform and the Loppa High. The Jason Fault Complex is N-S trending and is connected to Leirdjupet Fault Complex to the north and Ringvassøy-Loppa Fault Complex to the south (Glørstad et al., 2010).

1.5.3 Bjørnøya Basin

The Bjørnøya Basin is NE-SW trending and is separated into a deeper part (west) and a shallow part (east) by the Leirdjupet Fault Complex. The basin is bounded by Bjørnøyrenna Fault Complex to the southeast, and a faulted slope from the Stappen High to the northwest.

The form of Bjørnøya Basin is relative to the Early Cretaceous subsidence, and it seems filled very thick Early Cretaceous sediments. The upper part of the sequence has been eroded. This basin has a negative gravimetric anomaly and the depth to basement is considered about 11-13km (Roufosse, 1987). The gravimetric measurements indicate a possible palaeobasin formed earlier than the present Bjørnøya Basin in Late Carboniferous to Permian time (Ziegler, 1988). The structure of central area in the Bjørnøya Basin is not complicated, while the boundaries have some complex structures such as Bjørnøyrenna Fault Complex. There are some faulting and inversion related to the Bjørnøyrenna Fault Complex from the Late Cretaceous and Tertiary in this basin, and it can be interpreted as a half-graben (Gabrielsen et al., 1990).

There are some dome structures interpreted in the Bjørnøya Basin in previous paper (Faleide et al.,1984), while others investigated that there are no salt diapirs exist there (Rønnevik et al., 1984). Based on the new seismic interpretation of the Bjørnøya Basin, there maybe have some dome structures but must exist in deeper parts.

1.5.4 Bjørnøyrenna Fault Complex

Bjørnøyrenna Fault Complex is NE-SW trending, and it is situated in the boundary between the Loppa High to the southeast and the Bjørnøya Basin to the northwest. This complex terminated to the south at the tectonically complicated area at the northern termination of the Tromø Basin. (Gabrielsen et al., 1990).

The Bjørnøyrenna Fault Complex is formed by extension of the basin. The vertical displacement measured in reflection seismic sections varies along strike between approximately 3s and 6s (TWT) at Upper Triassic levels. In general, the complex is termed as the normal faults with large throws, and there are some associated dome structures in some places. However, signs of inversion are abundant, and domal features, deformed fault planes, reverse faults and strong deformation of footwall blocks have been reported. A marked dome feature is found in the complex where there is only one master fault in a narrow zone. (Gabrielsen et al., 1990).

The Bjørnøyrenna Fault Complex was active in the Late Jurassic to Early Cretaceous, and reactivated in Late Cretaceous and Tertiary times. The main faults are in Palaeozoic and older origin and were reactivated several times during the Mesozoic and Tertiary

(Larssen et al., 2002). In Cretaceous, the complex is a weak zone because of the thick sediments represented in the southeastern boundary. In Middle Jurassic to Early Cretaceous, this area is dominated by the extension and subsidence. In Early Cretaceous, the reverse faults associated with minor hang wall folder formed. In Late Cretaceous, the basin subsidence again and formed several major inversion faults (Gabrielsen et al., 1990).

1.6 General Stratigraphy of South-Western Barents Sea

1.6.1 Paleozoic Succession

Based on the well data, the Barents Shelf penetrated down to the Permian strata. The Permo-Carboniferous rocks are distributed in the Barents Sea, which are considered to be similar as those of Svalbard, Bjørnøya and Northeast Greenland (Faleide et al., 1993). From borehole and deep seismic reflection/refraction data, the presence of the late Paleozoic strata is thought to be the deepest sequence in the south-western Barents Sea (Jackson et al., 1990; Faleide et al., 1991; Faleide et al., 1993). The Triassic strat is present throughout the Barents Sea, and it shows transgressions and regressions deposition (Mørk et al. 1989).

Falk Formation belonged to Gipsdalen Group, which covers from mid-Carboniferous to early Permian succession. The Falk Formation composed of a mixture of shallow marine sandstone, siltsone and shallow marine carbonates. All this depositions are interpreted to be in shallow marine shelf environment. Age assigned to be of late Bashkirian to early-middle Gzelian (Dalland et al., 1988).

Ørn formation is composed shallow marine carbonates, interbedded carbonates and evaporates, which is deposited in shallow marine carbonate environment as a result of high frequency and high amplitude fluctuation of sea level changes. Age assigned to be of late Gzelian to early Sakmarian (Dalland et al., 1988).

1.6.2 Mesozoic Succession

Snadd Formation is composed of grey shale, which is coarsening upward into shale interbedded with grey siltstone and sandtone. Limestone and calcareous interbed with thin coaly lens can be recognized in the lower and middle part of formation. It is interpreted to be deposited in distal marine environment with age assigned to be of Ladinian to early Norian (Dalland et al., 1988).

Frulholmen Formation is comprised of grey to dark grey shale with interbedded sandstone, shale and coal. It is deposited in fluviodeltaic environment. Age assigned to be early Norian for the basal part and Triassic/Jurassic for the top part of the formation (Dalland et al., 1988).

Tubåen Formation is composed of sandstone with subordinate shale and minor coals. The sandy unit in the formation represents stacked series of high energy marginal marine environment while coals and shale in the formation represents lagoonal environment (Dalland et al., 1988).

Nordmela Formation is comprised of interbedded siltstone, sandstone, shales and claystones with minor amount of coal and it is interpreted to be deposited in tidal flat to flood plain environment. Age assigned to be of Sinemurian to late Pliensbachian (Dalland et al., 1988).

Stø Formation is composed of moderately to well sorted sandstone with thin units of shale and siltstone are also present. And in some well phosphatic lag conglomerates are also identified. The sandy unit in the formation is interpreted to be deposited in prograding coastal regimes environments. Age assigned to this formation is late Pliensbachian to Bajocian (Dalland et al., 1988).

Fuglen Formation is composed of pyritic mudstone with interbedded thin whit to brownish limestone and dark brown shale. It is interpreted to be deposited in marine environment with age assigned to be of late Callovian to Oxfordian (Dalland et al., 1988).

Hekkingen Formation is composed of brownish grey to dark grey shale and claystone with thin interbeds of limestone, dolomite, siltstone and sandstone. It is assumed to be deposited in deep marine water under anoxic condition. It is of late Oxfordian/early Kimmeridgian to Ryazanian (Dalland et al., 1988).

Knurr Formation is composed of dark grey to greyish brown claystone with thin interbeds of limestone and dolomite. Thin sandstone units can also be recognized in the formation .The formation is assumed to be deposited in open and generally distal marine environment with local restricted bottom condition. It is of Ryanzanian/Valanginian to early Barremuan in age (Dalland et al., 1988).

Kolmule Formation is composed of dark grey to green claystone and shale with thin siltstone interbeds and limestone and dolomite stringers. Traces of glauconite and pyrite can be recognized in the formation. It is interpreted to be deposited under open marine environment and is suggested to be of Aptian to mid-Cenomanian (Dalland et al., 1988).

1.6.3 Cenozoic Succession

Torsk Formation is composed of light to medium grey or greenish grey non-calcareous claystone in some cases stringers of siltstone and limestone can be seen in the formation. Tuffaceous horizons can also be observed in the lower part of the unit. The formation is deposited under open to deep marine shelf environment and is interpreted to be of late Paleocene to Oligocene in age (Dalland et al., 1988).

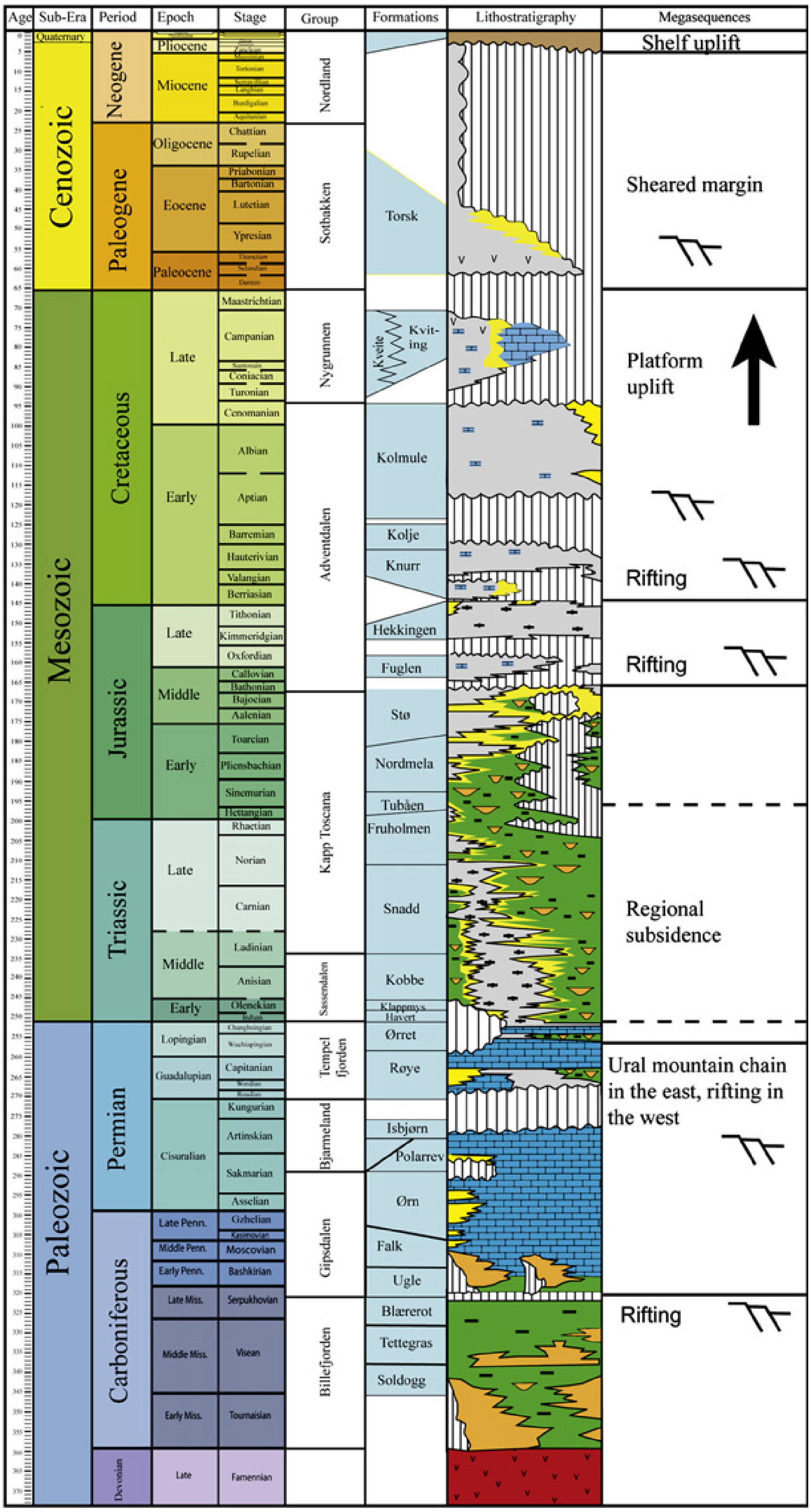

Fig. 7 General stratigraphy of western Barents Sea, with geological Time scale and megasequences (modified from Glørstad-Clark et al., 2010)

1.7 Petroleum System

The petroleum system is defined as a system with active source rock and all related oil and gas. It includes all the geologic processes and elements for oil and gas accumulation. The important elements include the source rock, reservoir rock, seal rock and overburden rock. The essential processes include trap formation and generation, migration and accumulation of petroleum. All the events and processes should be placed right in time sequences and space for the availability of the occurrence of the functioning petroleum system (Magoon et al., 1994).

In the Barents Sea three different petroleum systems: Paleozoic, Early-Mid Triassic and Late Jurassic can be found (Henriksen et al., 2011) (Fig. 8). The petroleum system of the study area contains Late Jurassic system in Bjørnøya basin.

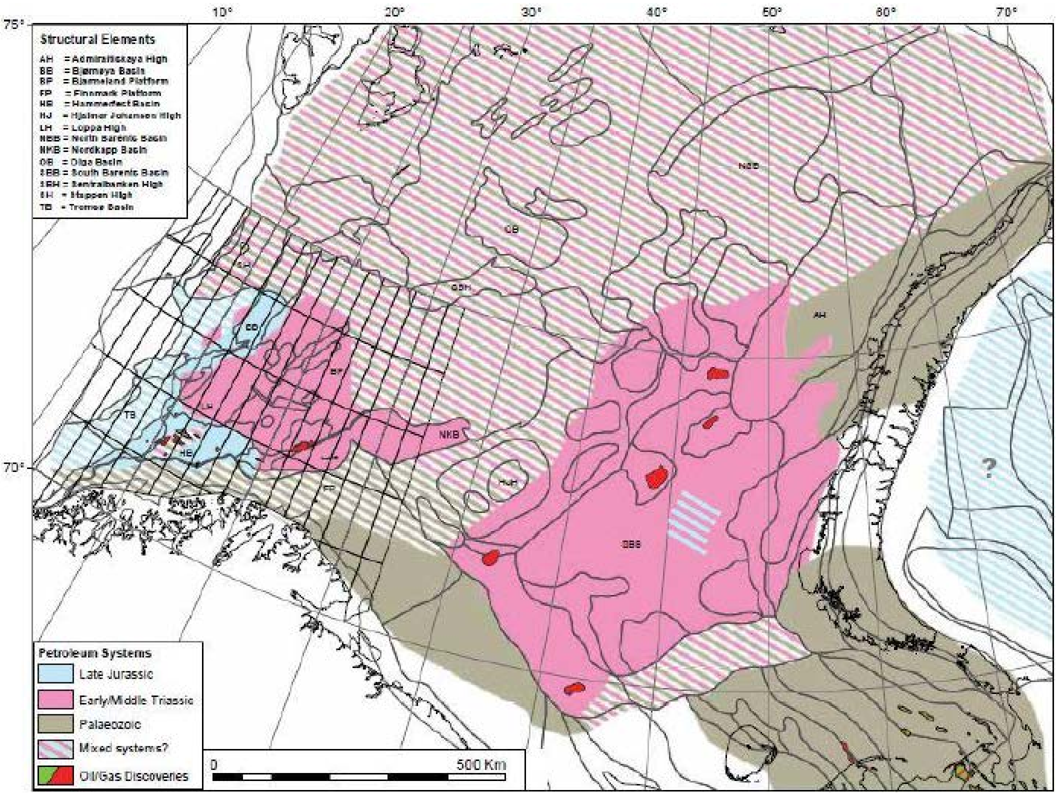

Fig. 8 Petroelum system of the Barents Sea

1.7.1 Source Rock of SW Barents Sea

Source rock is termed as a sedimentary rock that contains sufficient amounts of organic matter of the right type to produce petroleum. It represents in the sediments, and migrates into a reservoir after forming. A typical source rock contains greater than usual organic matter (> 1% TOC in the clastic rocks) which remains preserved in the oxidation environment (Dore, 1995). For the regional aspect, the Hekkingen Formation from Late Jurassic is considered as the source rocks in SW Barents Sea (Fig. 9). Hekkingen Formation is very thick, and it can generate significant quantities of hydrocarbons and extends regionally in the Barents Sea, Early Jurassic Nordmela and Tubåen Formations and Early and Mid Triassic Formations, Snadd, Kobbe, Klappmyss and Havert formations (Dore, 1995). Hekkingen Formation contains dark organic rich shales which were deposited in anoxic deep marine conditions, as consequence of the local barriers to circulation created by the Kimmerian movements (Dalland et al., 1988).

The formation is most prolific because of its total organic carbon (TOC) and the hydrocarbon generative potential (Fig. 9). In the Hammerfest basin, most of the Triassic source rocks enter the oil window, when the Hekkingen Formation is just early mature. This means Triassic source rocks entered into the gas window when the Hekkingen formation is in oil window. During exhumation and erosion In Hammerfest basin, the temperature needed to generate hydrocarbon went down thus preventing further hydrocarbon generation, the main negative consequence of hydrocarbon generation in the uplifted area. However, evidence of non-cogenetic system gas has been reported in this area, which shows a possible live petroleum system in the area (Dore, 1995).

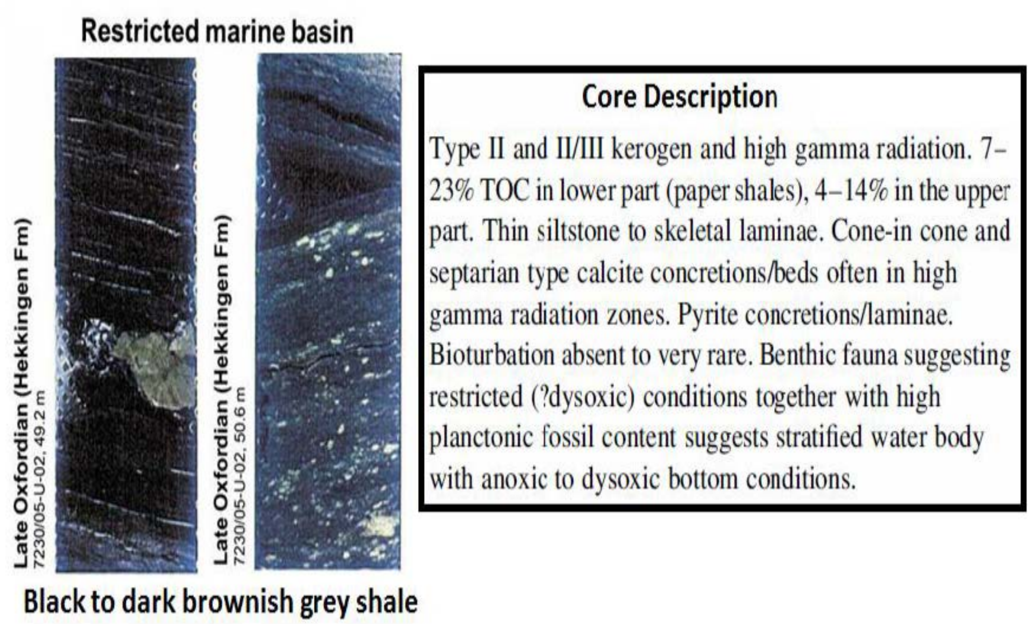

Fig. 9 Core description of the Hekkingen formation

1.7.2 Reservoir Rock of SW Barents Sea

The most significant reservoir rocks in the study area are in the strata of Jurassic age, and the major discoveries have a principal reservoir rock of Stø Formation from Lower to Middle Jurassic. It is believed that 85% of the reservoir rocks exist within the Stø Formation in the Norwegian Barents Sea, and most of them are expected to generate natural gas (Dore, 1995). The Lower Jurassic Nordmela and Tubåen formation also have good reservoir quality. The depositional environments of these formations are coastal, deltaic, marine to shore face settings.

The Stø Formation consists of mature sandstones with thin beds of shale and siltstone. The depositional environment for Stø Formation is in prograding coastal areas, and shales and siltstone patches depicts regional transgressive episodes (Dalland et al., 1988). There are two different subunits of Stø formation shown below (Fig. 10). The upper part of the formation is poorly sorted compared to the lower part. Due to the influence of the high energy conditions and low bioturbation, the upper part of the Stø Formation shows good reservoir quality.

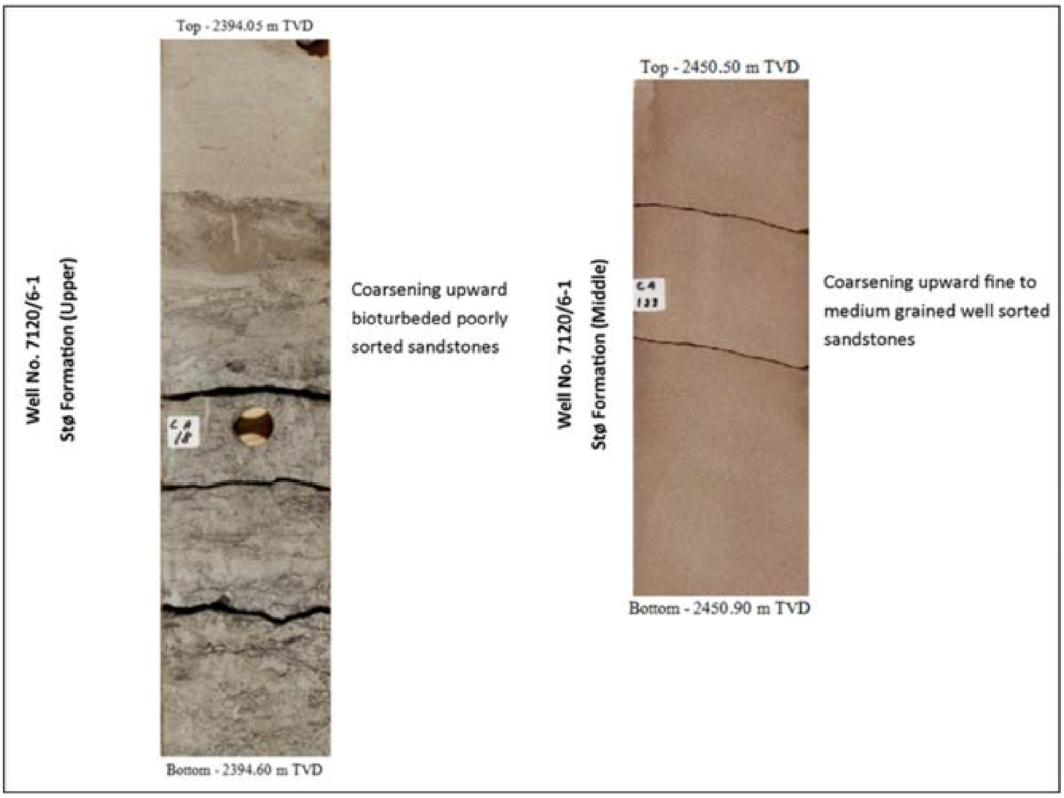

Fig. 10 Core data of the Stø formation from Well 7120/6-1

Nordmela Formation is deposited in subtidal or tidal channel, which reflects lenticular and flaser bedding (Fig. 11). Channel sands are thought to have vertical fluid flow restriction. However, horizontally distributed channels have good conection and they are good quality reservoirs. Tubåen Formation is dominated by sandstones with subordinate shales and minor coals (Spencer et al., 2008). Tubåen Formation shows better reservoir quality than Nordmela Formation because it has fine to medium grained sandstones. However, the reservoir quality of Tubåen Formation is not as good as Stø Formation. Because of deeper burial depth, digenetic history destroys the reservoir quality more in the compare to the Stø Formation.

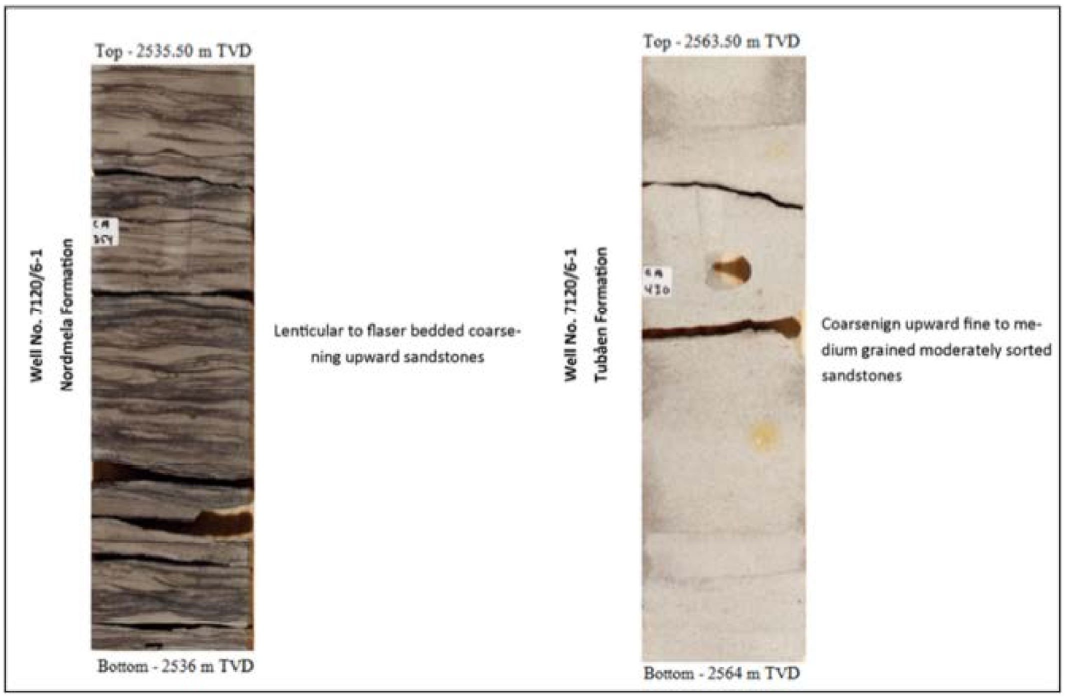

Fig. 11 Core photographs of Nordmela and Tubåen formation from the Well 7120/6-1

1.8 Existing Problems to be Solved

As described before, Skrugard and Harvis discoveries were found in this area last year. The reservoir contains thick sandstone formation and the reservoir quality is very good. The double flat spots were found in both Skrugard and Harvis discoveries. These two discoveries made the south-western Barents Sea become popular again. In this area, there are many other wells drilled before, but all these wells are abandoned as the dry wells (Fig. 12) (Fig. 13). There is no oil shows in well 7219/8-1 S. Well 7219/9-1 was abandoned as dry with residual hydrocarbons in Jurassic and Late Triassic Sandstones in 1988. All these cases shows contrast to Skrugard and Harvis discoveries, and the problem appears to the researchers: why there found commercial petroleum discoveries in Skrugard and Harvis, but the areas which adjoin to them do not have commercial petroleum, and all these wildcat wells were abandoned as dry wells?

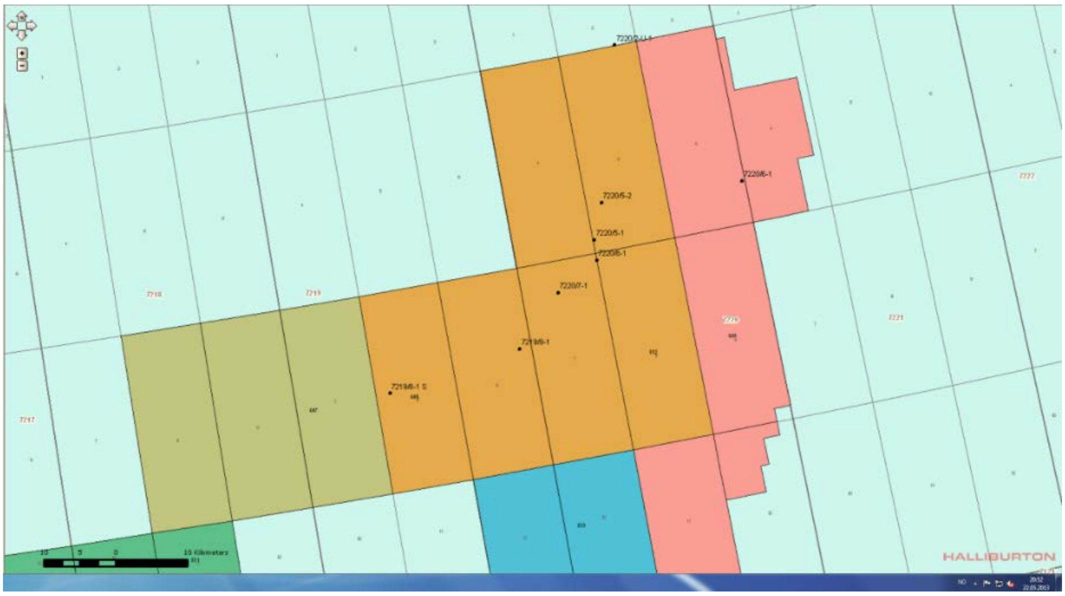

Fig. 12 Wells close to the Skrugard and Harvis Discoveries

Well	Liscence	Purpose	Discovery	HC Age
7220/5-1	532	Appraisal	Oil/Gas	Middle Jurassic&Early Jurassic
7220/6-1	225	Wildcat	Oil shows(Abandoned)	Permian
7220/7-1 (Havis)	532	Wildcat	Oil	Middle Jurassic&Early Jurassic
7220/8-1 (Skrugard)	532	Wildcat	Oil/Gas	Middle Jurassic
7219/8-1 S	182	Wildcat	Dry	
7219/9-1	136	Wildcat	Oil shows(Abandoned)	Jurassic
7220/10-1	533	Wildcat	Gas	Jurassic

Fig. 13 Well discoveries close to the study area

2. Data and Method

The general workflow of this study is shown in Fig. 14.

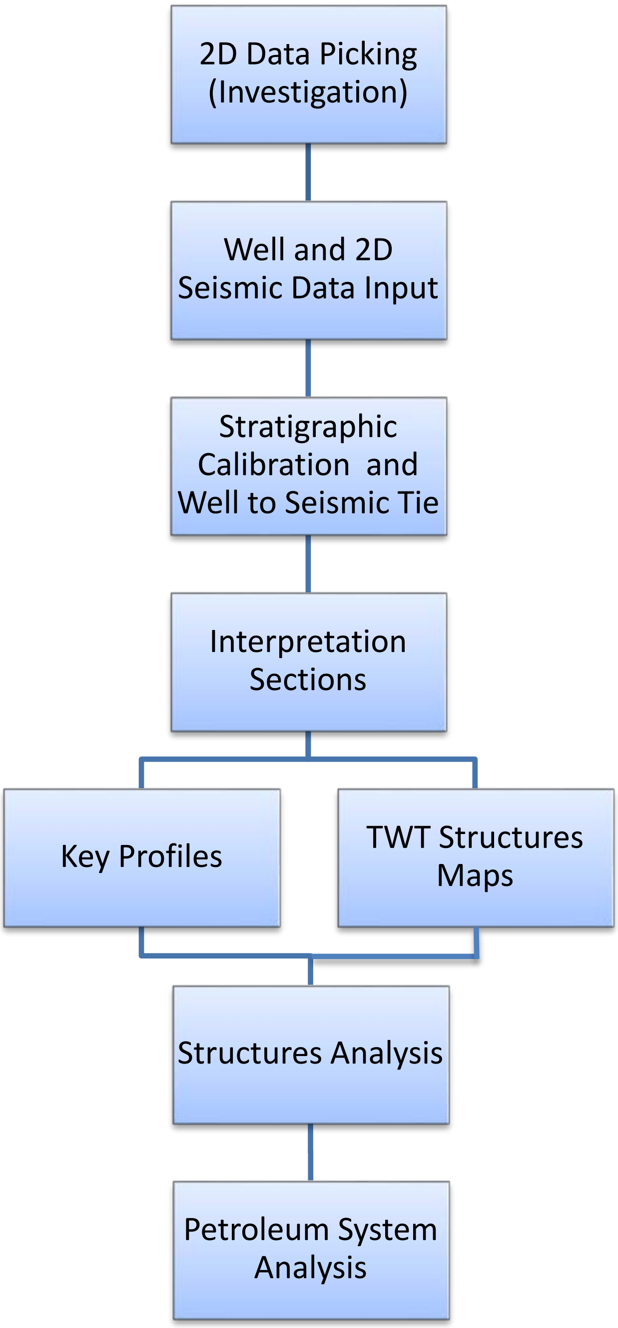

Fig. 14 General workflow of this project

2.1 Seismic Data

In this project, all the 2D seismic data were downloaded from PDP (Public Data Portal-Norway) website. From previous paper, Skrugard and Havis discoveries are located in liscence 532. In this area, F-86 was selected to do the interpretation work (Fig. 15). SG8608 was also selected to download at start, but this survey was cancelled because it only contains stacking data.

Fig. 15 2D seismic lines F-86

Well 7219/9-1 was used in the study area for the stratigraphic calibration and well tie to the seismic section (Fig. 16). Fig. 17 shows the general information of well 7219/9-1. Well 7219/9-1 is located in the Bjørnøya Sør area between the Veslemøy High and the Polheim Sub-platform. The main target in the well was the reservoir and hydrocarbon potential of Early-Middle Jurassic sandstones. Late Triassic sandstone of the Snadd Formation was a secondary target. Top reservoir, Stø Formation, was encountered from 1950.5 m to 2062 m with 99 m net sand of 17.8% average porosity. Nordmela Formation was penetrated from 2062 m to 2205.5 m with 59.5 m net sand with 16.5 % average porosity. The Tubåen Formation from 2205.5 m to 2305 m had 64.5 % net sand with 17.3% average porosity (NPD).

Era	Period	Formation	7219/9-1
			Top depth [m]
Cenozoic	Neogene	NORDLAND GP	379
	Paleogene	SOTBAKKEN GP	483
		TORSK FM	483
Mesozoic	Cretaceous	ADVENTDALEN GP	1468
		KOLMULE FM	1468
		KNURR FM	1836
	Jurassic	HEKKINGEN FM	1893
		FUGLEN FM	1919
		KAPP TOSCANA GP	1951
		STØ FM	1951
		NORDMELA FM	2062
		TUBÅEN FM	2206
	Triassic	FRUHOLMEN FM	2305
		SNADD FM	2877

Fig. 16 Lithostratigraphy of well 7219/9-1

Wellbore name	7219/9-1
NPDID wellbore	1138
Main area	BARENTS SEA
Well name	1942970
Geodetic datum	ED50
NS degrees	72° 24' 0.78" N
EW degrees	19° 57' 11.68" E
NS UTM [m]	8040679.94
EW UTM [m]	667003.56
UTM zone	33
Drilled in production licence	136
Drilling operator	Norsk Hydro Produksjon AS
Drill permit	568-L
Drilling facility	POLAR PIONEER
Drilling days	101
Entry date	17.11.1987
Completion date	25.02.1988
Release date	25.02.1990
Publication date	03.12.2004
Type	EXPLORATION
Purpose - planned	WILDCAT
Purpose	WILDCAT
Status	P&A
Reentry	NO
Content	SHOWS
Discovery wellbore	NO
Kelly bushing elevation [m]	23.0
Water depth [m]	356.0
Total depth (MD) [m RKB]	4300.0
Final vertical depth (TVD) [m RKB]	4286.0
Maximum inclination [°]	8.2
Bottom hole temperature [°C]	145
Oldest penetrated age	LATE TRIASSIC
Oldest penetrated formation	SNADD FM

Fig. 17 General information of well 7219/9-1

2.2 Interpretation Software

Petrel version 2012 was used in this project. This software was provided by Schlumberger and it helps increase reservoir performance by improving asset team productivity. Geophysicists, geologists, and reservoir engineers can develop collaborative workflows and integrate operations to streamline processes (www.slb.com). In this project, the Petrel Geophysiscs section was mainly utilized.

2.3 Seismic to Well Tie

In this project, 2D seismic lines are used to do the seismic interpretation work. Because there are no wells located in any seismic lines, the loading well data cannot show on the seismic section and do the seismic well to tie directly. All the well tie works are based on the previous paper (Fig. 18) and well data, and the formation and horizons were picked as bellows.

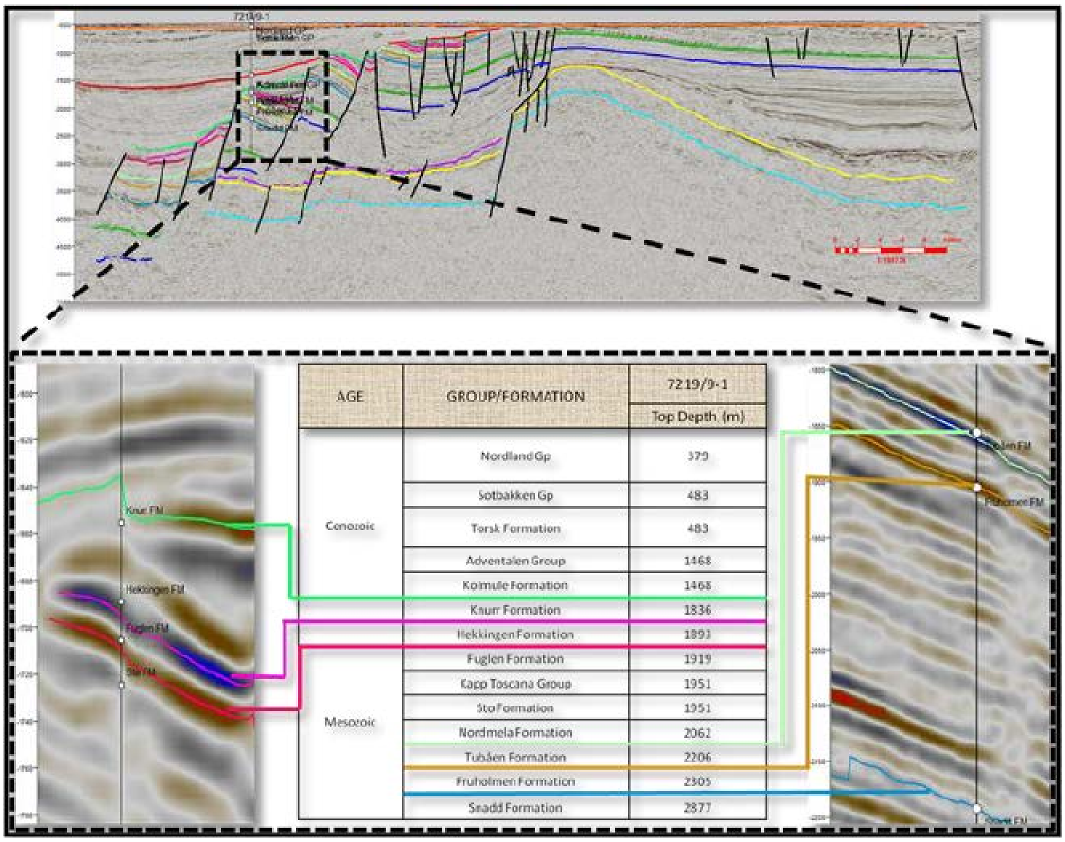

Fig. 18 Based on seismic tie to well 7219/9-1 (Muhammad, 2012)

There are six horizons picked to do the interpretation work in this project. The reflectors with different color codes are presented in figure below (Fig. 19).

Reflector	Formation	Color
Sea Floor	F1	
Cenozoic	F2	
Base Cretaceous	Knurr FM	
Upper Jurassic	Hekkingen FM	
Base Jurassic	Tubåen FM	
Base Triassic	Snadd FM	

Fig. 19 Color codes for the interpreted horizons in this project

The sea floor horizon is easily picked because it is always the first strong reflector shown on the section (Fig. 21). Due to the reflection coefficient theory:

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$Z = \rho * v$$

Where R=reflection coefficient

$Z = \text{Acoustic Impedance}$

$\rho = \text{Density}$

$v = \text{Velocity}$

The density and velocity in water is both smaller than in sands, so the acoustic impedance of water is smaller than sands. From the equation above, it is easily know that the reflection coefficient is positive, which means the sea floor horizon is positive reflector. The color table of using in this project is the default setting. Based on the color table (Fig. 20), the red reflector shows positive, while the blue reflector indicated negative. So the first red reflector was marked as the sea floor horizon.

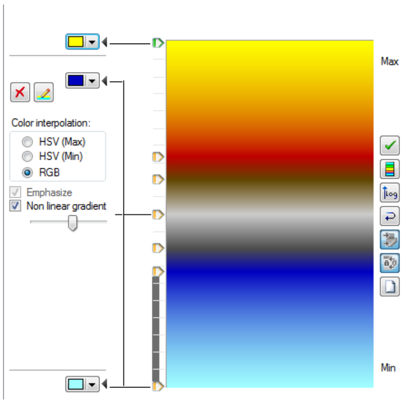

Fig. 20 Color table used in this project

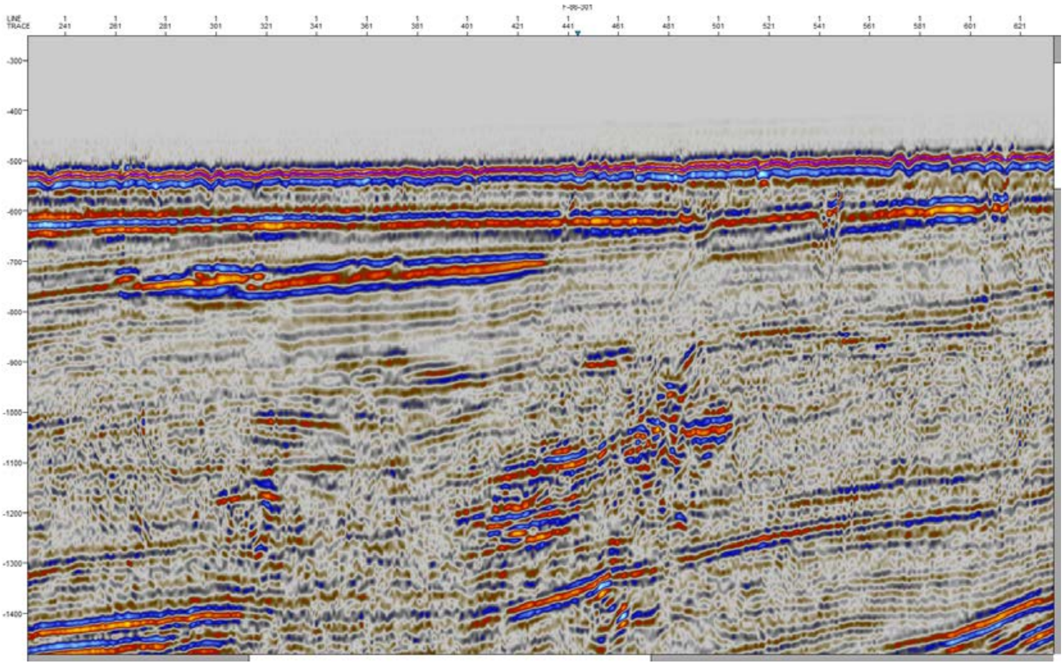

Fig. 21 The reflector of sea floor (purple line)

Formation 1 is marked as the Base Cenozoic formation (Fig. 22). Because there is no well top shown from well data, so Formation 1 was set as the name of this formation. Formation 1 is a strong reflector on the section. On the section, the reflector has marked between 1000-1500 ms TWT.

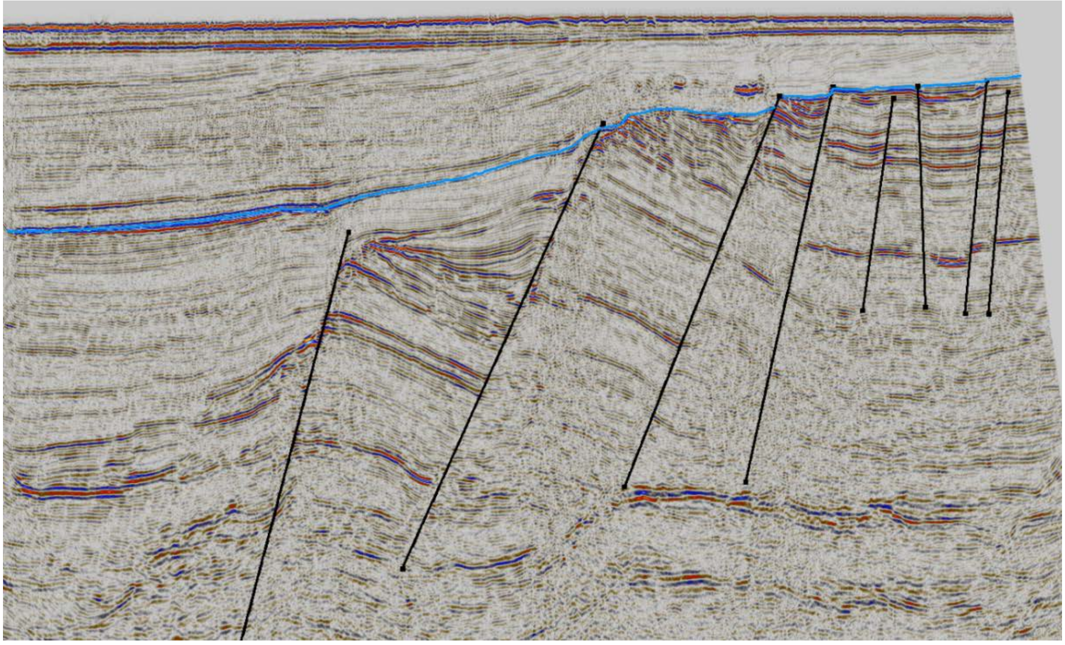

Fig. 22 The reflector of Formation 1 (blue line)

Knurr Formation was picked as the Base Cretaceous formation (Fig. 23). This formation is composed of claystone with thin interbeds of limestone and dolomite (Dalland et al., 1988). Knurr Formtaion can be considered as the top of the syn-rift, which will discuss detailed in the next chapter. On the section, the reflector has marked between 1500-1700 ms TWT.

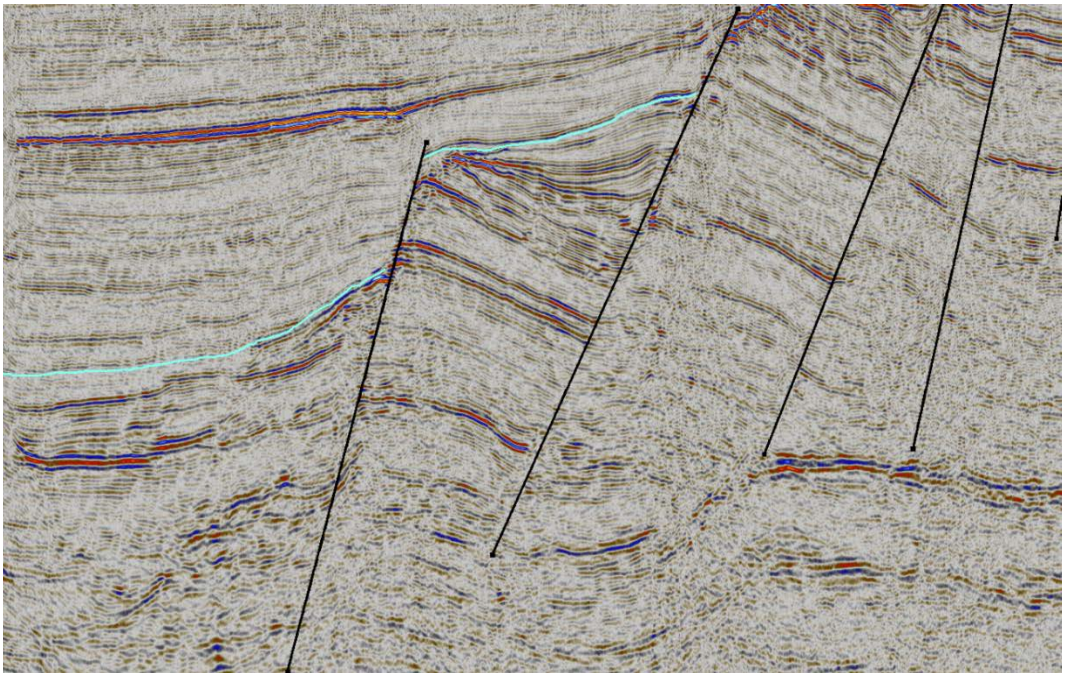

Fig. 23 The reflector of Knurr Formation (cyan line)

Hekkingen Formation was picked as the Upper Jurassic formation which exhibits a strong positive reflection (Fig. 24). Hekkingen Formation is composed of grey shale and claystone with interbeds of limestone, dolomite, siltstone and sandstone (Dalland et al., 1988). There is an obvious unconformity occur in this formation, which means there is some erosion happen and following by deposition. Below Hekkingen formation, all the reflectors are parallel to each other. On the section, the reflector has marked between 1750-2000 ms TWT.

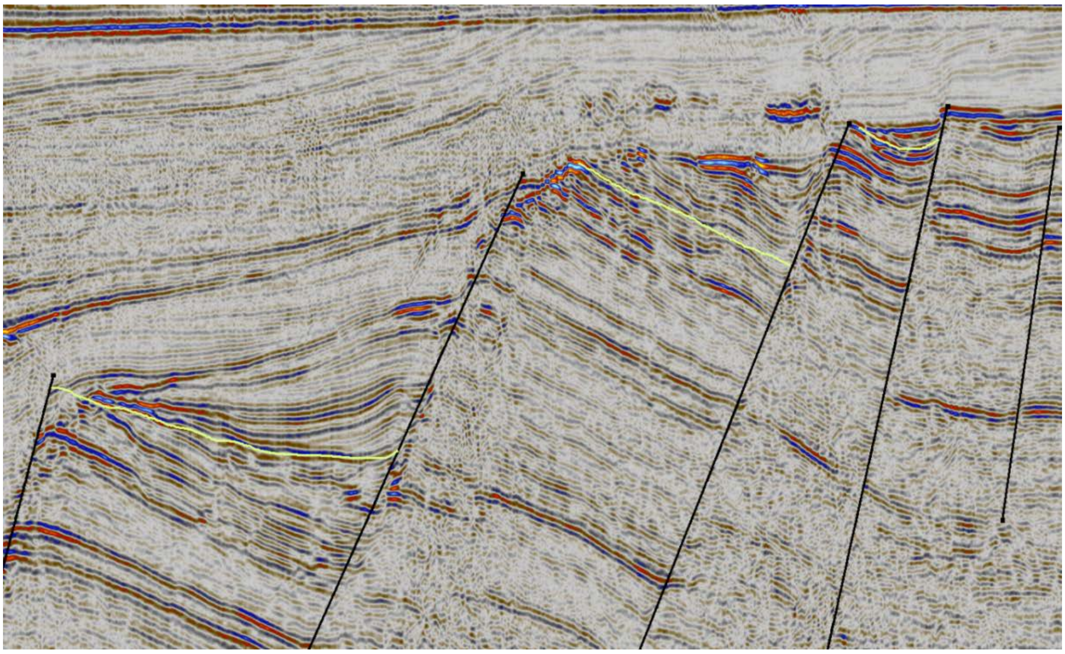

Fig. 24 The reflector of Hekkingen Formation (yellow line)

Tubåen Formation was picked as the Base Jurassic formation by a strong reflector (Fig. 25). This formation is only marked within Bjørnøya Basin and it is not present at the Loppa High. The formation is comprised of sandstone, shale with minor deposition of coal (Larssen et al., 2002). Although well 7219/9-1 is not located on any seismic lines, it is very close to the crossing point between F-86-205 and F-86-301. On a seismic section, the reflection has been marked between 2200-2500 ms TWT.

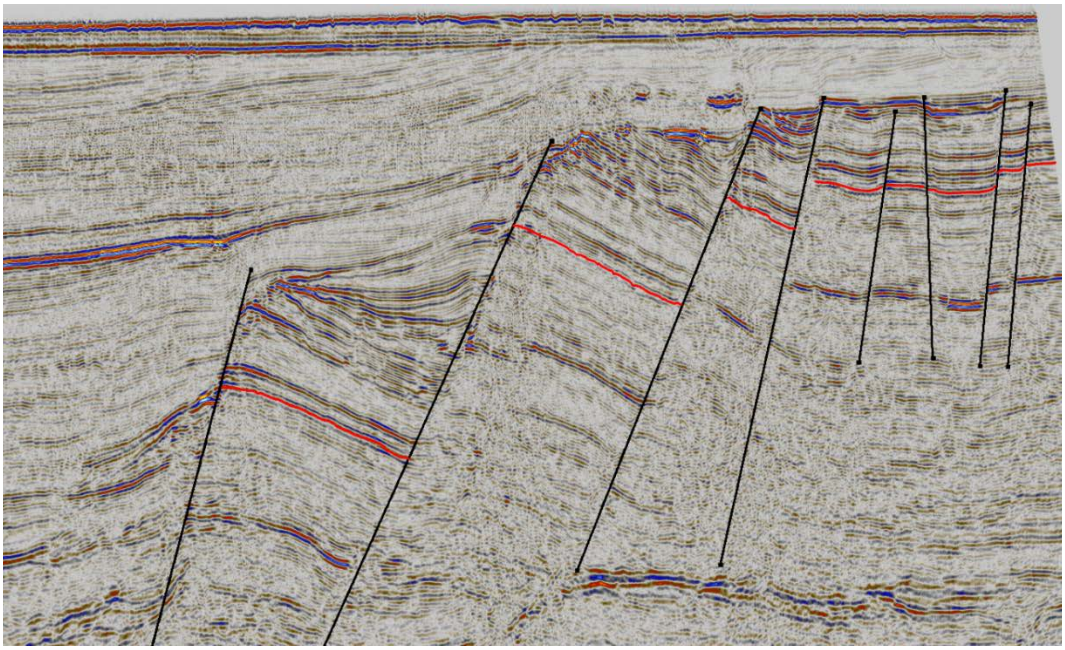

Fig. 25 The reflector of Tubåen Formation (red line)

The way to track the Tubåen Formation is based on the strong reflector shown on the section. (Fig. 26)From the section, it is obvious to see that there are three strong reflectors in the entire section. Because Tubåen Formation is marked as the Base Jurassic, and also the well data shows the deepest of the three reflectors as the Tubåen Formation.

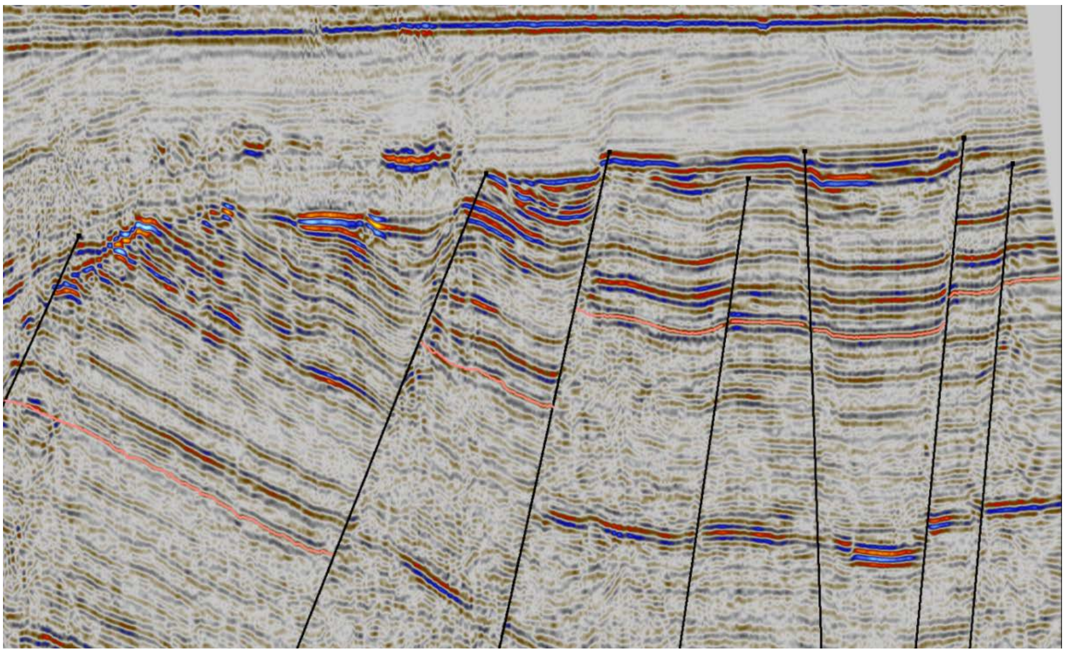

Fig. 26 The deepest one of the three strong reflectors indicates Tubåen Formation

Snadd Formation was picked as the Base Triassic formation by a strong reflector (Fig. 27). The formation predominantly comprised of grey shale with interbeds of siltstone and sandstone (Dalland et al., 1988). On a seismic section, the reflection has been marked between between 2750-3000 ms TWT.

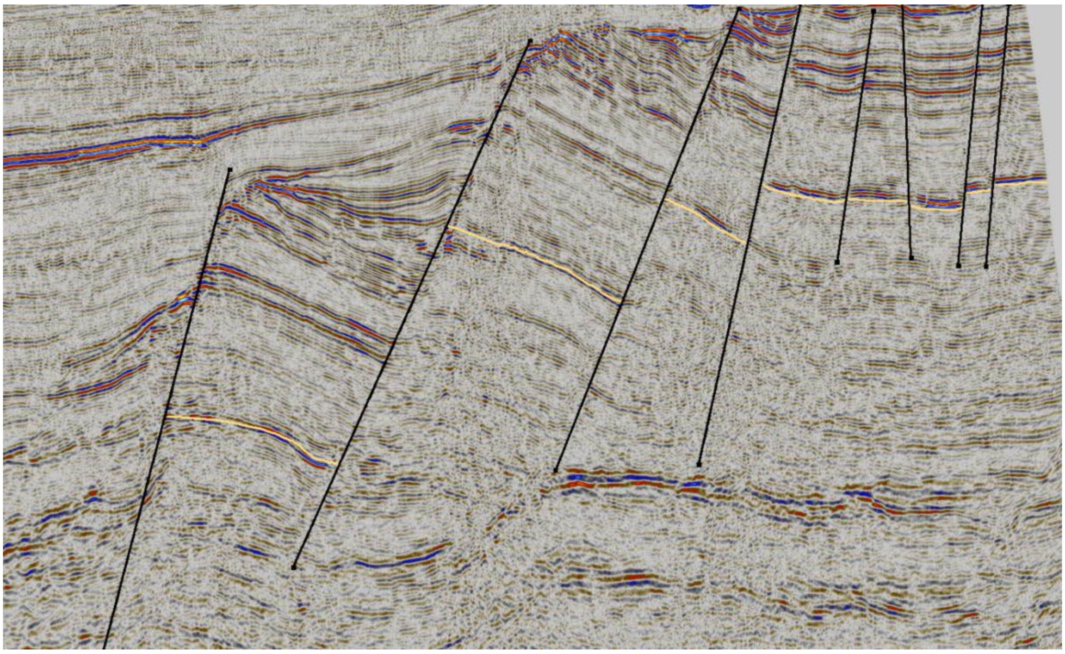

Fig. 27 The reflector of Snadd Formation (yellow line)

2.4 Key Technique Used in Petrel

Flatten horizon is one of the key techniques used to do the interpretation. The principle of this technique is the same subsidence rates of the sediments. For the pre-rift formation, all the formations have the same subsidence rates and the thickness should be almost the same. The Fig. 28 shows the interpreted horizons on section of line F-86-203, flatten horizon was used to examine the correction of interpreted horizons. After using the flatten horizon function for Snadd Formation and Tubåen Formation separately, it is obvious to see that the thickness of Jurassic and Triassic formation have small changes (Fig. 29).

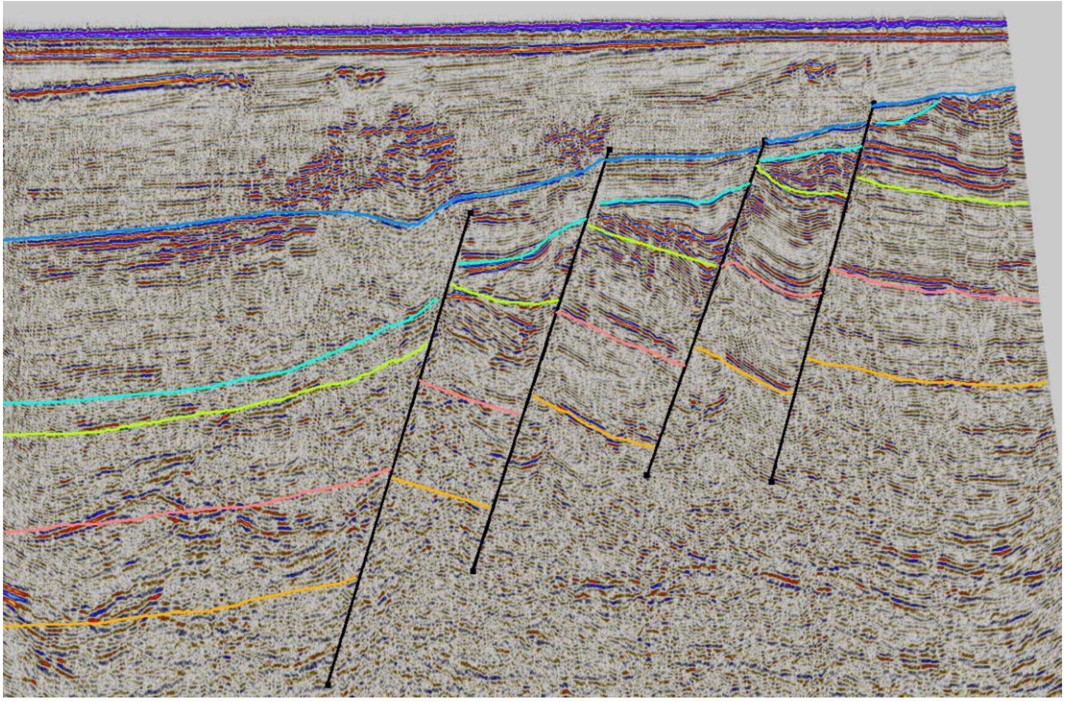

Fig. 28 2D seismic line F-86-203 with interpreted horizons

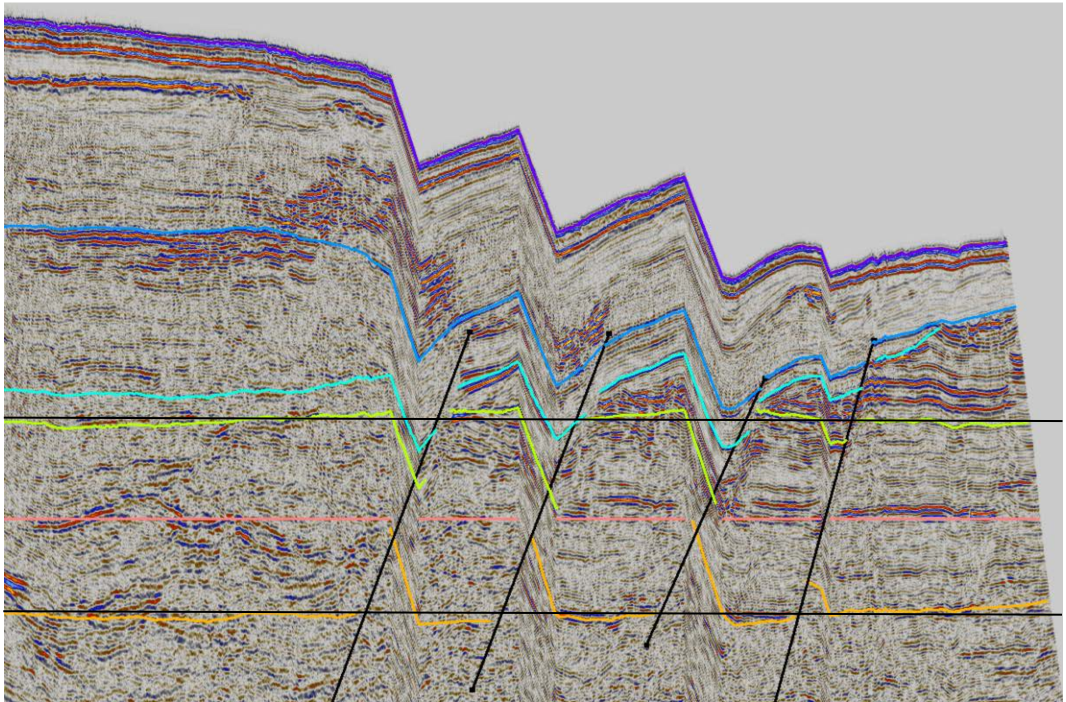

Fig. 29 Used flatten horizon function on Tubåen Formation. The thickness of the Triassic and Jurassic formation has small changes

3. Seismic Interpretation

3.1 Key Seismic Lines

3.1.1 Key Profile 1

The first key profile line is F-86-301, which is a NE-SW trending 2D seismic line located at the boundary zone of Bjørnøya Basin and Loppa High (Fig. 33). There are many wells (well 7219/9-1, 7220/7-1, 7220/5-1) close to this line, it means line F-86-301 contains many different geological structures. Furthermore, Skrugard discovery has already been reported found in well 7220/8-1, but 7219/9-1 was abandoned as a well with residual oil shows. Interpretation of this line may give some ideas about why these two close areas have different oil shows.

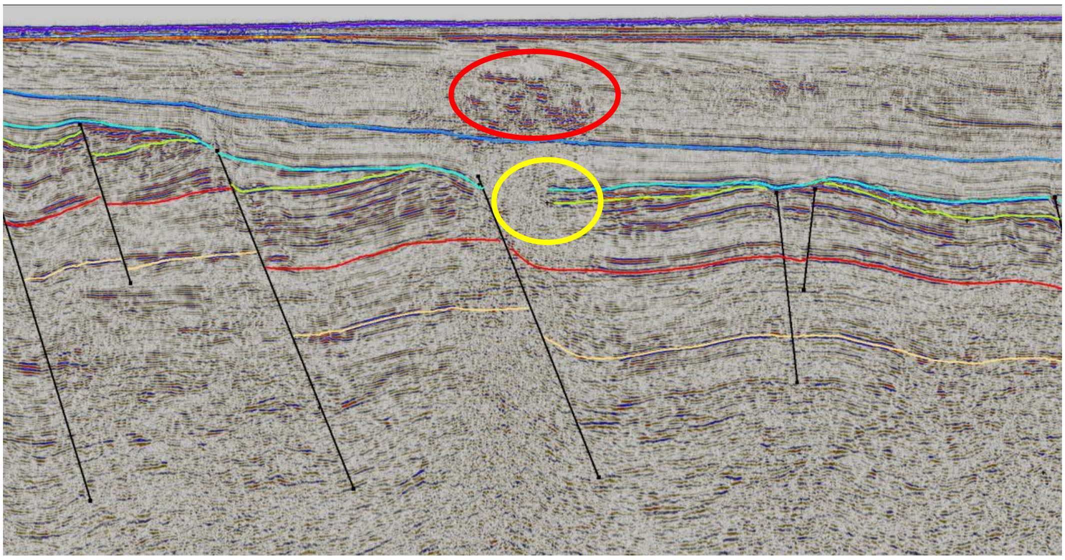

Fig. 30 Gas indacator (yellow circle) and gas Leakage (red circle)

On this section, it can be seen that the right part of the section (SW area) subsidence deeper than the left part (NE area). There are a many normal faults in this section, which means it was under extension during rifting. There is an obvious erosion occurred during Late Jurassic, and an unconformity occurred between Jurassic and Cretaceous.

In the middle part of the section, there is a blind zone related to the faults (Fig.30). It is obvious to see that the seismic data quality is not as good as the area adjoined to it. From the upper part of the blind zone, there are clearly visible lower seismic horizons, which mean the velocity is lower. This is an indicator for gas because the velocity is lower in gas than in sediments, and it need take longer time to travel. There shows many bright spots above these two faults, because Paleogene is too young to form the petroleum, the gas was migrated from the lower part along the faults. This gas leakage indicates there was petroleum generation below this area and there were possible traps in the ancient time.

On the left side of the middle faults mentioned above, there found structure traps related to the fault. The Hekkingen Formation mainly contains shale, which can form good quality seal function. The Stø Formation is mainly composed of sandstone, which can form good reservoir sand. The Snadd Formation contains shale and it can be source rock as described before. If the fault is sealed, there seems that this trap has all the elements to form petroleum. Fortunately, there found a flat spot in this trap (Fig. 31). Flat spot is normally an indicator for oil/water or gas/water interface. Because of the different acoustic impedance between water and petroleum, there will show an obvious flat spot. The Not that a flat spot is not always perfectly flat, it can be dipping causing by dipping fluid contact. From the previous investigation, well 7220/8-1 is located approximate here and it is believed that the target of well 7220/8-1 is to test the petroleum shown in this structure trap. Based on the well information, the Skrugard discovery was found here and it has been already certificated as a commercial found.

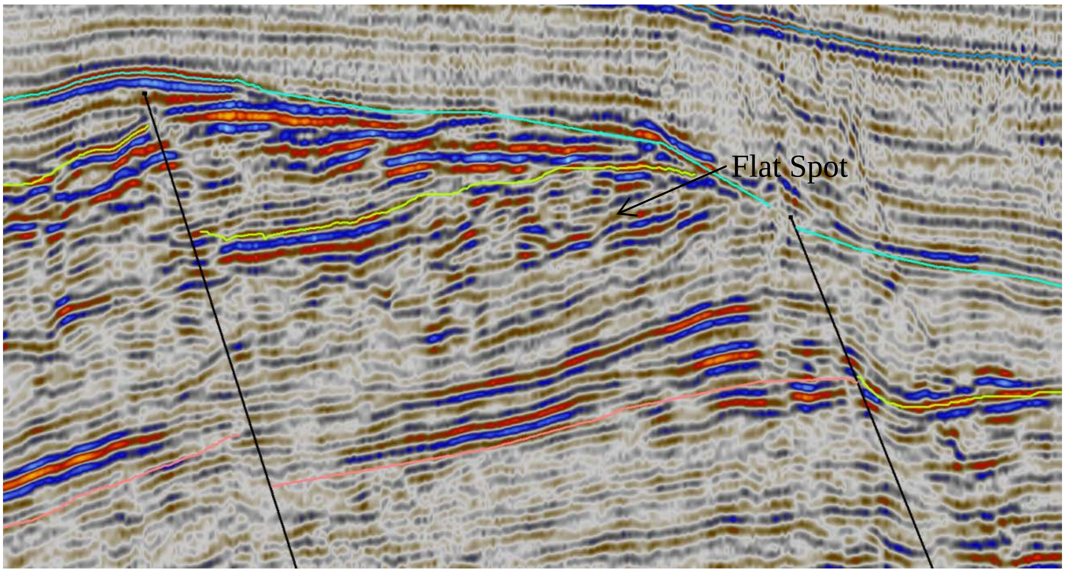

Fig. 31 Flat spot shown on the section

On the right side of the middle fault, there shows another structure trap (Fig. 32). This trap also has all the same elements as the trap described before, but it seems that the rifting destroy this trap. It can be thought a rifting event after this trap formed, and the two faults destroy the seal of the trap. It can be believed that this trap contains petroleum before rifting happened, and the gas leakage over this trap also prove that the rifting destroyed the trap which has petroleum before rifting. Well 7219/9-1 is located close to this trap, and the logs and RFT data indicated the reservoir to be water bearing with possible residual oil.

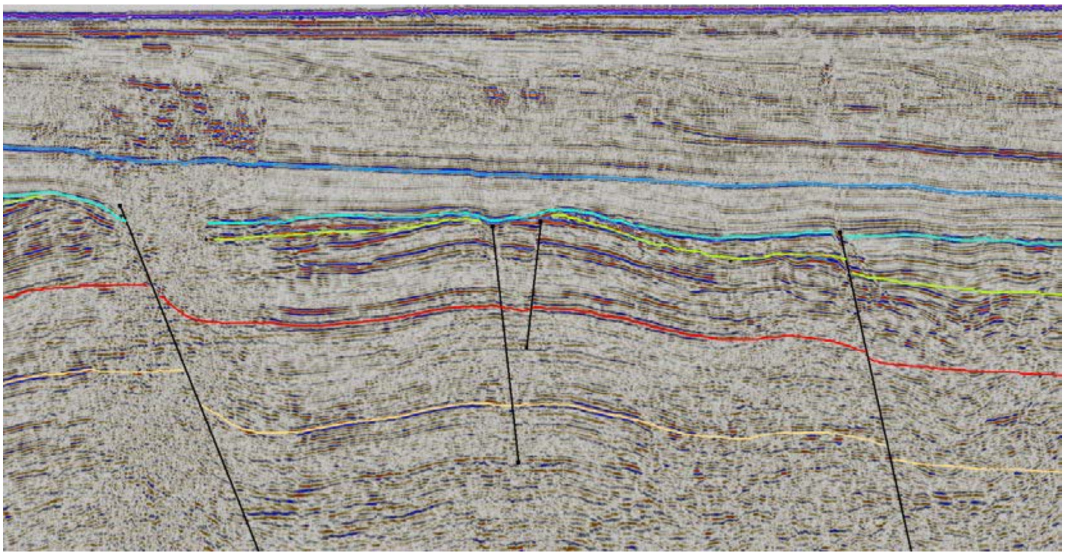

Fig. 32 Structure trap on the left side of the middle faults

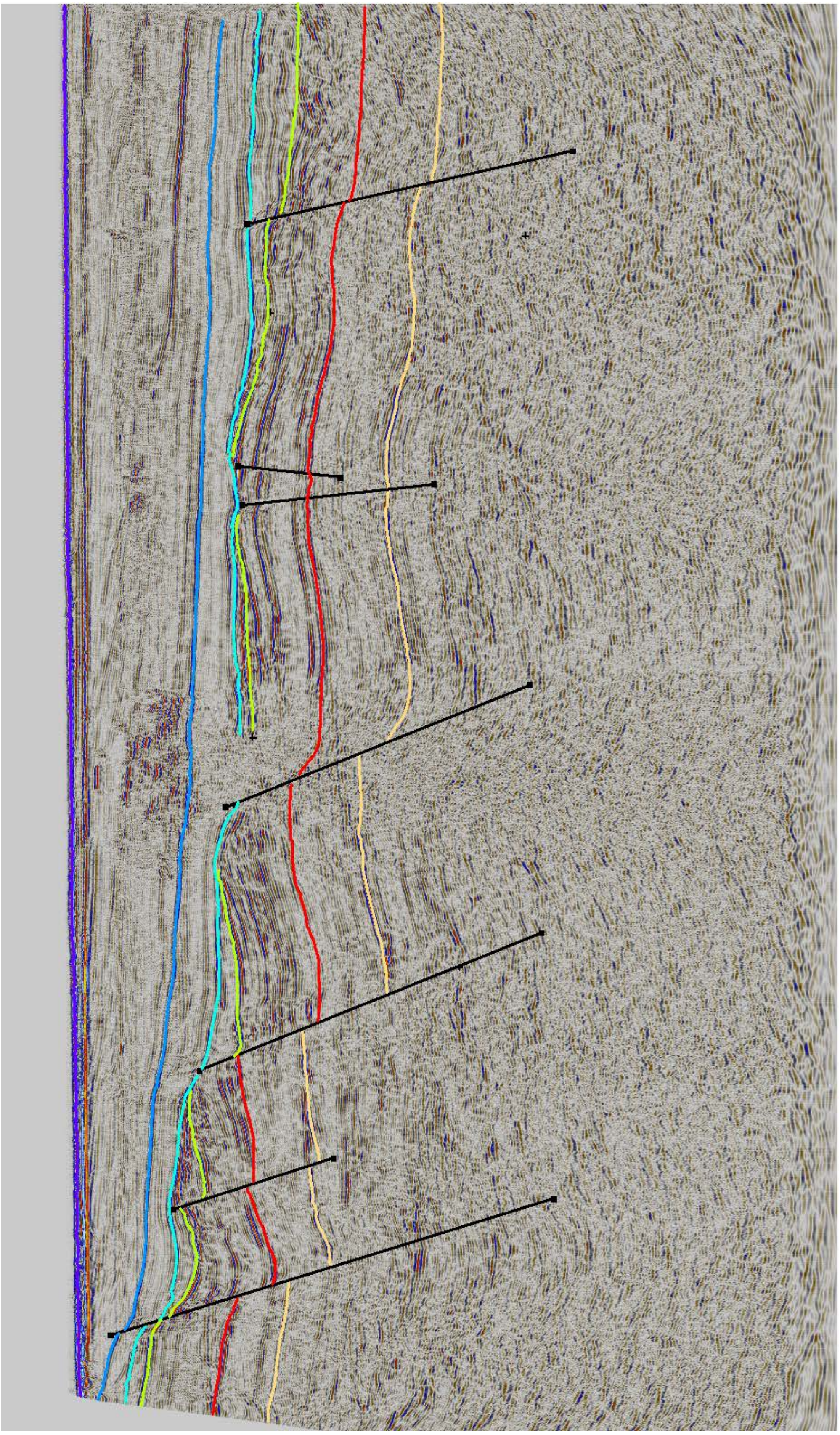

Fig. 33 Key profile 1-2D seismic line F-86-301

3.1.2 Key Profile 2

2D seismic line F-86-205 is located in the Bjørnøya Basin, which the direction of the line is NW-SE trending (Fig. 38). Well 7219/9-1 is adjoined to this seismic line, and it is a dry well with residual petroleum. This is the reason why select this seismic line one of the key profiles, and it maybe can find some interpretations about why there are only residual petroleum in well 7219/9-1.

In the section of F-86-205, four major faults and five horizons were picked and interpreted. In the east part of the section, there are some related faults picked. All the major faults are dipping northwest and they are all normal faults. In the NW-SE direction, the basin is under extension during the tectonic time.

There are two types of rift events, pre-rift and syn-rift shown in this seismic section. The pre-rift means the deposition of sediments occur before the rifting, and it can be easily recognized by small changes of thickness and sedimentary facies across the rift faults. The syn-rift indicates the sediments deposit during the active rifting event, and it is typically showing changes of thickness and sedimentary facies across the active faults (Fig. 34).

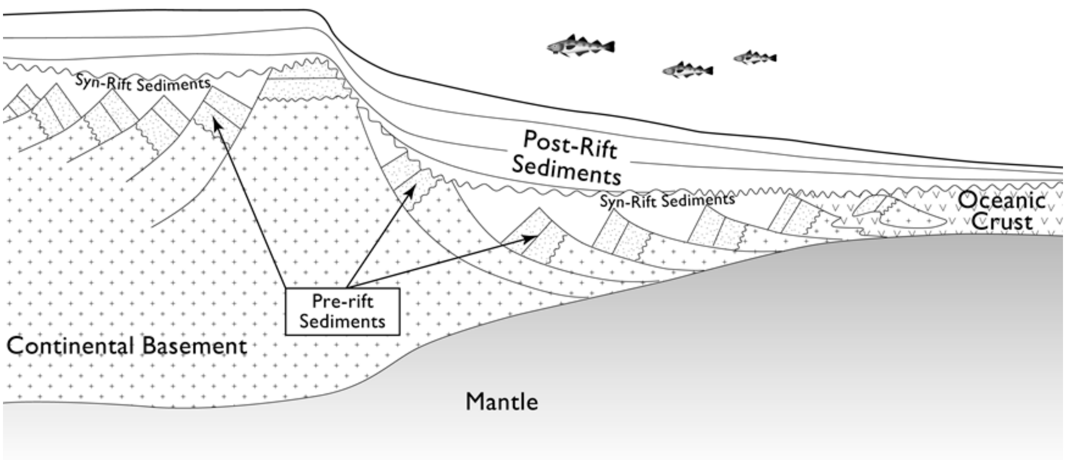

Fig. 34 The structure of pre-rift, syn-rift and post-rift

The thickness of the Triassic and Jurassic formation is almost same, which means the Triassic and Jurassic formation subsidence during pre-rift time (Fig. 35). The basin in this area was under a stable subsidence until the rifting event happened after Jurassic, and the Jurassic formation was not destroyed by rifting during geological evolution. The syn-rift began in Cretaceous time, and the rifting stopped until Cenozoic time, which the post-rift event started.

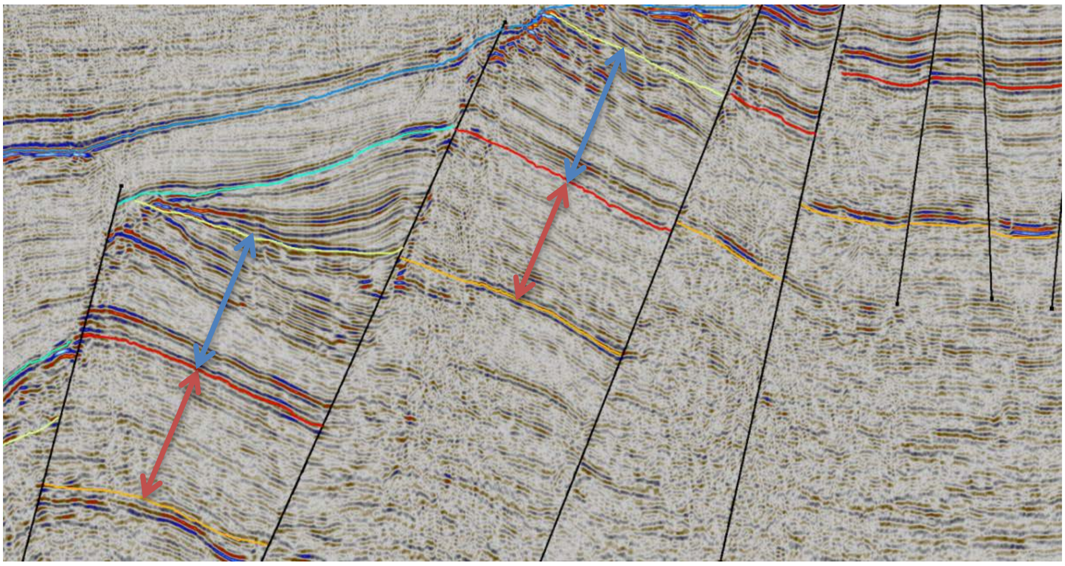

Fig. 35 Measured thicknesses of the Triassic and Jurassic formation are almost same

There are many potential traps on this section (Fig. 36). All these traps are divided into four major areas related to the major faults. Although there are many potential traps, there could not find any DHI indicators in these traps.

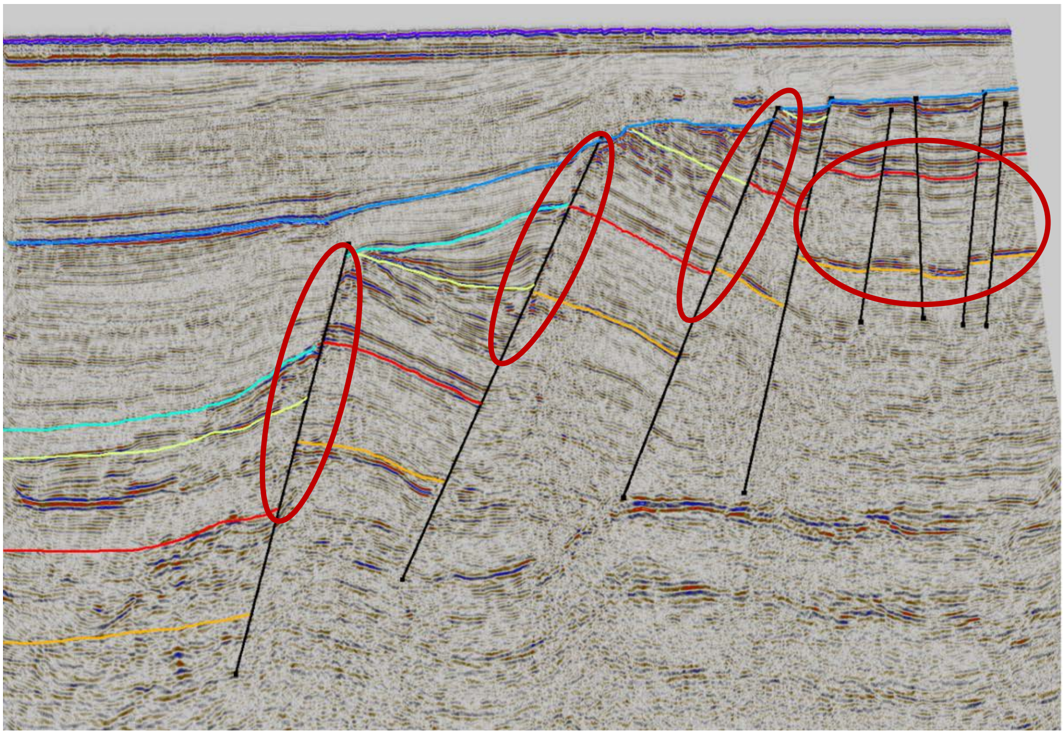

Fig. 36 Potential traps on section F-86-205

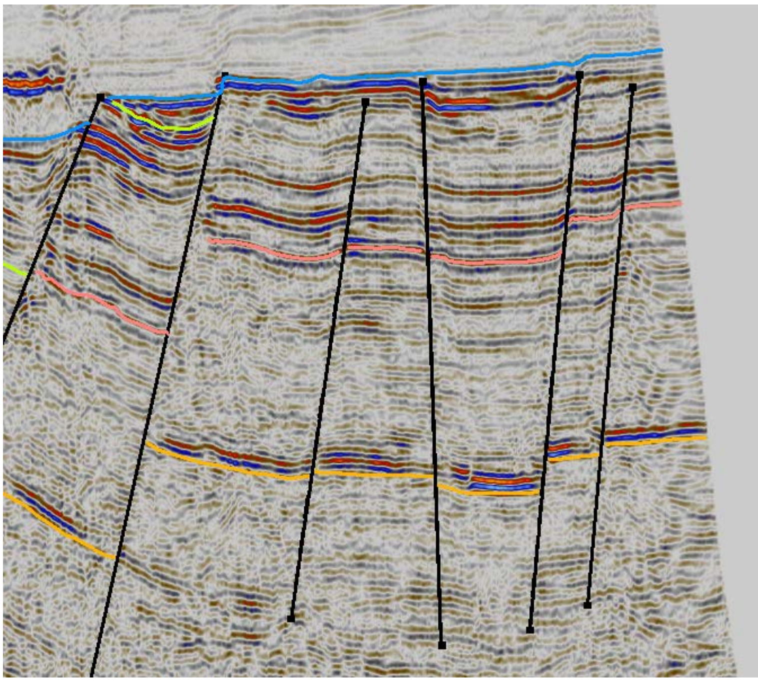

Fig. 37 Graben and horst structure

On the east of the section, there exist graben and horst structures (Fig. 37). A graben is the result of a block of land being downthrown producing a valley with a distinct scarp on each side. A relatively low-standing fault block bounded by opposing normal faults. Graben can form in areas of rifting or extension, where normal faults are the most common type of fault. Between graben are relatively high-standing blocks called horsts (www.slb.com).

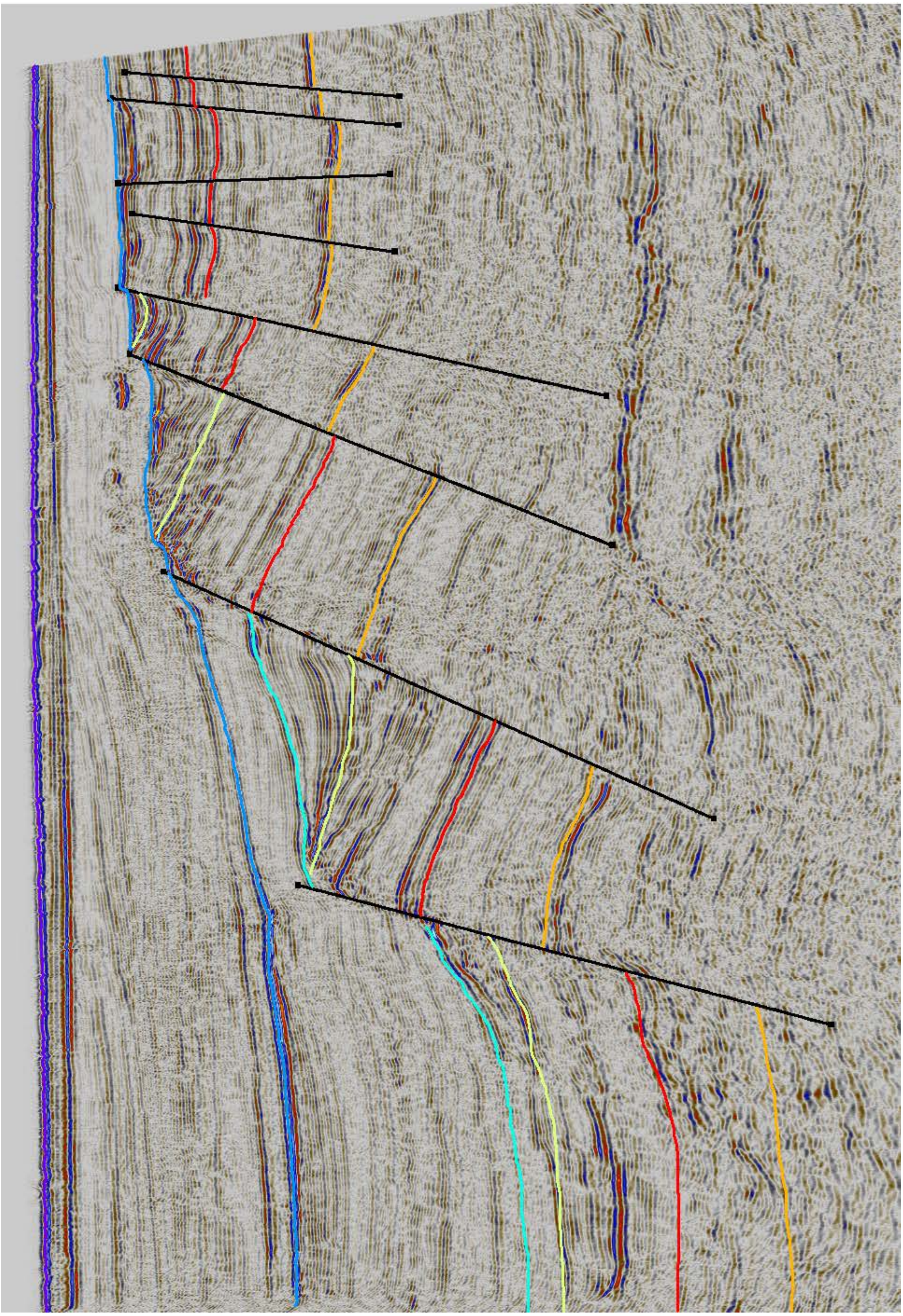

Fig. 38 Key profile 2- 2D seismic line F-86-205

3.1.3 Key Profile 3

2D seismic line F-86-203 is located in the Bjørnøya Basin, which the direction of the line is NW-SE trending (Fig. 42). As described before, there is a gas leakage area shown on section of seismic section F-86-301, and this line was selected to analysis the gas leakage in this area.

On the west of this section, the seismic data quality is a little mass there. It is not easy to interpret the horizons because of the deep complicated structures (Fig. 39). Flatten horizons function was used to help pick the horizons. Because of the same subsidence of the formations, the thickness should be the same for every formation. After processing this function, the horizons were picked in the deep part of the section (Fig. 40).

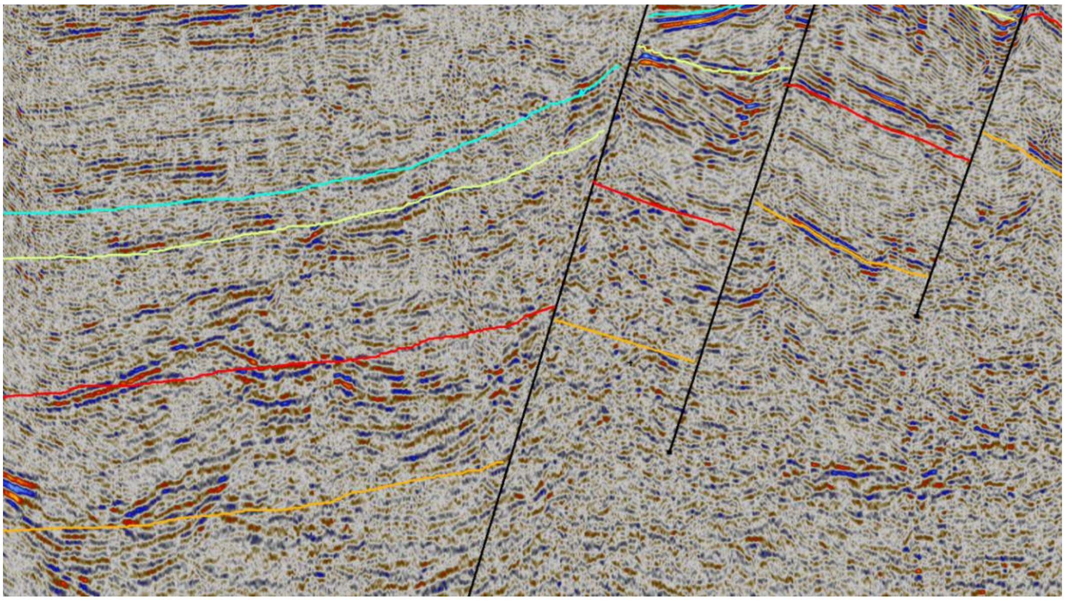

Fig. 39 Horizons shown before flatten horizon function

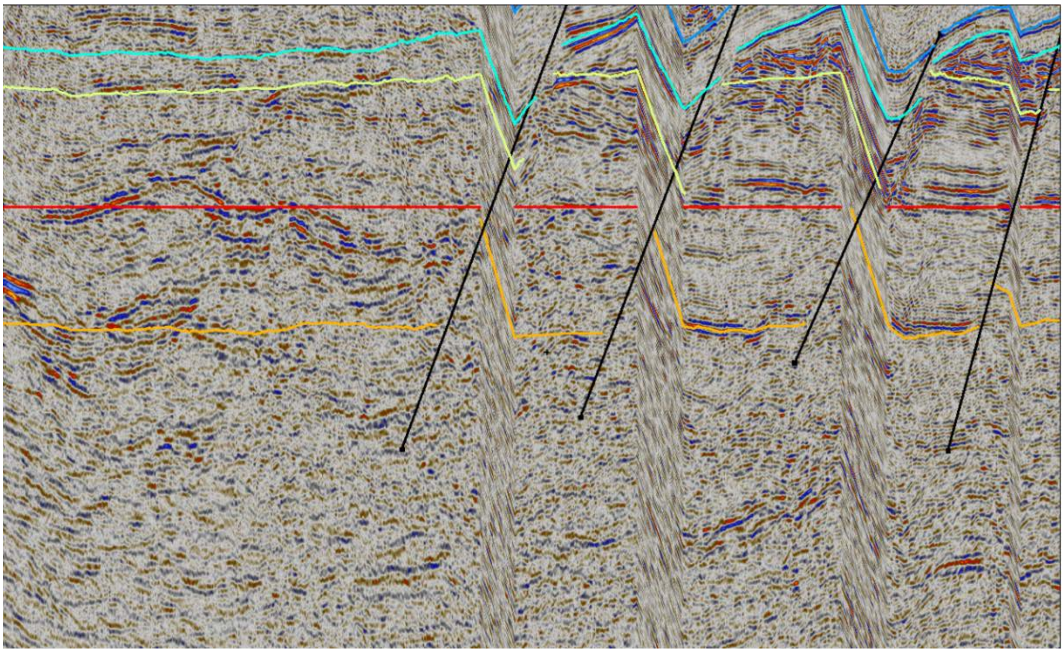

Fig. 40 Horizons shown after flatten horizon function

There are two areas shows the gas leakage on this section (Fig. 41). The large gas leakage area (red circle) is thought to be formed by the seal broken, and the gas migrated from the shallow formation to the shallow formation. The small gas leakage area is considered to be formed by the fault open, and the gas migrated along the fault from the deep to shallow formations.

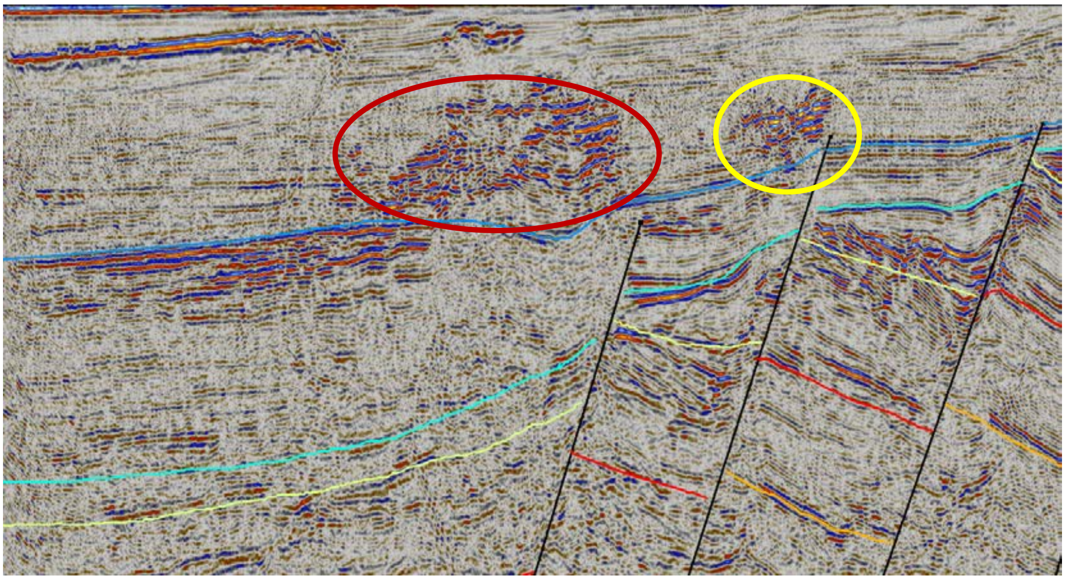

Fig. 41 Gas leakage shown on the section

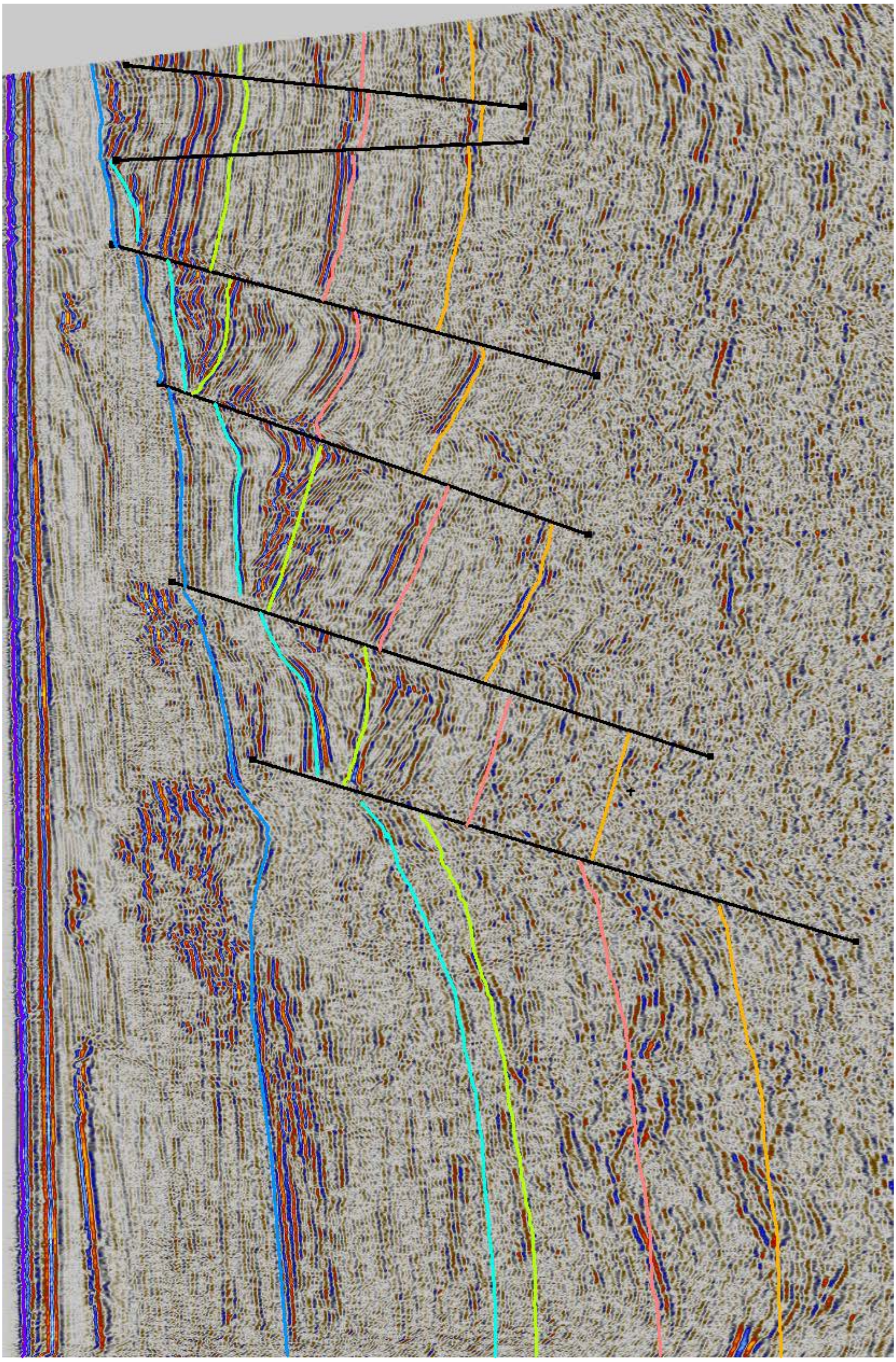

Fig. 42 Key profile 3 – 2D seismic line F-86-203

3.2 Time Structure (TWT) Maps

This section primarily focuses on presenting and describing the time-structure maps with faults for the interpreted horizons. The time structure maps can give an overview of the structure features of the study area, and it can help to analysis the petroleum system further. Hekkingen Formation (Upper Jurassic) time-structure map have already been mainly described in order to analysis the structure of the study area. In this section, time-structure maps derived at the Cenozoic, Base Cretaceous, Upper Jurassic, Base Jurassic and Base Triassic.

3.2.1 Formation 2 (Cenozoic)

Cenozoic time structure map was generated by using the Formation 2 interpreted horizons, which is the top interpreted horizon on the section (Fig. 43). The time scale of this map is from 550ms-1700ms, and the color is transferred from red to yellow.

Formation 2 is the base of the post rift, and there are no faults shown on this structure map. The time-structure map on the Formation 2 shows general westward deepening of the reflection represented by color variation from yellow to red.

3.2.2 Knurr Formation (Base Cretaceous)

Base Cretaceous time structure map was generated by using the Knurr Formation interpreted horizons (Fig. 44). The time scale of this map is from 600ms-3000ms, and the color is transferred from red to purple. The time-structure map of the Formation 2 shows general westward deepening of the reflection represented by color variation from purple to red.

Knurr Formation is the top of the syn-rift, and there are three major faults shown on this structure map. All the faults are NE-SW trending. The width of the faults shows the angel of the faults. The wider fault indicates the small angel faults, and the narrower fault indicates the more vertical fault. MF1 is a low angle fault, while MF2 and MF3 are high angle faults. MF4 is not shown on this formation, because the uplift of the east side of the formation and the erosion happened there.

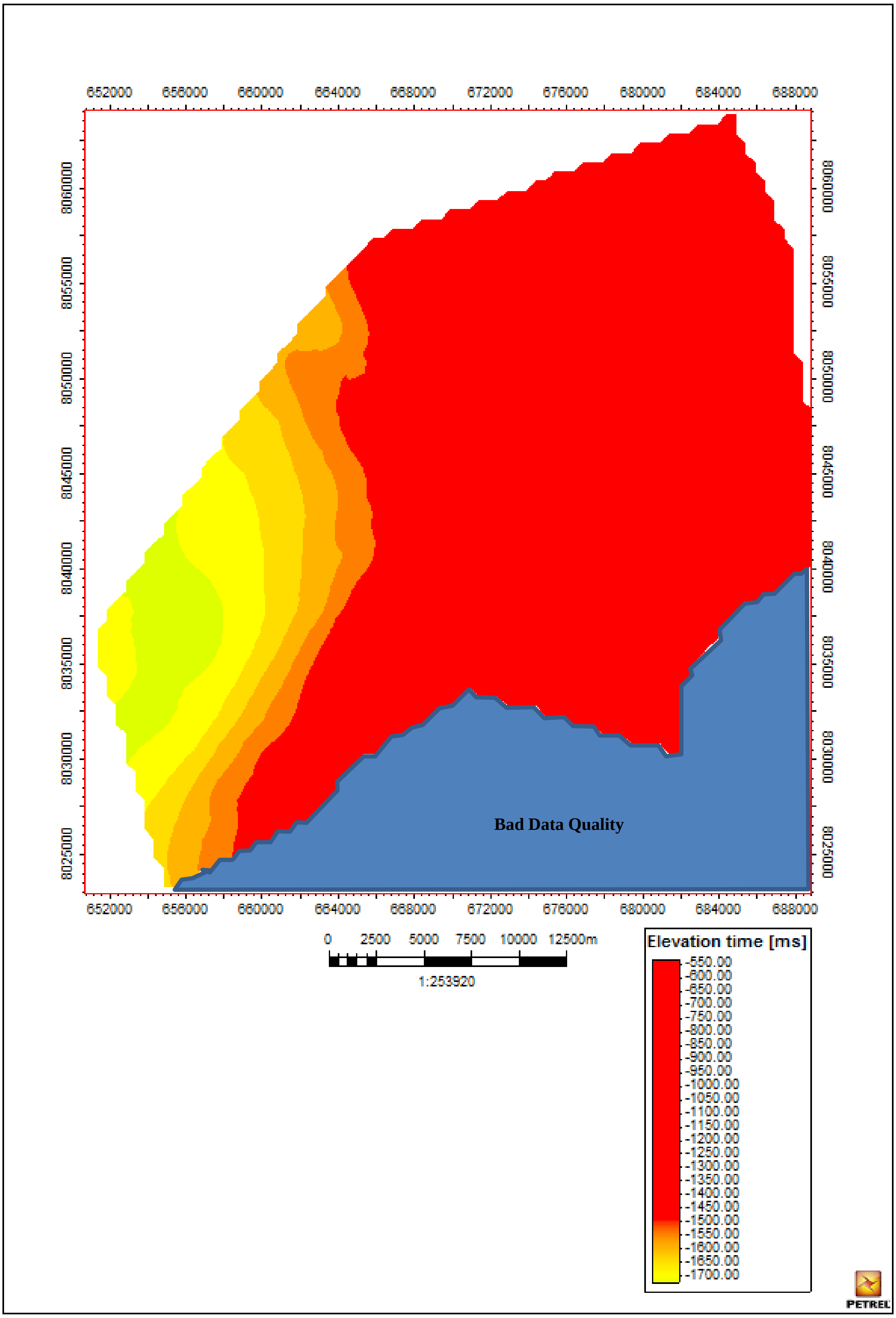

Fig. 43 Time structure map of Formation 2 (Cenozoic time)

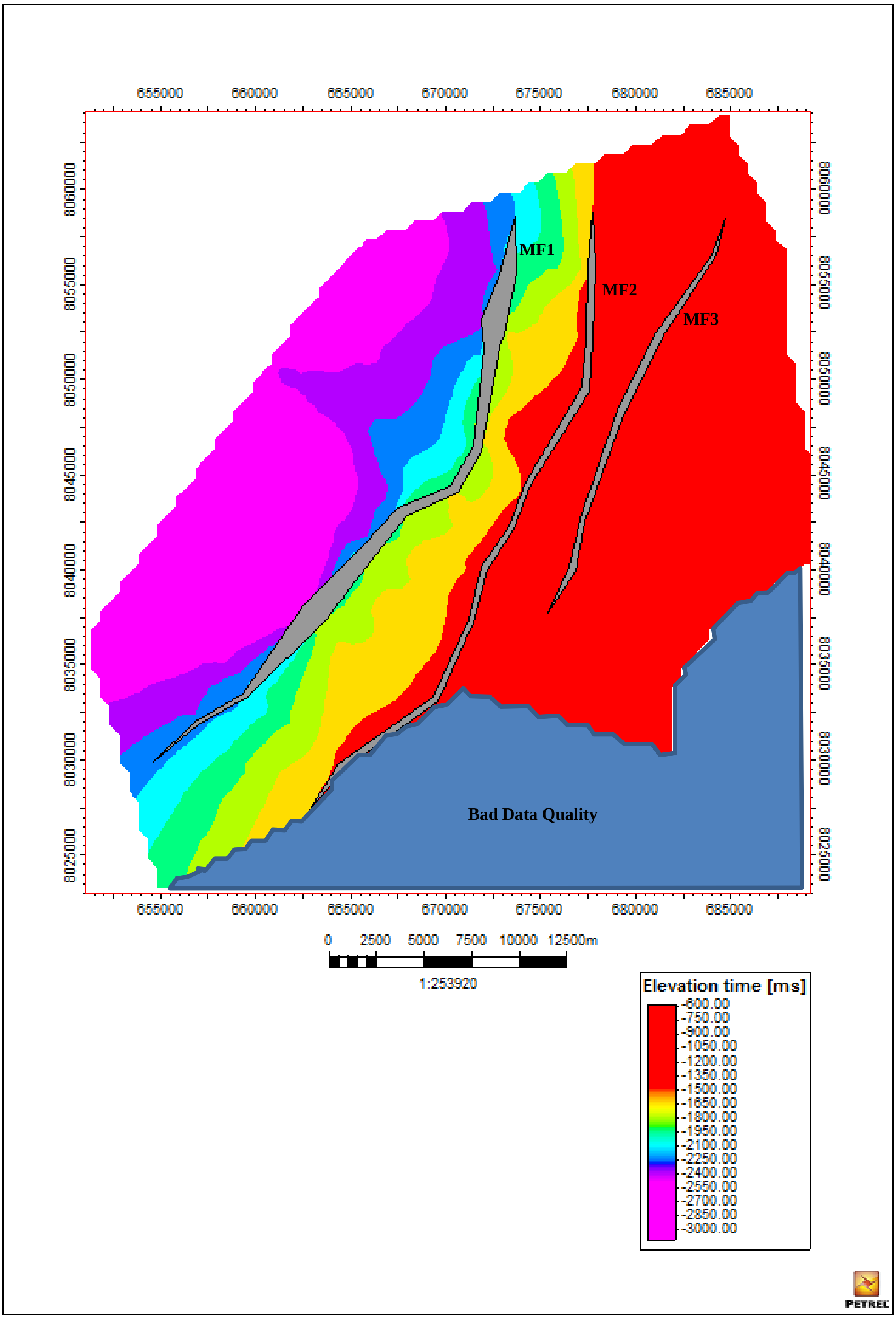

Fig. 44 Time structure map of Knurr Formation (Base Cretaceous)

3.2.3 Hekkingen Formation (Upper Jurassic)

Upper Jurassic time structure map was generated by using the Hekkingen Formation interpreted horizons (Fig. 46). The time scale of this map is from 750ms-3150ms, and the color is transferred from red to purple. The time-structure map of the Hekkingen shows general westward deepening of the reflection represented by color variation from purple to red.

Hekkingen Formation is the top of the pre-rift, and there are four major faults shown on this structure map. There are many potential traps related to MF1. These traps can be divided into three areas (Fig. 45). Area 1 seems have a good trap, which the green area has a sealed trap outline. The yellow area in area 2 was related to MF1 and MF2, and the trap was formed between these two faults. There have small traps in area 3 related to the faults.

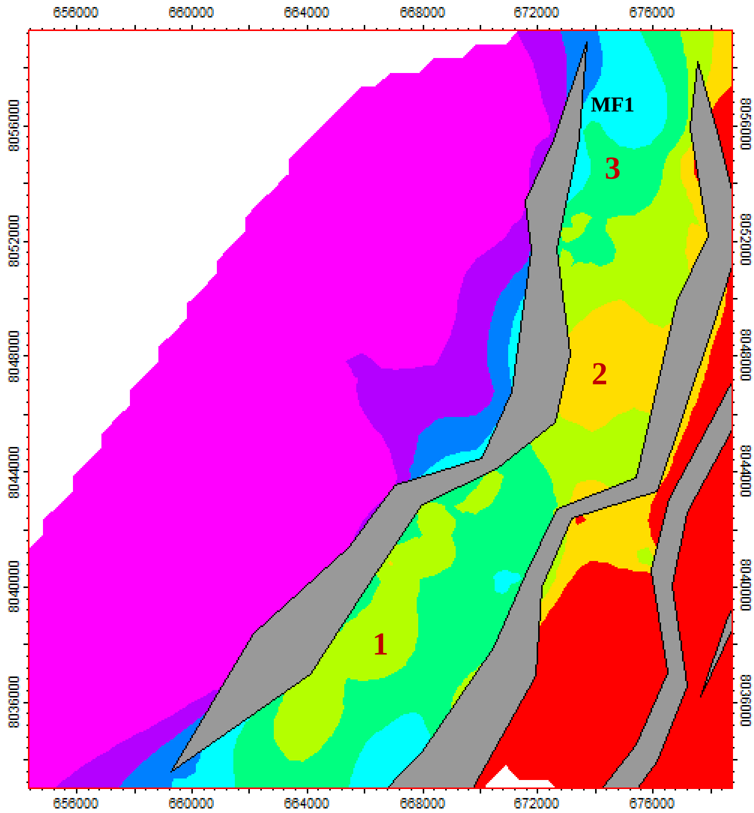

Fig. 45 Potential traps at Hekkingen Formation

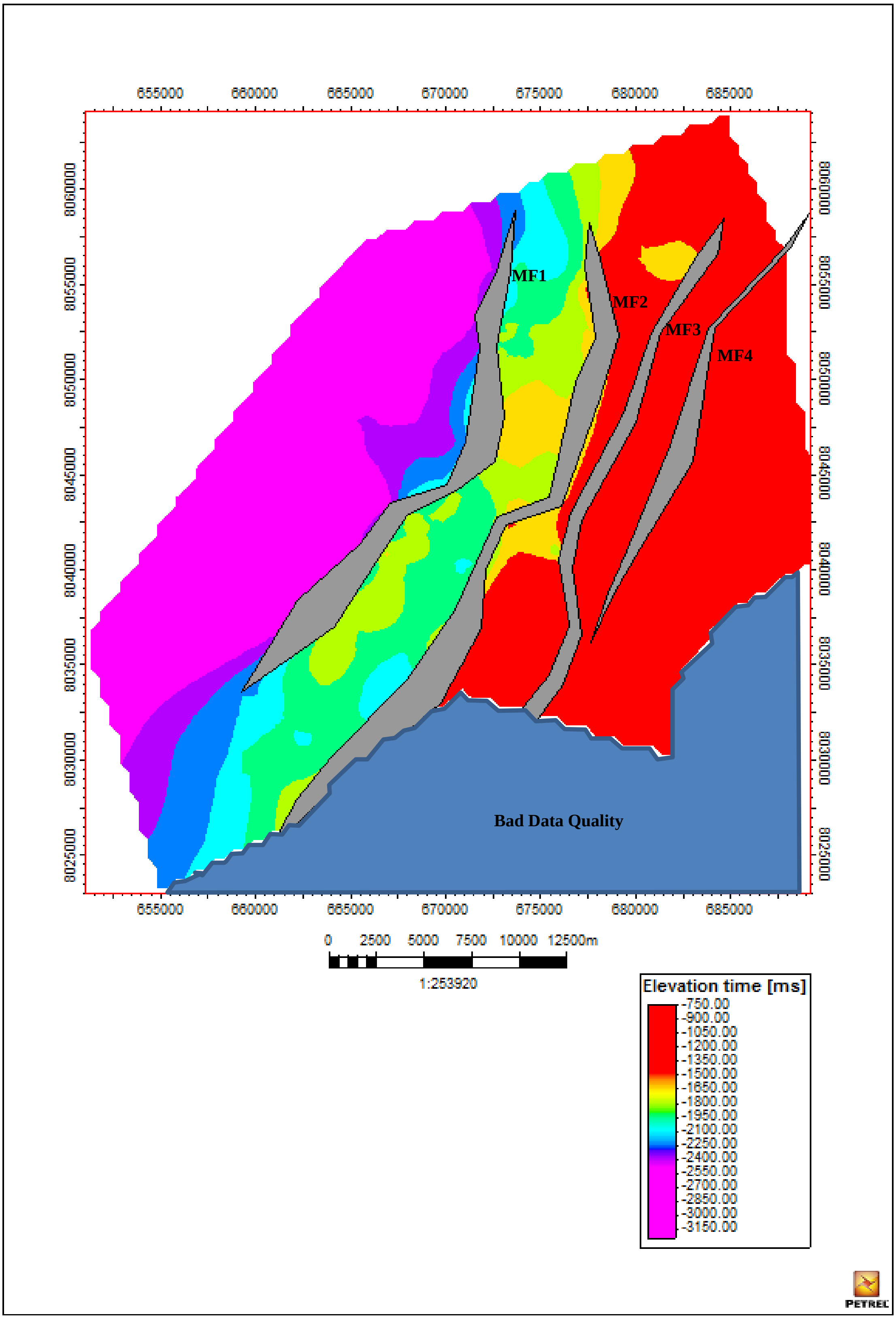

Fig. 46 Time structure map of Hekkingen Formation (Upper Jurassic)

3.2.4 Tubåen Formation (Base Jurassic)

Base Jurassic time structure map was generated by using the Tubåen Formation interpreted horizons (Fig. 47). The time scale of this map is from 1000ms-3600ms, and the color is transferred from red to purple. The time-structure map of the Tubåen shows general westward deepening of the reflection represented by color variation from purple to red.

Jurassic Formation is the main reservoir formation, and there are four major faults with three small faults shown on this structure map. All the faults are NE-SW trending. There are many traps related to the faults shown on the Base Jurassic structure map.

3.2.5 Snadd Formation (Base Triassic)

Base Triassic time structure map was generated by using the Snadd Formation interpreted horizons (Fig. 48). The time scale of this map is from 1600ms-4200ms, and the color is transferred from red to purple. The time-structure map of the Tubåen shows general westward deepening of the reflection represented by color variation from purple to red.

Triassic Formation is the deep formation in the interpreted horizons, and there are four major faults with three small faults shown on this structure map.

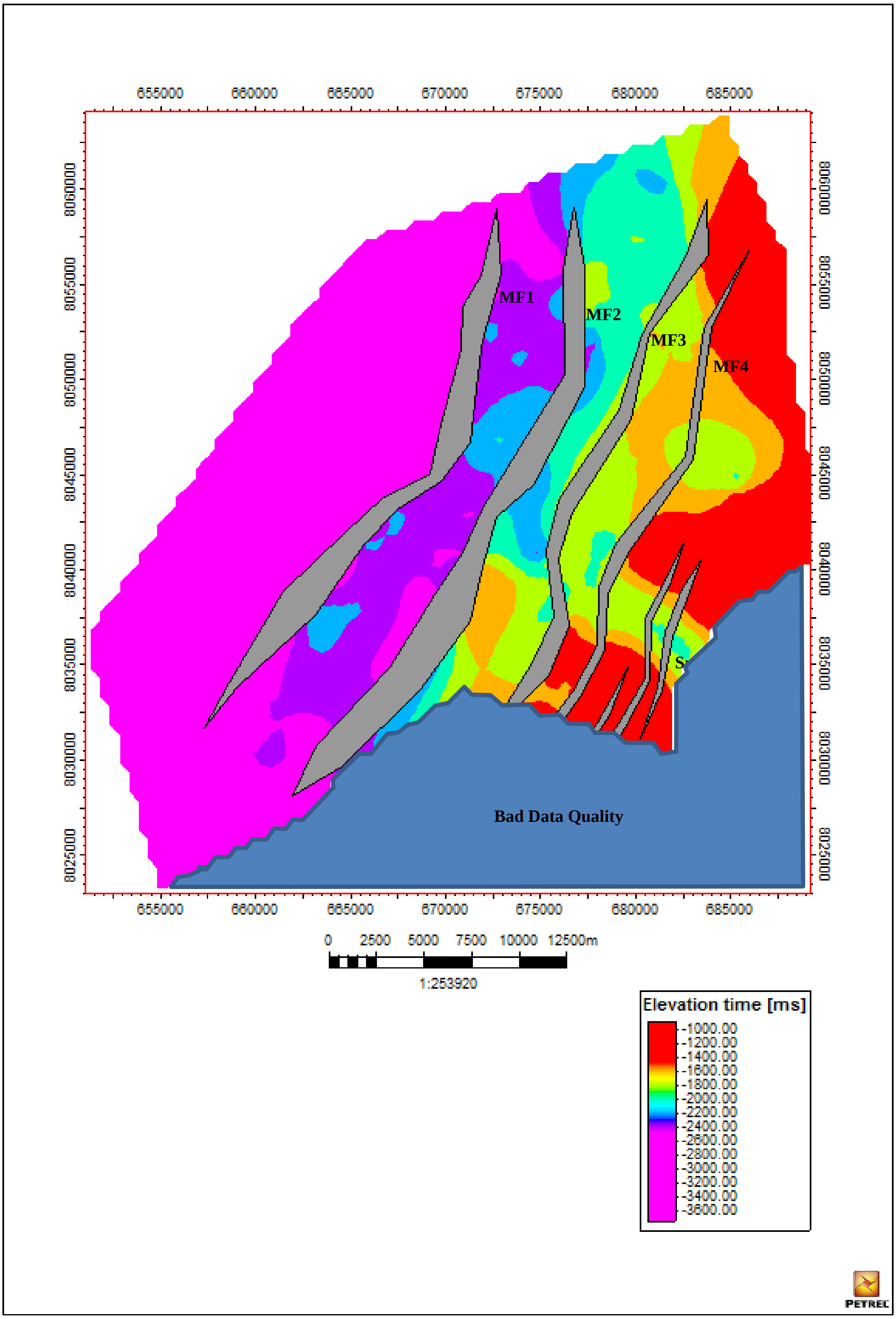

Fig. 47 Time structure map of Tubåen Formation (Base Jurassic)

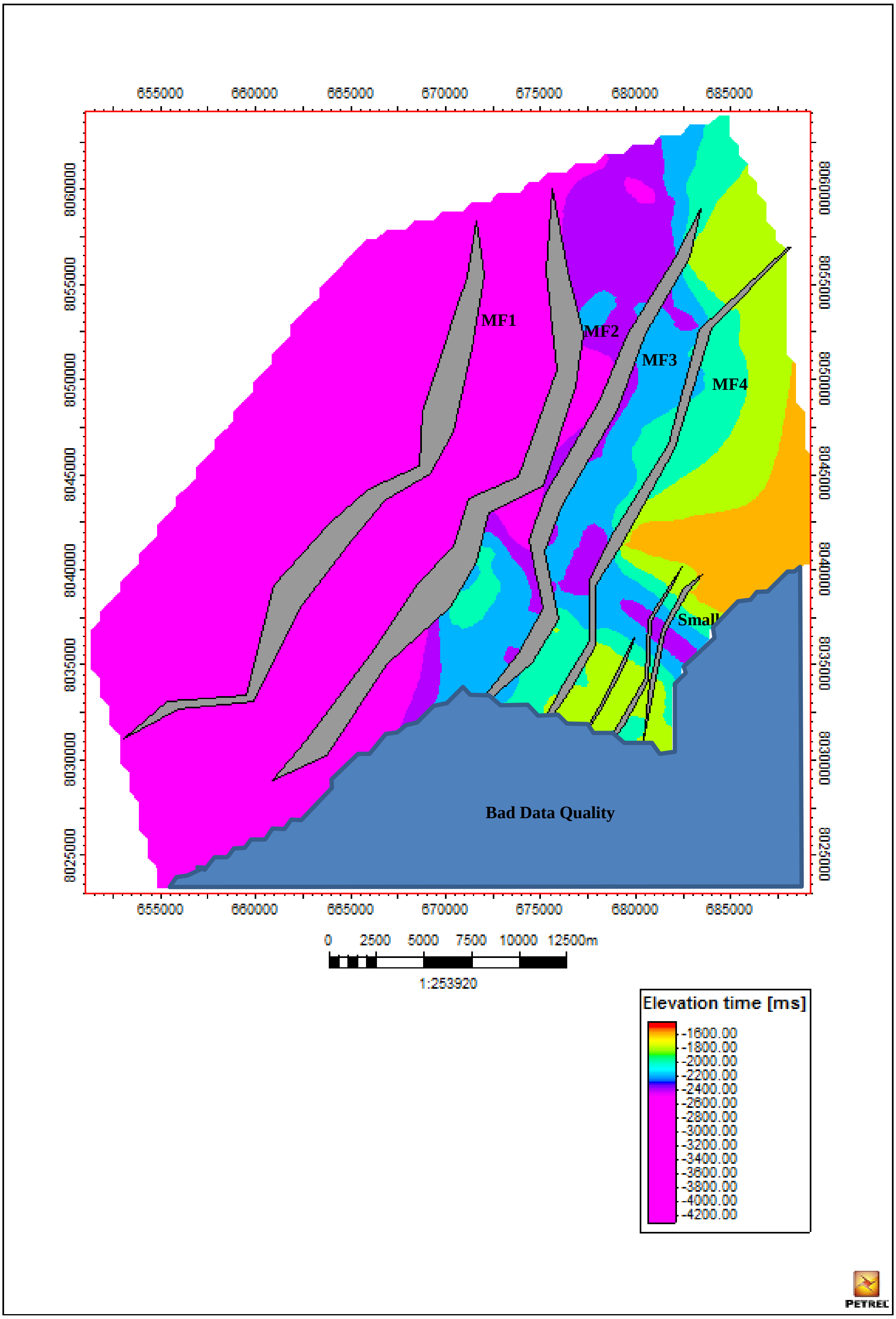

Fig. 48 Time structure map of Snadd Formation (Base Triassic)

4. Discussion

In the study area, the most significant reservoir rocks are in the strata of Jurassic age, and the major discoveries have a principal reservoir rock of Stø Formation from Lower to Middle Jurassic. If Jurassic formation was considered as the main target to analysis, the Hekkingen Formation structure map should be used.

Although it is lack of the well log data, well 7220/7-1, 7220/8-1 and 7220/5-1 were loaded into the structure maps. Only the location data were used in these three wells, and it will be helpful to analysis the Skrugard and Harvis discoveries.

Based on the previous seismic interpretation, the gas leakage seems the key solution to solve the problem in this area. Although the gas is shown in Cenozoic formation, it should leakage from the deeper traps. The gas location marked on the maps will give some ideas about the gas leakage zone (Fig. 49).

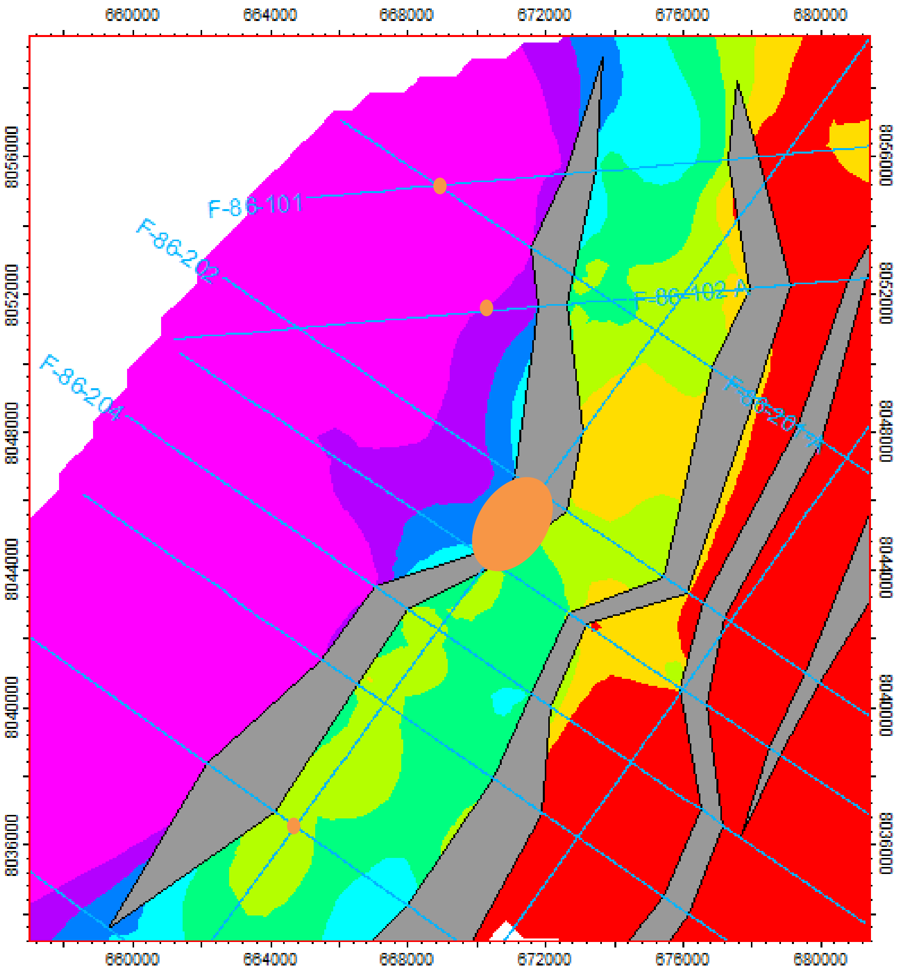

Fig. 49 Gas leakage areas (yellow circle) marked based on the seismic interpretation

From Fig. 49, there is a big gas leakage zone in the middle part of the area. There are two reasons for this gas leakage, seal broken and faults open. Fig. 50 shows these two possible reasons for the gas leakage, blue circle indicates the possible seal broken and the red circle indicates the possible faults open. For the seal broken, the top seal was broken by the rifting and causing the leakage of hydrocarbon from deep formation to the shallow formation. For the seal open, if the fault is not sealed, the hydrocarbon will migrate from the deep formation to the shallow formation along the fault.

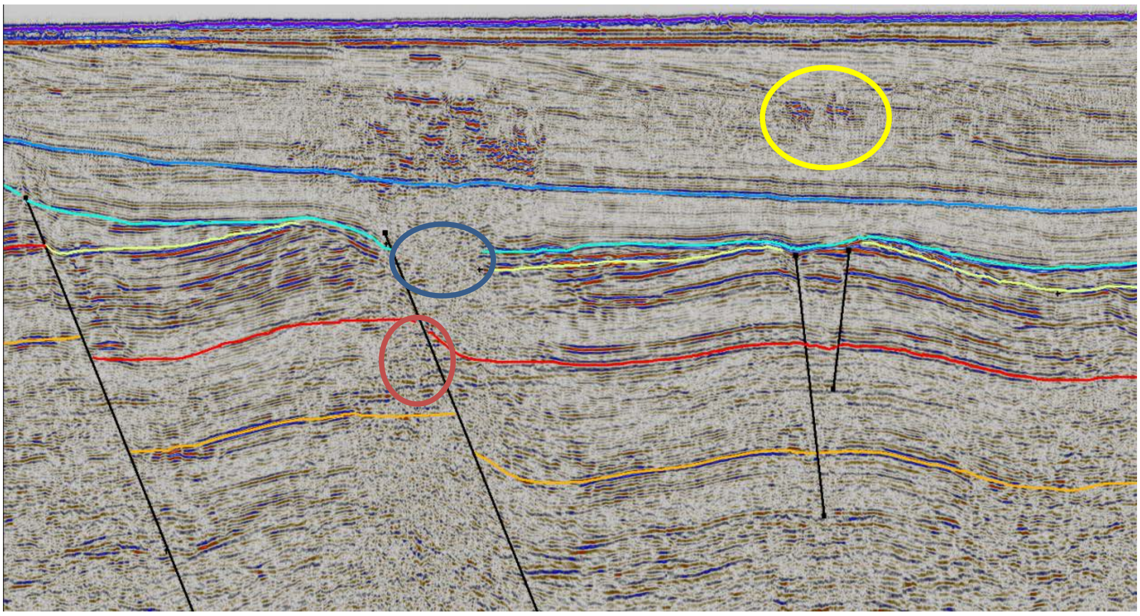

Fig. 50 Gas leakage in the study area

There is another small gas leakage happened in the yellow area in Fig. 50. This gas leakage was formed by the rifting. There seems a very good structure trap until the rifting started, which broke the seal of the trap. The gas also migrated from the deep formation from the shallow formation because of the broken seal.

Fig. 51 shows the time structure map of Hekkingen Formation with wells. Well 7220/5-1, 7220/7-1 and 7220/8-1 were loaded into the formation only with location data. Because of the width of the faults, some wells are shown in the faults in the figure below. Well 7220/5-1, 7220/7-1 and 7220/8-1 were found the Skrugard and Harvis discoveries, while 7220/9-1 only shows the residual oil. This was caused by the broken seal or the faults open. Seal broken was caused by the complicated geological and pressure history of the Barents Sea, then following re-distribution of hydrocarbons within the basin.

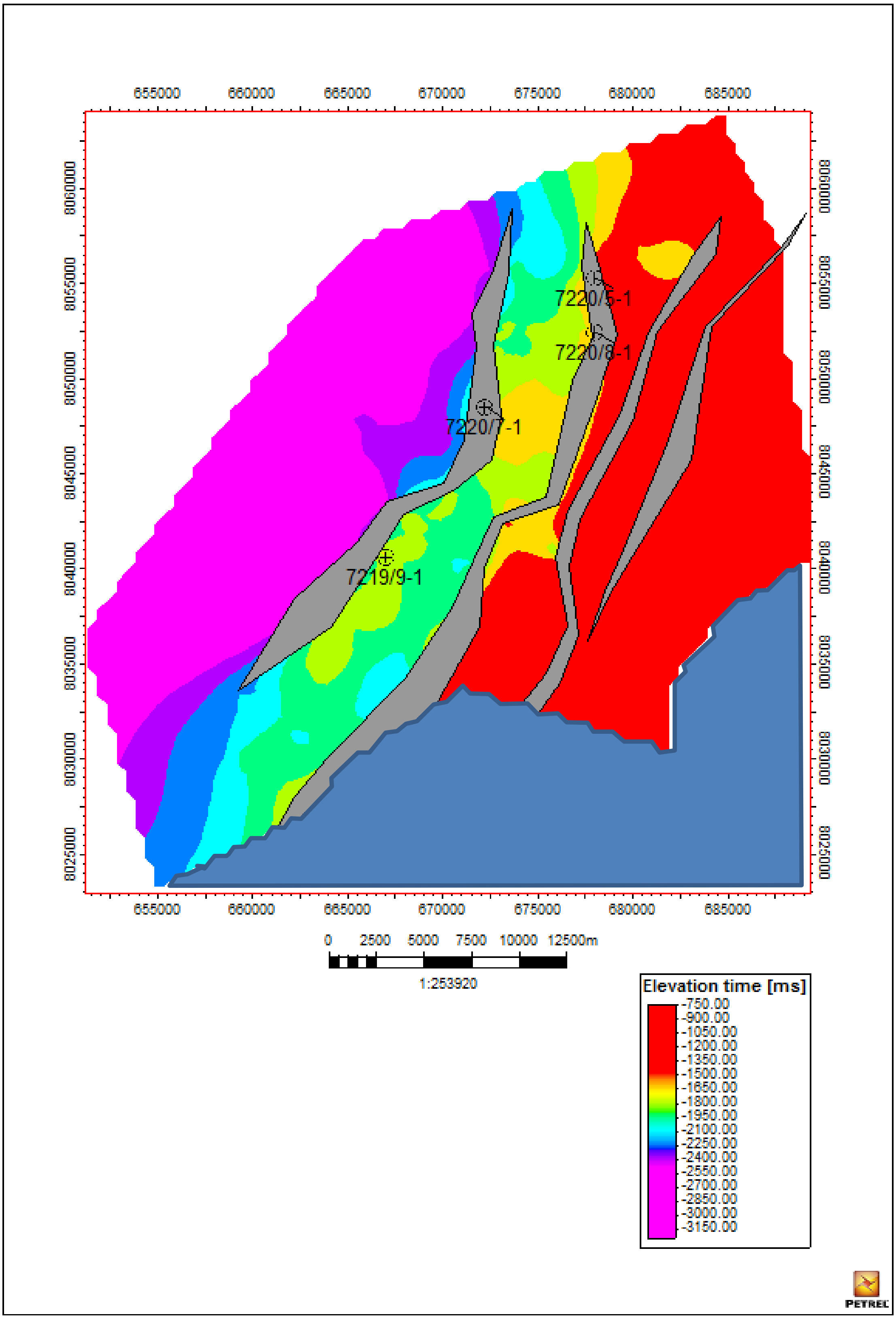

Fig. 51 Time structure map of Hekkingen Formation (Upper Jurassic) with wells

5. Conclusion

In the south-western Barents Sea, the most significant reservoir rocks are in the strata of Jurassic age, and the major discoveries have a principal reservoir rock of Stø Formation from Lower to Middle Jurassic. For the regional aspect, the Hekkingen Formation from Late Jurassic is considered as the source rocks in SW Barents Sea. Hekkingen Formation is very thick, and it can generate significant quantities of hydrocarbons and extends regionally in the Barents Sea, Early Jurassic Nordmela and Tubåen Formations and Early and Mid Triassic Formations, Snadd, Kobbe, Klappmyss and Havert formations.

The study area is in the Bjørnøya basin, which contains the Late Jurassic petroleum system. The Stø Formation from Jurassic age acts as the reservoir, the Snadd Formation acts as the source rock and the Hekkingen Formation acts as the seal rock. There are many structure traps related to the faults in the study area, and there seems many potential traps containing hydrocarbon.

Although there found commercial discoveries (7220/7-1, 7220/8-1), the study area is not fully understood since there are dry wells, some with shows (7219/9-1). Based on the seismic interpretation, the two possible reasons are broken seal and faults open for these dry wells and wells with residual oil (7219/9-1). These results are a consequence of the complicated geological history of the Barents Sea that includes several periods of exhumation and erosion, causing re-distribution of hydrocarbons within the basin.

The future work will be to discuss the cause of the seal broken and faults open. In order to know how the seal broken and faults open formed, it is necessary to analysis the pressure of this area.

During this work, there is another wildcat well began to drill in this area. This well is named as 7220/5-2 and it is located in the southwest of the Skrugard discovery. I believe this well is also drilled to Middle Jurassic Formation, and there must have the oil shows and discover the commercial hydrocarbon.

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