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Identification of Internal Salt Body Geometry Using Seismic Attributes, Volve Field, North Sea

Ratapong Jamroenkahjohnsuk*

Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
*Corresponding author email: ratapong.j@outlook.co.th

Abstract

Volve field is an important oil field of the Norwegian sector in the North Sea. Main oil reservoir in this field is Jurassic shallow marine sandstone. The structure of reservoir in Volve field is highly controlled by salt tectonics. The Upper-Permian Zechstein Group is considered to contain mainly evaporites and carbonates which is overlying the Lower-Permian Rotilegendes group and underlying the Triassic detrital clastic sediments. Zechstein salt doming started to develop in Early-Triassic and provides accommodation space for Triassic and Jurassic minibasins in this region until salt started to move out from the field in Early-Jurassic. The result of salt withdrawal caused a reduced Zechstein thickness than the original thickness and left the residual evaporites and carbonates in the Volve field. The evidence of salt withdrawal can be observed in seismic section by apparent downlap of Triassic reflector onto Zechstein reflector. The brittle property of residual Zechstein layer can be observed in seismic section where faults can cut through Zechstein layer. The salt thickness also varies throughout the field. Seismic attributes help to reveal the inhomogeneous lithology and lineations in Zechstein layer. Faults and lineations in Zechstein layer and surrounded sediment also align with regional structural trend. The NE-SW fault trend aligns with Viking graben axis, while NW-SE trend aligns with the Norwegian-Danish basin axis. The presence of faults and lineations in Zechstein layer confirmed that Zechstein layer in Volve field is the residual lithology resulting from salt withdrawal and it was affected by the complex tectonics in the North Sea.

Keywords: Seismic attributes, Volve field, Salt Identification

1. Introduction

Field History

The field was discovered in 1993 and started to produce in 2008. Main reservoir is Hugin formation a Middle-Jurassic sandstone. Reservoir thickness and geometry are controlled by salt tectonics and basement involved faults. The field mainly produces oil with minor gas and condensate. The production in Volve declined continuously after 2009. The field was shut down in 2016 and delivered almost 63 million barrels of oil through the field life.

Structural Geology and Tectonic Settings

Volve field is located in block 15/9 and lies in the Norwegian sector of the North Sea. Geology in Volve field is largely controlled by salt movement and basement involved faults. They affect structural style, sedimentary facies and thickness of overlying the sediments in the field. Major fault system in block 15/9 is NE-SW trending. It separates Sleipner Terrace from the Utsira high. Volve field is located on the eastern upthrown side of the main fault called "Gamma high" which is the southern extension of the Utsira high. This zone is the junction of 3 major structures in North Sea which are south Viking graben, Horda platform and Norwegian-Danish basin. Intersection of NE-SW and NW-SE trending faults limited the western boundary of the Utsira high. NE-SW fault called "Caledoniod" fault controls the west boundary of the Viking graben. NW-SE faults are trending parallel to the axis of the Norwegian-Danish basin. The NW-SE trend are considered to be pre-Permian basement fractures relates to the "Tornquist zone", the zone of weakness forming the southwestern boundary of the Fennoscanian-Russian platform. There is a NE-SW main fault with dip-to-the-west and a large displacement in the western part of Volve field. Smaller N-S faults with dip-to-the-east and smaller displacement are located in the eastern part of the field (Pegrum, 1984). These faults cause Volve field to be a local high area in Block 15/9.

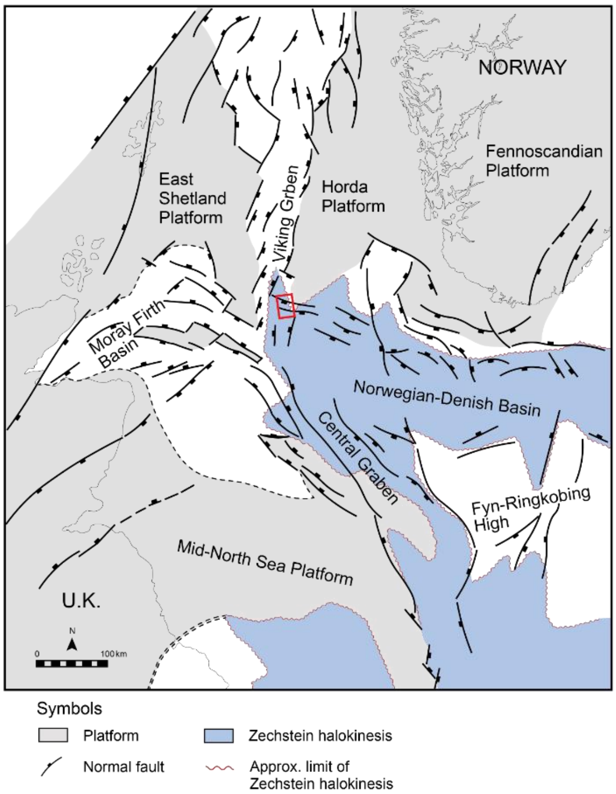

Fig.1. Structure elements map of North Sea. Block 15/9 (red rectangular) is located at the junction of Viking graben, Utsira high and Norwegian-Danish basin (modified from Pegrum, 1984).

Geological Stratigraphy

1. Lower-Permian (Rotilegendes group)

The Rotilegendes consists of interbedded red sandstones and breccia deposited in a fluvial-lacustrine to terrestrial environment. In some areas found dolomite-cemented sandstones interbedded with red silty shales indicates deposition in more basinward facies (R. M. PEGRUM and T. E. UONES, 1984).

2. Upper-Permian (Zechstein group)

There are no wells that penetrated the sub-Triassic section beneath Volve field. The Zechstein is overlain by red Triassic shale of Smith Bank formation and underlain by Lower-Permian Rotilegendes group.

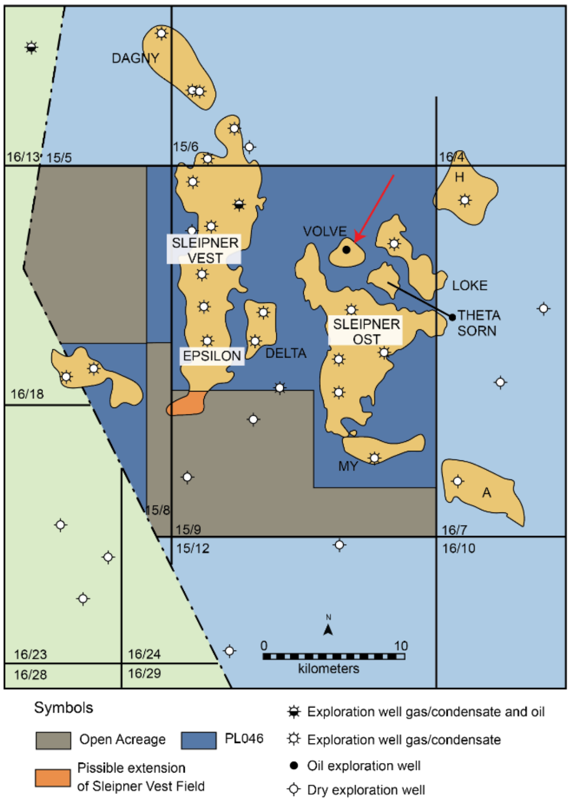

Fig.2. A map show location of block 15/9. Red arrow shows the study area. (modified from Malm, O.A. et al., 1993)

Stratigraphy of the Zechstein group in Netherlands can be divided into 5 formations, Z1 to Z5. Z1 consists of Copper shale at the base, carbonate, anhydrite and small amounts of salt. Z2 consists of carbonate at base overlain by thin basal anhydrite followed by relatively thick salt with thin roof anhydrite. Z3 consists of relatively thin claystone and platy dolomite at base followed by main anhydrite and overlain by relatively thick salt layer. Z4 consists of red salt clay at base followed by pegmatite-anhydrite and overlain by relatively thick K-Mg salt layer. Z5 consists of thin salt clay member at base overlain by thin salt layer. There is ZEUC claystone, Zechstein Upper Claystone Formation, overlain on top of Z5 (Geluk, M. C., 2000).

3. Triassic

The Triassic sediments covers throughout Block 15/9, but it has quite a complex stratigraphy. The sandstones dominated section are the Skagerrak formation.

The red shales dominated section are the Smith Bank formation (R. M. PEGRUM and T. E. UONES, 1984).

4. Jurassic

The Jurassic section consists of Kimmeridge high GR shale underlain by Heather shale. The main reservoirs are Hugin formation which are dominated by shallow marine sandstone, and Sleipner formation which consists of sandstone, coal and shale. The Lower Jurassic section is missing. It could be the result from regional uplift in this period (R. M. PEGRUM and T. E. UONES, 1984).

5. Cretaceous

The Lower Cretaceous section is Cromer Knoll Group from the top downward consists of Rodby Formation, Sola formation and Valhall formation. The sediments are predominantly marine shale, marl, and siltstone. On the Gamma high, the Lower Cretaceous is thinner, suggesting that the mid-Cretaceous compressive may have elevated Gamma fault block relative to the Sleipner terrace. The Upper Cretaceous consists of mainly thick Chalk. (R. M. PEGRUM and T. E. UONES, 1984)

6. Paleogene

The Paleocene sediments consists of shales interbedded with volcanic ash bands. All the Paleocene sands are referred to as the Rogaland Group. The Eocene section consists of marine claystone with thin carbonate and interbeds of sand and silt. The Oligocene section consists of marine shales and silts with stringers of limestone (R. M. PEGRUM and T. E. UONES, 1984).

7. Neogene

The Miocene sediments consists of a lower group of marine shales and claystone with stringers of silt and limestone, and the upper group of shallow marine shelf sands. The sands reservoir is belonging to the Utsira formation (R. M. PEGRUM and T. E. UONES, 1984).

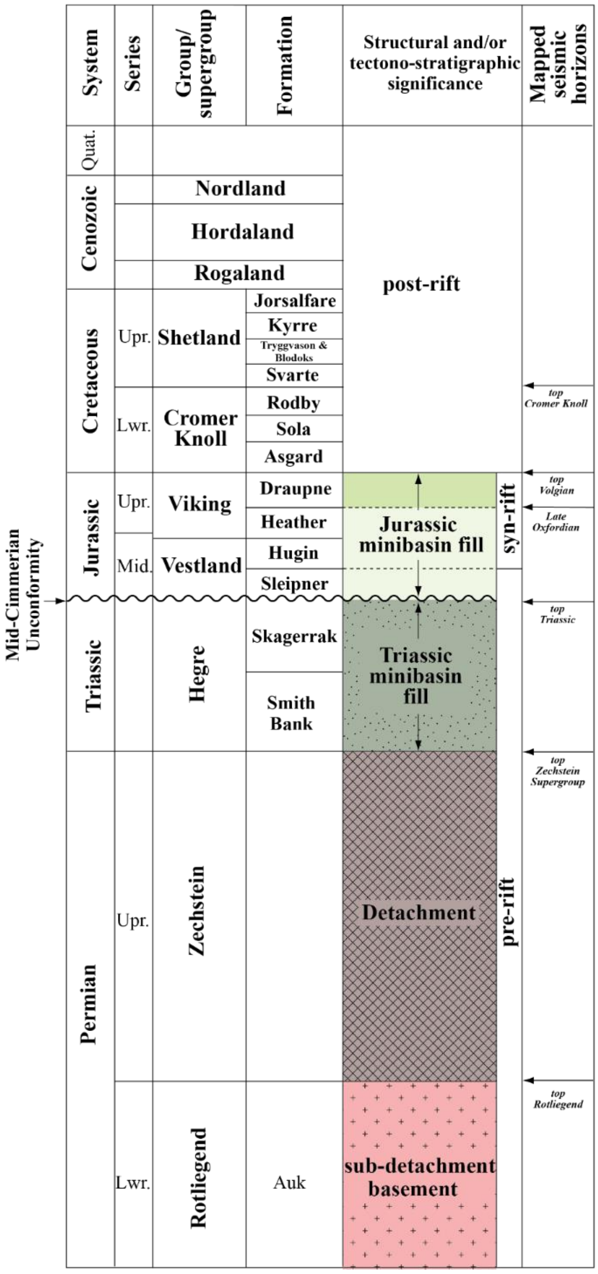

Fig.3. Composite stratigraphic column for the Norwegian sector of the northern part of the South Viking Graben (modified from Jackson, 2010) This study focuses on Upper-Permian Zechstein group.

2. Methodology

Seismic data ST0202 survey will be the main dataset for this study. This study will focus on identification of top salt, base salt and internal salt body using seismic attributes. There is no well data that penetrated Zechstein group

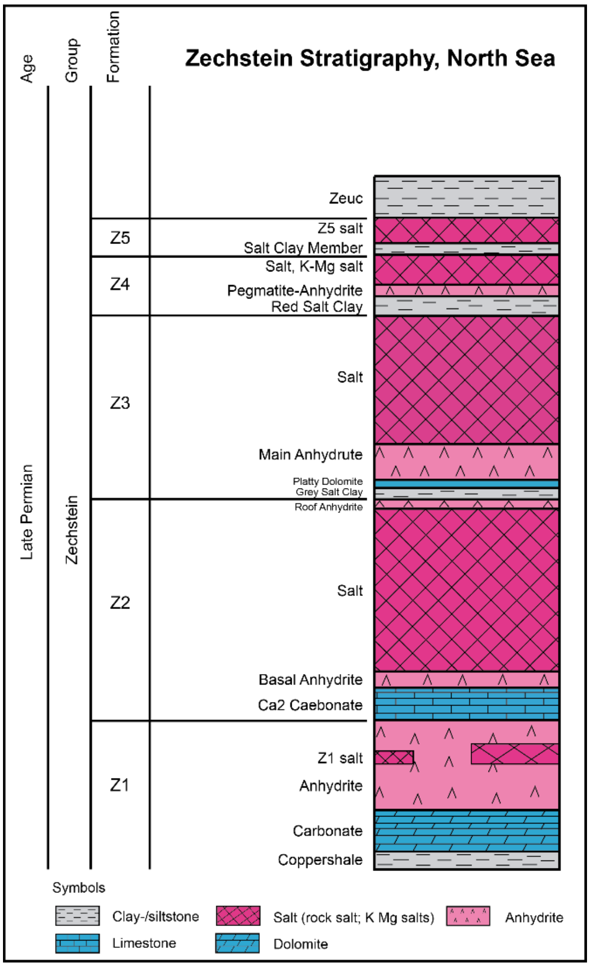

Fig.4. Show Zechstein stratigraphy and lithology in North Sea. Relative thicknesses of layers are indicated, but not to scale. The occurrence and thickness of units may vary with the facies (i.e., basin, slope, and platform). ZEUC, Zechstein Upper Claystone Formation (modified after F. Strozyk, 2017).

in Volve field. Therefore, evidence of salt movement, salt body geometry and deformation of sediments that are related to salt will be determined by the seismic data. Then, top salt reflector will be estimated. Top and base of salt reflector will be mapped along with most possible salt reflectors. Structural interpretation will be done based on seismic data. Seismic attributes will be used to identify the distribution of salt body and its internal structures. The challenge of this study is the absence of well logs data that penetrated Zechstein formations. Therefore, stratigraphy and lithology of Zechstein group will be referred from previous studies in North Sea. Zechstein group is expected to be mapped from its relatively high amplitude reflector of salt, anhydrite and carbonate compared to surrounded detrital clastic sedimentary rocks. In addition, the study is expected to identify internal Zechstein group seismic reflectors due to the contrasts of acoustic impedance of salt, anhydrite, carbonate and shale.

3. Data Description

The 3D seismic data of Volve field were used. The seismic survey ST0202 was acquired in 2002 and initially processed using pre-stack time migration. In 2004 the ST0202 was reprocessed using PZ and PS anisotropic depth migration. The seismic data is approximately 40 square kilometers and has 12.5 x 12.5 meters bin size. Sampling rate is 4 milliseconds starting from 0 to 3396 milliseconds. Data format is 8 bits. The study area includes 401 inlines and 640 crosslines. The data is normal polarity and processed with zero phase wavelet. The section below base Cretaceous unconformity, including Zechstein salt interval and pre-Zechstein rocks, has low resolution with frequency range 10-30 Hz. The database was provided by Equinor ASA company.

4. Results and Interpretations

Zechstein Reflector Identification

Top and base Zechstein reflector were picked based on reflector estimation because there is no well that penetrated into Zechstein group in this field. To estimate top and base Zechstein layer, salt morphology, seismic reflector termination and acoustic impedance will be considered.

There is apparent downlap or rotated onlap of Triassic sediments on Zechstein layer present in seismic section. This feature occurs when Triassic sediments deposits onlap to Zechstein evaporites in Triassic minibasins on Zechstein layer which started to develop during Early-Triassic. Increasing amounts of Triassic sediment load promotes the development of

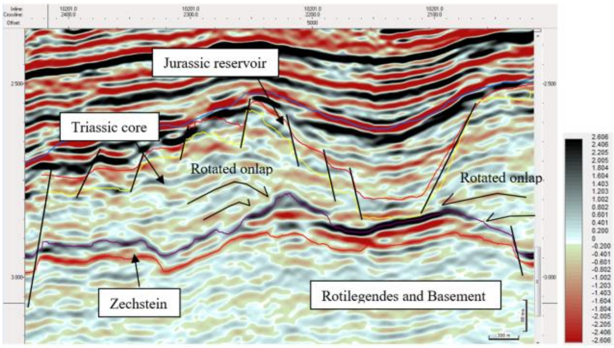

Fig.5. Inline 10201 show Zechstein salt geometry underneath Triassic sediments. Triassic reflector shows rotated onlap or apparent onlap to the Zechstein layer.

minibasins and salt domes in Volve field. During this period, location above salt dome is a structural high, the location between salt dome forms accommodation space for Triassic sediments. This causes thick Triassic-cored sediments between salt dome with thinner Triassic layer above salt dome. During Jurassic, salt dome started to withdraw from Volve field. The location above previous salt domes become a structural low and accommodation space for Jurassic sediments in the field. This causes the previous onlap of Triassic sediment to Zechstein salt dome to become rotated forming onlap or apparent downlap to Zechstein layer when salt body collapsed (Jackson, 2010). Therefore, top Zechstein should be picked on the surface which Triassic reflector terminated on and show rotated onlap. In addition, the acoustic impedance (AI) of Lower-Triassic, Smith Bank formation, derived from well 15/9-F1 will be considered to support top and base Zechstein group. Average AI of Smith Bank sandstone

Lithology	Density(g/cc)	Velocity (m/s)	AI
Halite	2.20	4,500	9,900
Anhydrite	2.90	6,500	18,850
Dolomite	2.87	6,300	18,081
Limestone	2.70	6,000	16,200

Table 1. Physical properties of main evaporite minerals (modified from Ian F. Jones, 2014 and Bourbié, 1987).

and shale near well TD at 3,330 TVD RKB are 9,000 and 10,000 respectively. Rock physics properties which are expected to be found in Zechstein group are present in Table 1.

As a result of the acoustic impedance calculation, the seismic reflector of top Zechstein group is supposed to be a high amplitude peak when lithology changes from Triassic shales or sandstones into Zechstein anhydrite and carbonates section. Then, it changes to be a trough when lithology changes from the Zechstein to clastic sediments of Rotilegendes group. In seismic section, Triassic sediments show termination (rotated onlap) on high amplitude peak of irregular top Zechstein horizon, this indicate that top Zechstein reflector should be high acoustic impedance rock such as residual anhydrite or carbonates.

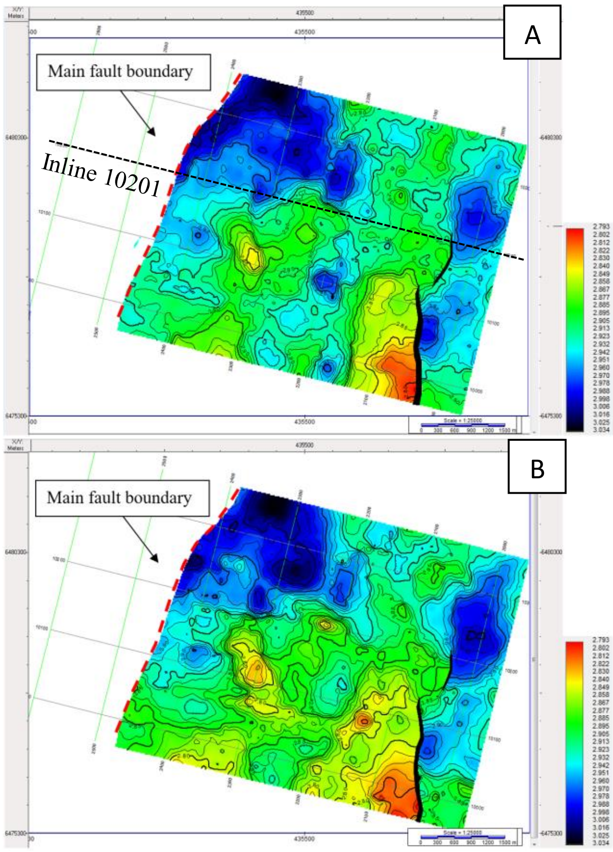

Fig.6. Time structural map of Zechstein group. Scale is 1:25,000 with contour interval 0.01 ms. A.) Top Zechstein horizon. B.) Base Zechstein horizon.

Top Zechstein horizon map show irregular shape due to salt body geometry. There is the main fault in the west part in Volve field which forms the boundary of the field. This fault dips to the west and has very large displacement. There are some faults that dip to the east located in the eastern part of the field. Obvious faults in the field have strike in NE-SW direction, the same direction with the Viking graben. The Zechstein layer on the structural high in the southern part is flat and more stable than other parts. There is no distinguishing salt dome present in the field. Base Zechstein structural map imply morphology of the Rotilegendes basement, overall map is approximate to Top Zechstein because the Zechstein layer in this field is thin and low relief.

Internal Salt Body Identification

A seismic attribute is any measure of seismic data that helps the interpreter to visually enhance and quantify features of interpretation interest. Seismic attributes are a powerful aid to seismic interpretation (Chopra and Marfurt, 2007).

Trace Envelope attribute represents the total instantaneous energy of the complex trace independent of the phase. The envelope relates directly to the acoustic impedance contrasts. It can help to indicate acoustic impedance contrast, bright spots, gas accumulation, unconformities, spatial correlation to porosity, lithologic variation and major changes of lithology.

The result of trace envelope attribute is close to RMS amplitude attribute. It can help to indicate salt body in section and time slice. Zechstein group show high amplitude in the map because in has high acoustic impedance contrast of Upper-Permian Zechstein evaporites and carbonates compared to detrital clastic sediments in Triassic and Lower-Permian. The variation of amplitude inside Zechstein layer could indicate that there is inhomogeneous lithology in Zechstein layer. This could be the combination of the result from salt movement deposition, tectonic activity or depositional environments.

Similarity attributes can help to reveal abrupt structure or stratigraphic change. The lateral similarity indication is computed as semblance. It is a measurement of waveform and amplitude similarity to highlight discontinuity between seismic traces. Therefore, this attribute is expected to indicate discontinuity between Zechstein group and nearby sediments. In addition, it was expected to indicate lithology change, fault, fracture and structure change either in surrounded sediments or inside Zechstein salt body.

As a result, similarity attribute can indicate major fault zone in the western part but failed to indicate salt boundary in time slices. This is due to salt in Volve field being a low relief salt and does not show a distinguished salt geometry. However, the attributes can indicate discontinuity inside Zechstein layer that could be variation in lithology or faults and fractures due to brittle property of residual evaporites and carbonates.

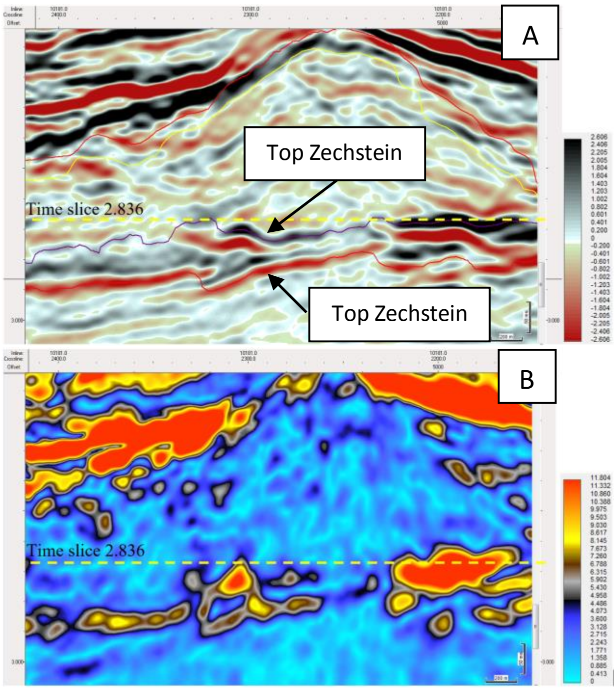

Fig.7. Inline 10181 show layer of Zechstein group. Vertical scale is 50 ms with horizontal scale 200 m. A.) Complexity of top and base Zechstein mapping. B.) Trace envelope attribute, closely with RMS amplitude attribute, reveals lateral and vertical inhomogeneous lithology in the Zechstein layer.

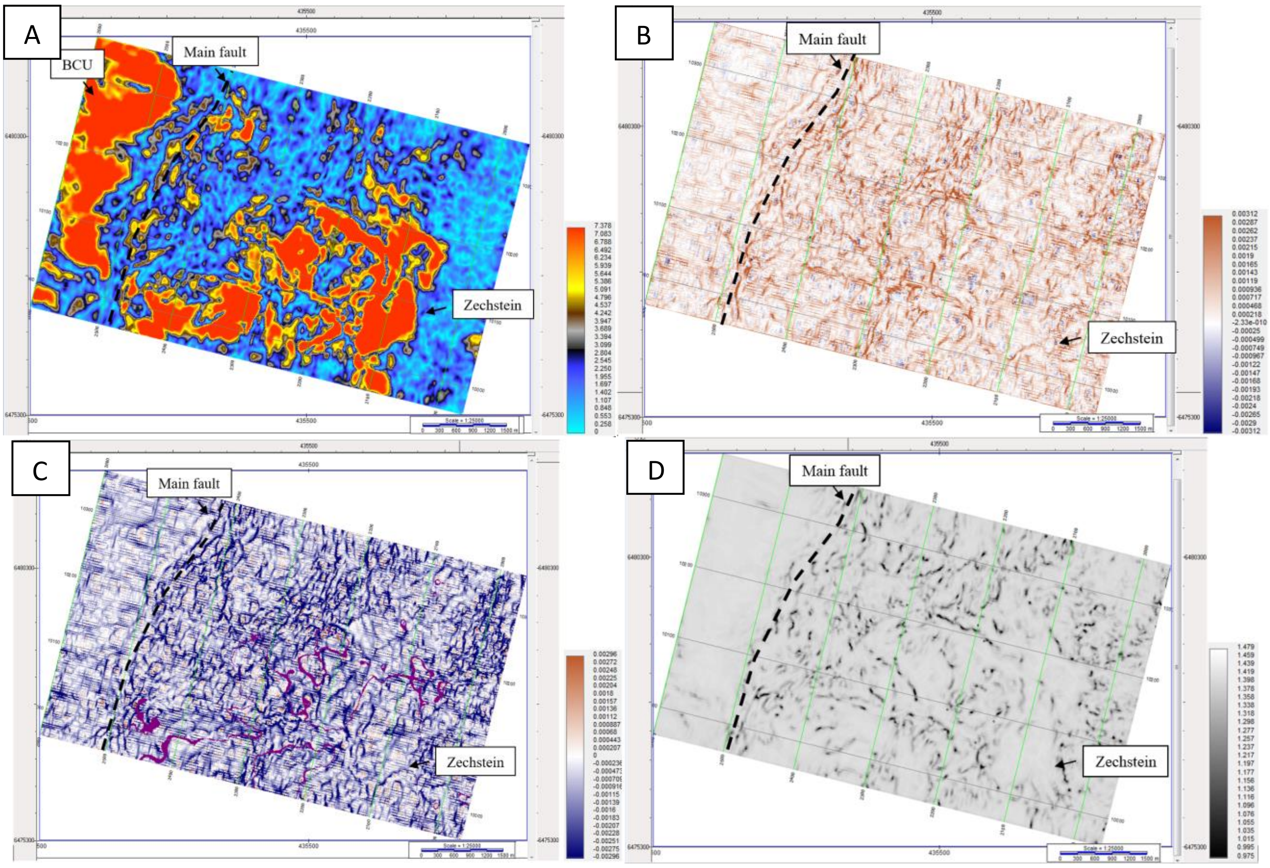

Fig.8. Time slice 2.836 with computed with various seismic attributes. Map scale is 1:25,000. A.) Trace Envelope attribute can indicate Zechstein layer boundary and reveal its inhomogeneous lithology. B.) and C.) Most Positive and Most Negative attribute cannot detect Zechstein boundary, but they can indicate lineation trends in Zechstein layer. D.) Similarity attribute also cannot indicates Zechstein layer boundary but it can indicate discontinuity and lineation trends inside the Zechstein layer.

Curvature attributes describes how bent a surface is at a particular point. The more bent the surface is the larger its curvature. Curvature is defining as the rate of change of direction of the curve. Curvature attribute maps are a powerful tool for visualization and interpretation of structural features (Mario E. S., 2003). Curvature attributes can be used to detect geological features such as incised valley, channel, salt dome, anticline, syncline and faults. Most positive and most negative curvature attributes were selected to identify salt structure and internal salt body for this study.

As a result, in Volve field, curvature attribute can help to indicate structural dip change and discontinuity of reflectors. It can indicate the main fault in the western part of the field which is a long linear trend in NE-SW for both most positive and most negative attributes. Orientation of curvature in the field is dominated by NE-SW direction with a few NW-SE, that aligns with Viking graben axis and Tornquist zone respectively. However, curvature attribute fails to indicate boundary of Zechstein layer, but it can indicate discontinuity, small faults, fractures and lineaments inside salt body which demonstrates that Zechstein layer is brittle. Lineation in Zechstein dominated by NE-SE trending which align with South Viking graben axis with minor lineation in NW-SE direction, indicates that Zechstein group could have been influenced by tectonics from South Viking graben and Norwegian-Danish Basin.

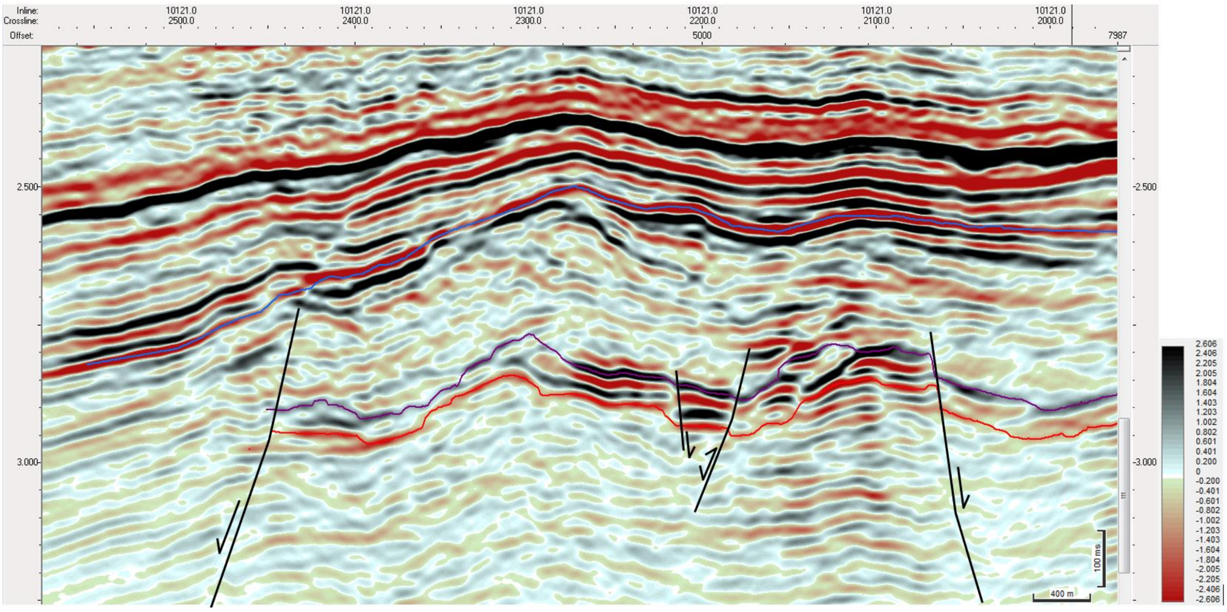

Fig.9. Inline 10121 show faulted Zechstein layer, indicates brittle property of residual carbonates and evaporites in Volve field. Thickness of Zechstein is varying in the field. Purple horizon is top Zechstein. Red horizon is base Zechstein. Blue horizon is Base Cretaceous Unconformity.

Volume Attribute

Similarity volume attribute can be used to compute similarity between top and base of Zechstein salt to identify fault, fracture and lineaments inside Zechstein salt body. This technique needs to input top and base Zechstein horizon, then select the preferred attribute to run. This study uses root mean square function for output amplitude, it helps to highlight discontinuity in the salt body with clean and smooth output. The output horizon will be generated in the middle between top and base Zechstein with similarity attribute which calculated a window within top and base Zechstein salt.

The results from similarity volume attribute show discontinuity trend which can be defined in two directions. The first direction is NE-SW direction which is parallel to the axis of the Viking graben, the second direction is NW-SE which is parallel to Tornquist fault zone. These discontinuities can be fault, fracture and lineament of brittle rocks, the residual evaporites and carbonates inside Zechstein group, that are affected by Viking graben and Tornquist fault zone. However, some discontinuity which does not correspond with the major faults trend could be the result from salt movement.

The presence of brittle and inhomogeneous rock of Zechstein also supports the interpretation that the main volume of salt was moved from the field and left the residual evaporites and carbonates behind in the field.

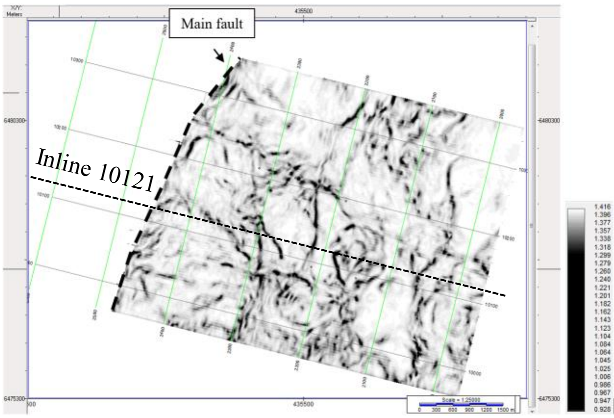

Fig.10. Similarity attribute computed from top to base Zechstein group show discontinuity of reflector inside Zechstein layer.

Zechstein Isochron/Isopach Map

Time-depth chart of lower Triassic sediments and Zechstein layers cannot be generated due to the limitation of well data that

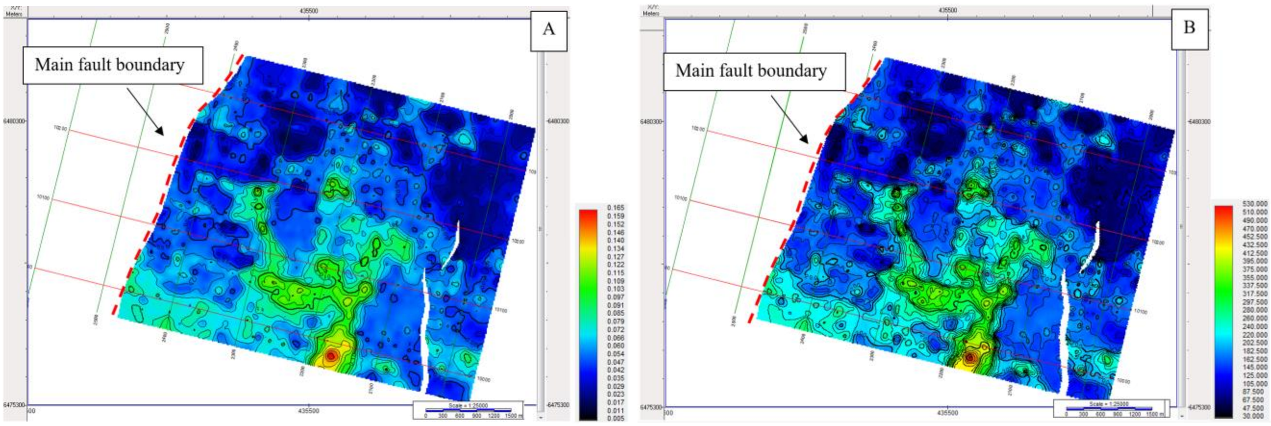

Fig.11. Zechstein isochron map (A) and isopach map (B), show thickness of Zechstein group in Volve field in TWT time (ms) and depth (meters) respectively. Map scale is 1:25,000.

never penetrated to Zechstein layer in Volve field. In addition, carbonate rocks in Zechstein layer may cause high variation of velocity both horizontal and vertical direction. Isochron map is generated by using different of time between top and base Zechstein horizons. Then isopach map can be generated using estimated average velocity from carbonates and anhydrite at 6,266 m/s, based on information from Table.1.

Isochron/Isopach map indicates that Zechstein group in Volve field is mostly a thin layer throughout the field in the present day. Zechstein layer is thin in northern area. The central and southern area have slightly thicker than overall area. The thinnest Zechstein layer is located in northern part with approximate thickness of 50 meters. The thickest Zechstein layer is located in southern part with approximate thickness of 500 meters.

In the past, salt in Volve field is expected to be thicker than the present day. This result can be supported by salt doming and salt withdrawal model. Zechstein salt which is more mobile than carbonate, anhydrite and shale started to move out from the field during Jurassic. This cause thickness of Zechstein group to be reduced. Therefore, in the present day, the Zechstein group in Volve field probably remains as the thin residual Zechstein formations which is more brittle and less mobile than salt left in the field.

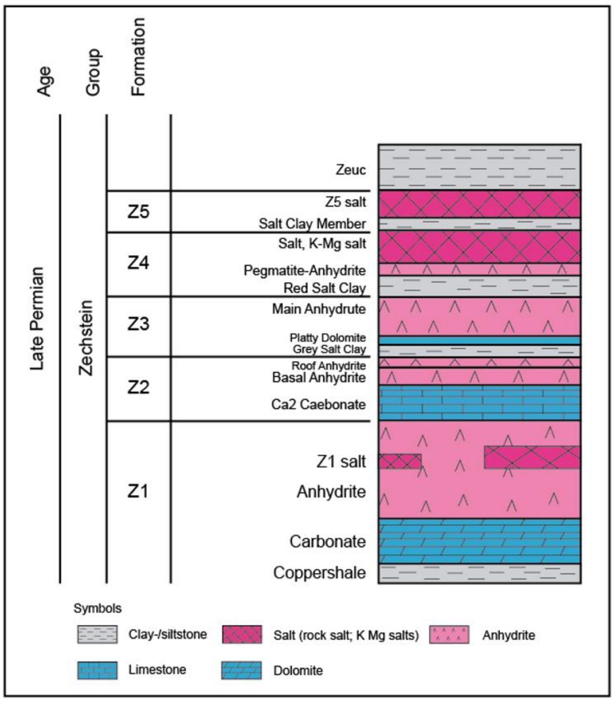

Fig.12. Illustrates the estimated lithology of residual evaporites and carbonates that are left behind in Volve field after main salt body started to move out from the field since the Jurassic. Relative thicknesses of layers are indicated, but not to scale (modified from F. Strozyk, 2017).

5. Discussion

There is salt influence structure in Volve field, especially in Triassic and Jurassic sediments. Triassic cores with thin overlying Jurassic sediments were observed throughout the field. Previous studies of salt tectonics along Utsira high and Sleipner areas found that salt doming, salt withdrawal and basement involved faulting are important for overlying sediments thickness and structure in region.

During the late Permian, a thick package of salt was deposited across the field area. Triassic sediments that consist of Smith Bank and Skagerrak formations were deposited onto the salt which creates depocenters in the areas of salt withdrawal and salt ridges and diapirs in adjacent areas. In Jurassic, Zechstein salt-cored structural high which were previously a site of low accommodation and capped by thin Triassic sediments become a site of minibasin and accommodation of Jurassic sediments. Thinner Jurassic layers were deposited on the Triassic highs (Jackson, 2010).

The evidence of minibasins that development above Zechstein layer from this study is aligned with previous studies in this region. Salt thickness in Volve field in the past is expected to be thicker than the present day. Halokinesis of salt during Triassic-Jurassic is important to influence the formation of minibasins in this region. When Zechstein salt volume started to move out from the field during Jurassic, most of salt volume is more mobile than carbonates and anhydrite. Therefore, residual anhydrites, carbonates and shale is expected to be left behind in the field. This is supported by the evidence of faulted and fractured Zechstein layer in seismic section and seismic attributes, which indicates that residual Zechstein layer is brittle and not dominated by salt anymore. Thickness of Zechstein group in Volve field is thin and variable throughout the field area compared to nearby fields in block 15/12 which is located approximately 30 km to the south and can thicken up to 1,154 meters (R. M. PEGRUM and T. E. UONES, 1984). In addition, the residual Zechstein group in Volve field also shows inhomogeneous lithology in the layer. This can be indicated by variable amplitudes in both seismic volume and seismic attributes. The inhomogeneous lithology in the Zechstein layer could be the combination of the result from salt movement, tectonic activity and its deposition.

6. Conclusion

a.) There is a reduced amount of Zechstein salt remaining in Volve field and the thickness also is thinner than expectation compared to nearby fields. This observation can be supported by salt withdrawal model during Jurassic.

b.) Salt withdrawal during Jurassic has left a residual of evaporites, carbonates and shales in Zechstein succession behind in the field. This hypothesis is supported by the evidence of brittle and faulted of Zechstein layer in the field.

c.) High amplitudes of Zechstein layer the Volve field may be caused by contrast of acoustic impedance between residual Zechstein group and detrital clastic sediments of overlying Triassic and underlying Rotilegendes group.

d.) Zechstein layer in Volve field has an inhomogeneous lithology, this can be observed by amplitude variation of Zechstein layer throughout the field. This could be the result from salt movements, tectonic activity and depositional environments.

e.) Seismic attributes can help to reveal lineations and inhomogeneous property of Zechstein layer. Lineations of Zechstein layer and surrounded sediments are align with regional trends which are NE-SW and NW-SE trending of Viking graben and Norwegian-Danish basin respectively.

7. Acknowledgement

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