[EA]Influence of Mobile Salt on the Distribution and Preservation of Fulmar Reservoir Sands in the UK Central North Sea*

Mikhail Skaryatin[1], Matthew Brown[2], and Oliver Duffy[3]

Search and Discovery Article #11190 (2019)**
Posted February 4, 2019

*Adapted from extended abstract based on poster presentation given at AAPG/SEG International Conference and Exhibition, Barcelona, Spain, April 3-6, 2016
 DOI:10.1306/11190Skaryatin2019

[1]Gubkin Russian State University of Oil and Gas, Moscow, Russia (mailto:mvskaryatin@gmail.com)
[2]E.ON E&P UK Ltd., London, United Kingdom
[3]Imperial College London, London, United Kingdom

Abstract

Tectono-stratigraphic evolution models of the UK Central North Sea indicate that the Permian Zechstein evaporites were mobilised into a network of salt walls separated by intervening minibasins or ‘pods’ in the Triassic. This was followed by a phase of pod grounding, salt dissolution and salt valley formation, with the topography of salt valleys interpreted to have influenced the deposition of Upper Jurassic transgressive shoreface reservoir sands of the Fulmar Formation (Clark et al., 1998; Clark, 1999; Hodgson, 1992).

Analysis of the geometry and connectivity of the salt structures, and of the geometry of detailed mapping of sedimentary packages within the minibasins enables a model of salt evolution to be developed. Thickness variations between intra-pod layers clearly show the development of depo-centres through time in response to growth and collapse of salt structures. This study shows that salt kinematics commenced in the northern part of the study area and evolved progressively southward. Late fall of salt bodies led to the formation of valleys above the salt walls. This topography created accommodation space for subsequent deposition of Fulmar sands; a key reservoir in this region. Analysis of this evolving salt system therefore sheds light on the trap type distribution and Fulmar sands deposition and preservation.

Introduction

The Central North Sea (CNS) is a prominent, mature petroleum province with remaining exploration potential. One of the controlling geological factors for the petroleum plays of the region is salt tectonics. Permian salt is extensive across the North Sea, but the history of its movement varies depending on numerous factors. The study of salt kinematic processes such as salt growth, dissolution and collapse is of great importance for petroleum exploration.

This work applies existing concepts to a new area, which was not yet studied in detail using 3D seismic data. In this study we address: (1) controls on the structural styles of salt structures and pods, (2) processes related to syn-kinematic deposition and its impact on salt evolution, (3) the geographical and chronological positioning of key processes, and (4) implications for prospectivity.

Input Data and Methodology

This study is in a relatively unexplored region of the UK Central North Sea and uses a 3D marine seismic survey of 1600 km^2. Only one well is drilled in the area and it did not penetrate the intervals studied. To predict the distribution of the Fulmar reservoir sands we integrate:
(1) detailed structural interpretation of 3D seismic data and analysis of geometry, orientation and distribution of salt structures and pods,
(2) analysis of thickness variations between intra-pod beds and migration of depocentres (thick areas between surfaces controlling salt withdrawal) in time, and (3) modelling of the Jurassic paleotopography in accordance with the methodology of Clark (1999).

Salt Structures

Analysis of the present day salt geometries (Figure 1a) is an important step in understanding their evolution. Variations in area and ellipticity (length to width ratio) were used to classify three distinct types of salt structures (Figure 1b).

1) Salt wall ("SW"), with high area (>3 km^2) and high ellipticity (>2),
2) Salt diapir ("SD"), with medium area (>1 km^2) and small ellipticity (1-2),
3) Salt chimney ("SC"), with small area (<1 km^2) and small ellipticity (1-2).

The main trend in the area is associated with a decrease in the number of salt structures and increase of their area and ellipticity in the southern direction. Salt chimneys are concentrated in the northern quarter of the study area (Figure 1b) Salt diapirs are concentrated in the northern half of the study area and have no trend in size or elongation (Figure 1b).

Most salt structures are linked with the closest neighbours by salt rollers and some by salt pillows (Figure 1c). Studying this connectivity can be useful in understanding the initial stages of salt distribution during Early Triassic. The average time thickness of salt rollers and salt pillows is roughly 150 ms, it is reasonable to create polygons from isochore 150 ms to outline connected salt structures (yellow polygons on Figure 1c). These polygons form 11 chains of connected salt structures. Chain 2 is underlain by salt pillow connecting the adjacent salt structures into an isometric ring of salt structures. Chain 1 has very similar circular shape with the only difference being less time thickness of salt in the centre.

The spatial variation of the geometry and distribution of salt structures along with the style of their interconnection reveals the principal difference between the northern and southern regions in the level of structuration and maturity of salt tectonics. The northern part is more structured and mature suggesting the salt was first mobilised in the north.

Triassic Pods and Salt Rise

The study of thickness of sequences within Triassic pods reveals a consistent history of a parallel bedded package representing prekinematic stage (Figure 2) overlain by rim synclines, signifying syn-kinematic deposition. These syn-kinematic packages can be identified by divergence marking growth strata and onlap features signifying filling of accommodation space generated by salt withdrawal. The erosional truncations are evidence for erosion of uplifted sediments due to salt rise and can be associated with secondary rim synclines (sensu Trusheim, 1960).

Triassic subsidence in pods varies in style in relation to the Zechstein facies. Internal heterogeneity of the Zechstein supergroup depends on Permian paleogeography and is represented by a difference in proportion of halite (Clark et al., 1998). The marginal facies containing anhydrite and carbonate beds form salt pillows in pods and reduce the pod thickness (Figure 2).

Salt kinematics initiated with differential loading in the north of the area and progressed southward resulting in salt withdrawal and formation of salt structures (Figure 3). The main stages of salt structuration were finished by the Middle Triassic and the following salt evolution was associated with regional extension, which slowed the salt rise.

Diachronous pod grounding started from the north and triggered the depocentres to shift to the adjacent pod and develop the next salt structure to the south (Figure 3). The pod grounding augmented the differential erosion and salt dissolution providing an accommodation space between pods forming salt valleys.

Salt Fall and Salt Valleys Topography

The spatial differentiation of the tectonic styles of the salt evolution is based on the expression of salt structures in the overlying sediments. The Cretaceous isochore map (Figure 4a) shows four possible expressions of salt structures: (1) high time thickness above the salt structure, (2) low time thickness above the salt structure, (3) combination of high and low time thickness above the salt structure, and (4) no expression of salt structure in thickness change. These categories are geographically combined into three zones. Zone 1 is characterized by thick (150-175 ms) areas above salt structures of circular and horseshoe-shape. These areas are in hanging walls of normal faults (Figure 4b and 4c). Zone 2 is characterised by combination of areas of high time thickness of horseshoe shape (from 150 ms in the East to 250 ms in the West), which surround areas with low time thickness above the central part of salt structure (100-150 ms, Figure 4b and c). Zone 3 is characterised by thin areas above salt structures and areas without local expression. The long salt wall on the very south is expressed in low time thickness areas and even areas of zero time thickness controlled by normal faults. Several thick areas are localised around this salt wall representing the sinking flanks (up to 250 ms, Figure 4b).

Therefore, in general, zone 1 is characterised by collapsed salt valleys connected by growth faults, providing accommodation space on the hanging walls (Figure 4c), zone 2 - by partial salt structures experiencing synchronous rise and fall, and zone 3 is interpreted as rising salt structures with subsiding flanks. There is a notable exception from this rule concerning salt chimneys, which can be interpreted as collapsing structures regardless of geographical position. It can be explained by the lack of salt to keep the chimneys rising due to the growth of larger adjacent structures which took all available salt.

Jurassic Fulmar Sands Deposition and Preservation

The prospectivity of the area is associated with possible presence of the Upper Jurassic transgressive shoreface sands of the Fulmar Formation. It was proposed by Clark et al. (1998) and Stewart (2007) that the sand presence was controlled by sedimentation and preservation factors: (1) sedimentation is possible if there is a connection to the sea so sands can be transported and deposited, and (2) preservation is possible if these sands were not eroded by the following regression or by transgressive erosion (base wave erosion). The coexistence of both factors results in the presence of sands.

The Jurassic paleotopography was modelled following the methodology of Clark (1999), and analysis of salt structures expression in the overlying sediments. The model illustrates two possible sea level stages: low (Figure 5a) and high (Figure 5b). The modelled surface illustrates the regional dip to the northeast dictated by the basement structure and the Central Graben location.

Salt valleys are developed above salt structures and have varying inter-connectivity. Salt valleys have good connections within chains and poor connections with salt valleys from other chains. This suggests that the Upper Jurassic transgression from the northeast (basinward direction) fills these chains of valleys sequentially from the NE to SW due to the basement dip. The sedimentation occurred in topographic lows such as salt valleys, hanging walls of faults and active depocentres on the flanks of the long SW70 in the south (Figure 5c). Areas with good connection to the sea are exposed to erosion due to the relative sea-level changes, whereas semi-isolated valleys can preserve sands. However the amount (depth) of accommodation provided by the salt valley formation and left after the previous deposition of the Skagerrak Formation is also a significant control on Fulmar deposition. This suggests that end-members of chains from the western part are less exposed to the transgressive erosion in comparison with the eastern ones. The notable examples of the end-members can be found in the eastern part of chain 8 (Figure 1c). The presence of rising hills surrounded by falling salt in salt valley can contribute towards preservation as these features make salt valley topography more complex and form semi-isolated valleys (Figure 5c).

Therefore, the study area contains favourable locations for Fulmar deposition and preservation. The northeast corner of the study area is favourable for deposition of Fulmar sands on hanging walls of faults, and in salt valleys, however the preservation potential might be low due to non-isolation of valleys from the sea. The central part with its combination of collapsing and rising salt structures is prospective as the complex topography conditions allow sands to be deposited and preserved. The southern part is prospective on flanks of SW70, with large areas of potential Fulmar deposition and preservation formed by late salt withdrawal of the salt wall.

Discussion

The Triassic salt tectonics started after deposition of some amount of sediments on top of the salt. The observed rim synclines within pods underline thinning and thickening trends of the Triassic strata and the restoration of Triassic salt showed that the evolution of depocentres is one of the main controls and responses on the salt movement, which is in agreement with models proposed by Hodgson et al. (1992), Jackson and Talbot (1994), and Clark et al. (1998).

This study addresses the well-known problem of correlation of intra-pod reflections between salt pods. This can be solved by the analysis of the periods of salt exposure at the surface. According to our study, these periods are represented by truncations of intra-pod reflections. With this methodology it was possible to develop a relative time correlation of the northern and southern parts of the study area. Another reference section for the correlation between pods can be the pre-kinematic layer. However, it has to be used with care as its thickness gradually varies across the area.

Due to the absence of well control there are numerous uncertainties yet to exclude by further drilling. The stratigraphic tie uncertainty presumes that the age of the sediments is in the range from the Middle Triassic to Cretaceous in salt valleys, the Triassic to Upper Jurassic in hanging walls, and the Jurassic on the flanks of salt structures.

Another uncertainty is the relative sea level changes and associated provision of the accommodation space generated by dissolved salt valleys. The sea level impacts on facies distribution: the target shoreface facies were found in the adjacent northern quadrant (Clark, 1999), whereas to the South they could be changed to less favourable inland facies. Dissolution of salt valleys started in the Midddle-Late Triassic (Clark, 1999), so by the Upper Jurassic time they could be completely filled by the Triassic sediments, which creates an uncertainty on the presence of the Fulmar Formation in the salt valleys.

Conclusion

The potential for deposition and preservation of the Jurassic Fulmar sands was estimated from spatial variations of tectonic style of salt structures and thicknesses of overlying strata associated with the southward propagating trend of salt evolution. We demonstrate how the northeastern portion of the study area is characterised by the early collapse of salt structures and Fulmar deposition occurs in resultant salt valleys and fault hanging walls. The central part shows evidence of the influence of rising and falling salt structures forming semi-isolated salt valleys with complex morphology. These valleys may be favourable for preservation of infilled sediments. The salt structures in the southern part continued growing during the Jurassic, providing accommodation space for deposition on their flanks.

Understanding the geometry and evolution of salt structures provides important data to petroleum geoscientists throughout a project lifecycle. This study is an example of how it adds value in the first steps of exploration, shedding light on the distribution of accommodation space and hydrocarbon traps.

Acknowledgements

We thank E.ON E&P UK Ltd. and the JV partner companies StatOil, Nexen, Centrica, and DONG for permission to present this work. We are also very grateful to the subsurface team members of all these companies for their valuable feedback and contributions to this project.

References Cited

Clark, J., 1999, Controls of the distribution of Upper Jurassic Fulmar sandstones on the West Central Shelf, UK Central North Sea: Ph.D. Thesis, Imperial College of London.

Clark, J.A., S.A. Stewart, and J.A. Cartwright, 1998, Evolution of the NW margin of the North Permian Basin, UK North Sea: Journal of the Geological Society, v. 155, p. 663-676.

Hodgson, N.A., J. Farnsworth, and A.J. Fraser, 1992, Salt-related tectonics, sedimentation and hydrocarbon plays in the Central Graben, North Sea, UKCS: Geological Society, London, Special Publications, v. 67/1, p. 31-63.

Jackson, M.P.A. and C.J. Talbot, 1994, Advances in salt tectonics: Continental Deformation, Pergamon Press, Oxford, p. 159-179.

Stewart, S.A., 2007, Salt tectonics in the North Sea Basin: a structural style template for seismic interpreters, *in* A.C. Ries et al., eds., Deformation of the Continental Crust: The Legacy of Mike Coward: Geol. Soc. Special Publication, v. 272, p. 361-396.

Trusheim, F., 1960, Mechanism of salt migration in northern Germany: AAPG Bulletin, v. 44, p. 1519-1540.

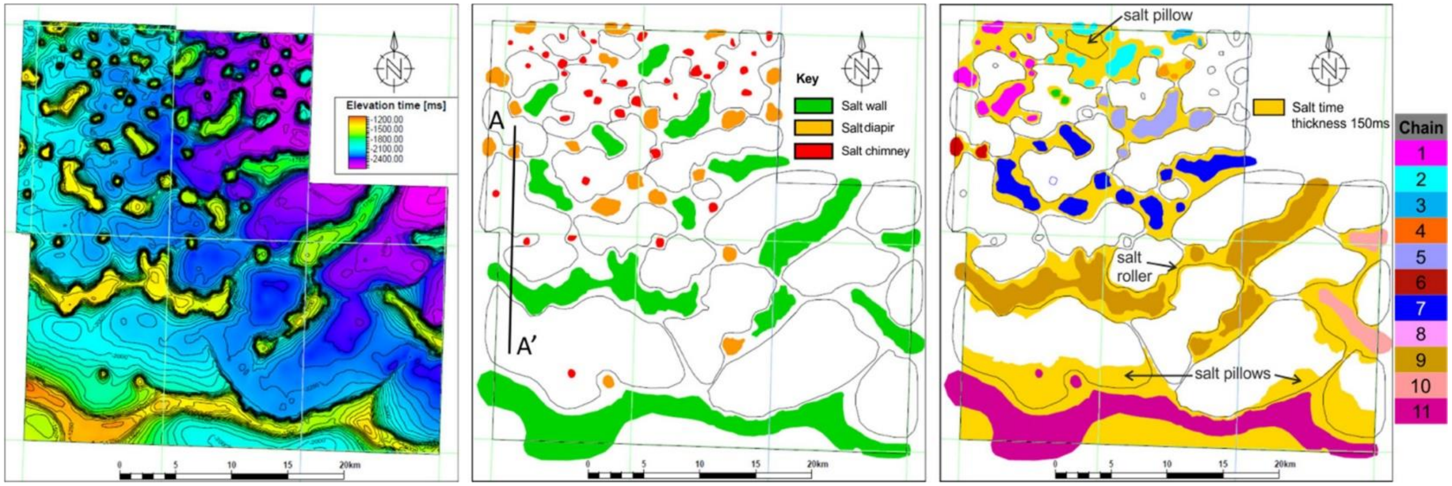

Figure 1. Analysis of the geometry and connectivity of salt structures: (a) TWT map of the Top Salt surface, (b) classification of salt structures by area and ellipticity, and (c) chains of salt structures formed by salt pillows and salt rollers.

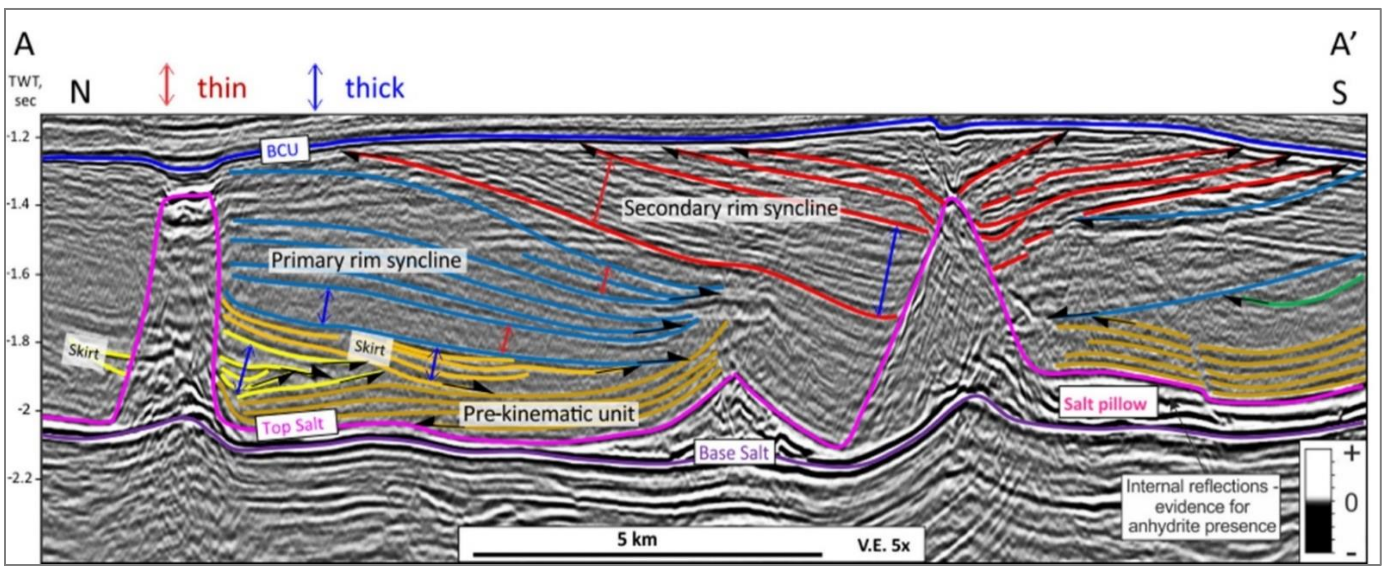

Figure 2. Triassic pod framework: illustration of the pre-kinematic unit of relatively constant thickness within a pod, overlain by rim synclines. The secondary rim syncline was formed due to the salt exposure to the surface and its collapse as top-laps mark the event of erosion. Skirts are locally distributed seismic packages around salt chimneys and diapirs thickening toward salt structures and with presence of erosional surface. The line of the seismic profile is shown on Figure 1b.

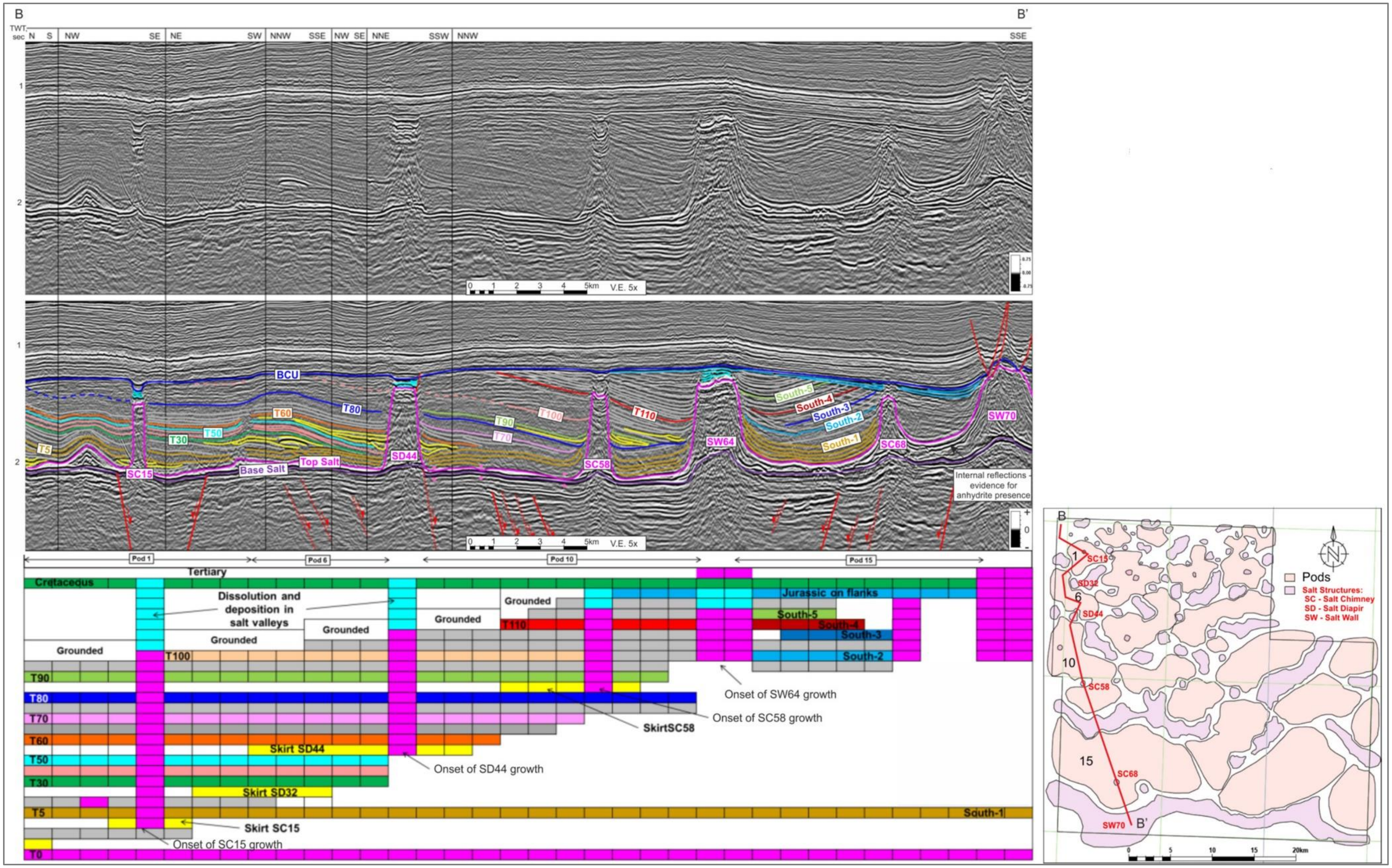

Figure 3. Salt evolution diagram represents sequential formation of salt structures in the southern direction, pod grounding, and deposition in salt valleys. Layers of anhydrites and carbonates underline marginal facies of the Zechstein Formation. Note the southern salt structures continued to grow during the Cretaceous and Tertiary.

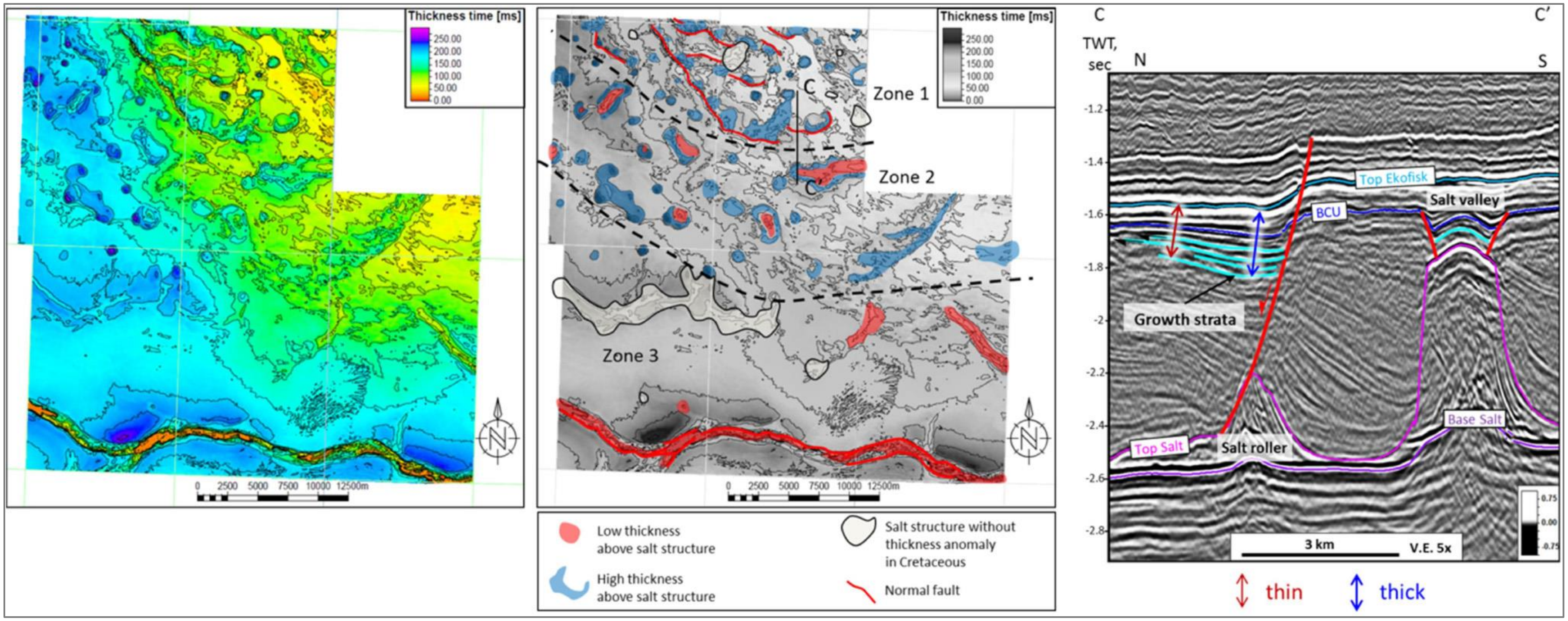

Figure 4. Salt fall and salt valleys topography: (a) isochore map of the Cretaceous surface, (b) expression of salt structures in the isochore map of the Cretaceous, and (c) seismic profile through the growth fault and salt valley illustrating the topography of the salt valley in section and the salt roller importance in the formation of the growth strata.

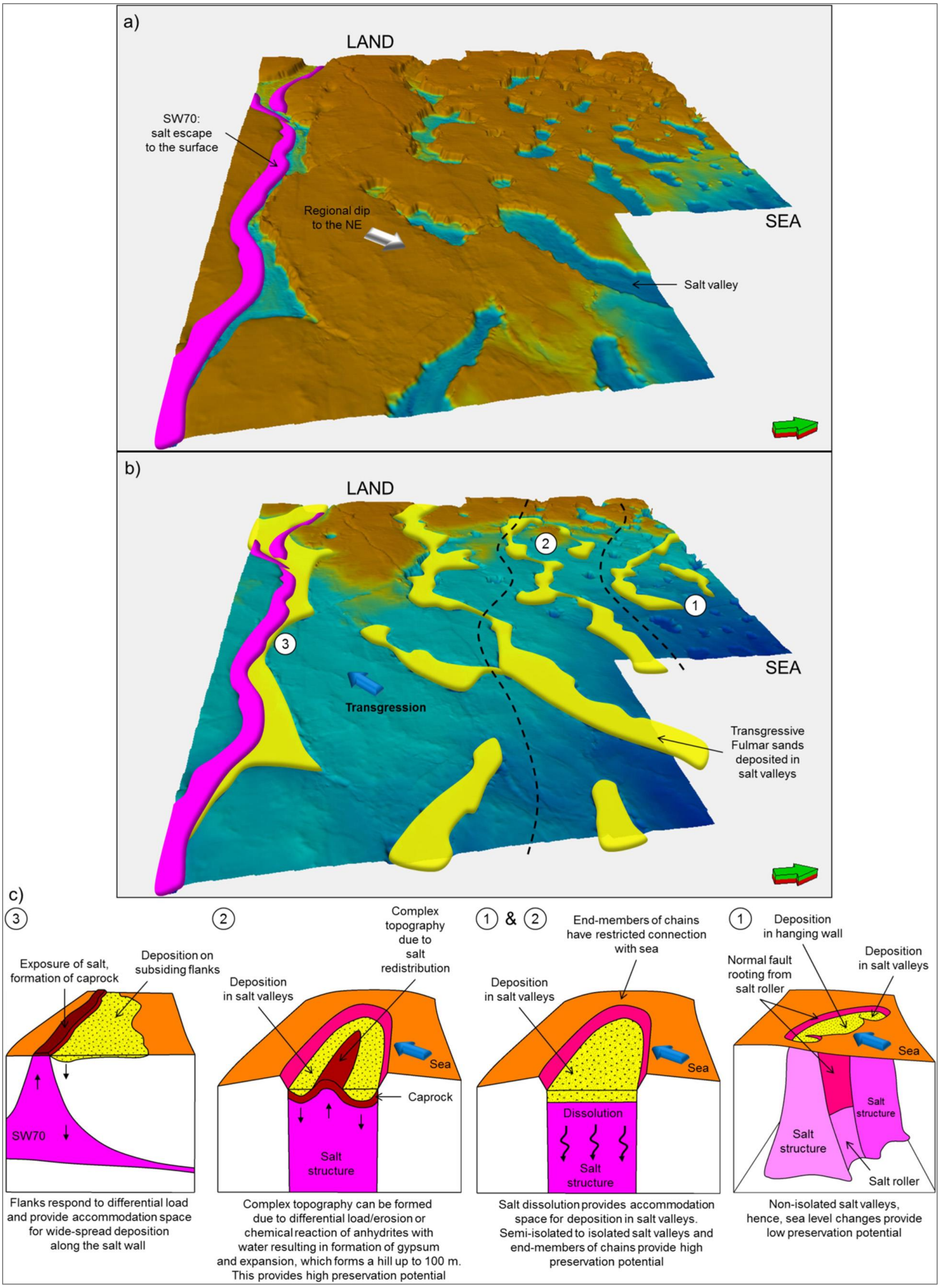

Figure 5. Results of the Upper Jurassic paleotopography modelling: (a) relatively low sea level position – salt valleys are a subject for the fluvial deposition of Skagerrak Formation; (b) relatively high sea level position – salt valleys exposed to the sea along with the subsiding flanks of salt structures on the South, and hanging walls of growth faults in the North were subjects for the Fulmar shoreface sands deposition during transgression. The accommodation space provided for the Fulmar sands deposition depends on the sea level position during the Upper Jurassic and the available accommodation space left in salt valleys after deposition of the Skagerrak Formation. The preservation of the potentially deposited Fulmar sands depends on the exposure to the transgressive wave base erosion. Distribution of the potential reservoir dictates the trap type variations in the study area.