Linking regional unconformities in the Barents Sea to compression-induced forebulge uplift at the Triassic-Jurassic transition

R. Müller\(^b\), T.G. Klausen\(^{b,c}\), J.I. Faleide\(^a\), S. Olaussen\(^a\), C.H. Eide\(^b\), A. Suslova\(^d\)

\(^a\) University of Oslo, Sem Sællands vei 1, 0371 Oslo, Norway
\(^b\) University of Bergen, Allégaten 41, 5007 Bergen, Norway
\(^c\) The University Centre in Svalbard, 9171 Longyearbyen, Norway
\(^d\) Lomonosov Moscow State University, 1 Leninskiye Gory, 119991 Moscow, Russia

**ARTICLE INFO**

Keywords:
- Forebulge uplift
- Basin inversion
- Halokinesis
- Reservoir development
- Triassic-Jurassic transition
- Barents Sea

**ABSTRACT**

The Triassic-Jurassic transition marks an important change in the basin configuration of the Greater Barents Sea. A contiguous basin with km-thick sedimentary successions changed into a partitioned basin with uplift in the west and foreland basins in the east with significant implication for the basin infill history. Our study employs a range of different high-resolution datasets from a distal part of the basin which unravels the complex pattern of differential uplift and erosion in the basin during this period. We record for the first time distinct angular unconformities between Upper Triassic strata and overlying Lower Jurassic strata within the basin, showing that large parts of it formed topographic highs. Our study links these angular unconformities to compression induced by the Novaya Zemlya Fold and Thrust Belt. A heterolithic basement below a thick sedimentary succession where the fold belt developed created a complex uplift pattern in the basin, at the same time similar to but different from typical forebulge areas. Compression caused inversion of older basement rooted faults defining platforms and graben systems throughout western parts of the Barents Sea basin, in addition to salt remobilization that resulted in differential uplift and erosion. These local zones of uplift controlled the sediment distribution pattern to the basin at a time when the most important reservoir units in the basin were deposited. This new understanding of the basin development explains hitherto enigmatic sequence boundaries that have inspired complex paleogeographic models in the past.

1. Introduction

The Upper Triassic to Lower Jurassic succession in the Norwegian sector of the Barents Sea basin (NBSB) is characterised by a pronounced transition from high rate of sedimentation and accommodation in the Triassic, to a condensed succession with limited accommodation, lower rates of sediment supply and bypass in the early Jurassic (Ryseth, 2014; Klausen et al., 2017). This transition was gradual at first, causing changes in river drainage basins (Klausen et al., 2014) but culminated at the Triassic-Jurassic transition causing a major depositional hiatus and changes in regional sediment supply patterns (Klausen et al., 2018). Despite much evidence for this important re-organization throughout the Greater Barents Sea Basin in the late Triassic-early Jurassic, the event itself and its driving mechanism has received relatively little attention and has so far remained poorly understood.

Conversely, the period is traditionally viewed as a period of tectonic quiescence in the Barents Sea (e.g. Faleide et al., 1993; Henriksen et al., 2011; Gjørgstad-Clark et al., 2011; Clark et al., 2014; Rojo and Escalona, 2018), and although several studies have noted that the Triassic-Jurassic transition is characterised by a distinct change in the sedimentation pattern (e.g. Smelror et al., 2009; Ryseth, 2014), few discuss the origin and causal mechanism of this change. Other studies have claimed that NBSB experienced a phase of extensional tectonics during the late Triassic to early Jurassic (e.g. Gramberg, 1997; Stoupakova, 2001; Gernigon et al., 2014; Serck et al., 2017). In Ryseth (2014), the transition between the Triassic and Jurassic is thoroughly described, but differences in basin infill between the two periods are mainly attributed to hinterland rejuvenation in Fennoscandia, larger annual precipitation and reduced subsidence rates. This change also coincides with compression in stress regimes set up by the Novaya Zemlya Fold and Thrust Belt which culminated in the late Triassic to early Jurassic (Buiter and Torsvik, 2007; Ritzmann and Faleide, 2009; Faleide et al., 2018), created foreland basins such as the North and South Barents basins in the Russian sector (Scott et al., 2010; Suslova, 2013a, 2013b). The potential...
influence of nearby compressional tectonics at this time has not yet been explored in the Norwegian Barents Sea Basin.

Partially, the lack of knowledge about this important transition is due to the condensed nature of the interval in combination with variable data quality, which makes it difficult to detect important, but subtle, variations on a basin-wide scale. Superficially, the interval appears layer-cake in regional conventional seismic and its thickness does not seem to change much across the basin. From well logs and cores, large internal variations are however apparent (Klausen et al., 2017) and in this study we therefore integrate detailed analysis of well data with regional 2D seismic sections to better understand the timing of the events, and its implications for the basin infill history. In addition, high resolution 2D P-Cable seismic are applied in areas where this is available and offer unprecedented insight into the lateral development of this interval which is normally below seismic resolution in conventional broadband seismic. The subsurface data offshore northern Norway are also considered in context with time-equivalent deposits on Svalbard and in the Russian sector of the Barents Sea.

In the present study, we use novel observations of prominent angular unconformities to investigate the distribution and longevity of pronounced hiatuses near the Triassic-Jurassic transition in the Barents Sea. The stratigraphic relationship is mapped across the basin to constrain the causal mechanism for developing angular unconformities and how these are affected by the protraction of the Novaya Zemlya Fold and Thrust Belt. It is beyond this study to present a full geodynamic model which explains the detailed impact of the Novaya Zemlya Fold and Thrust Belt on the Greater Barents Sea Basin, but the many important implications of our findings will likely stimulate further research on the topic and explain hitherto enigmatic stratigraphic relationships and salt reactivation across the basin.

2. Geologic setting and stratigraphy

The Barents Sea basin is characterised by a highly complex basin-maintaining structure, affected by the Timanian, Caledonian and Uralian orogenies (Gernigon et al., 2014), but generally experienced regional sag subsidence during the Triassic period (Glerstad-Clark et al., 2010; Clark et al., 2014) which accommodated kilometre-thick successions of siliciclastic deltaic deposits characterised by platform-scale clinoforms sourced primarily from the southeast (Mørk, 1999; Riis et al., 2008; Glerstad-Clark et al., 2010; Bue and Andersen, 2014). In the late Triassic, the basin infill pattern started to change due to uplift of the Novaya Zemlya fold and thrust belt, which altered drainage patterns that controlled sediment supply in the Carnian (Klausen et al., 2014). This fold and thrust belt culminated with a pronounced turnover in sediment supply at the transition from the late Triassic to the early Jurassic (Klausen et al., 2018).

The Realgrunnen Subgroup comprises the normal regressive off-shore to deltaic Fruholmen Formation (Norian-Rhaetian), the forced regressive Tubåen Formation (Rhaetian-Sinemurian), and the overall transgressive Nordmela (Sinemurian-Pliensbachian) and Sto (Pliensbachian - Bajocian) formations (Fig. 1B; Olaussen et al., 1984; Gjelberg et al., 1987; Mørk et al., 1999; Klausen et al., 2017; Klausen et al., 2018; Mulrooney et al., 2018). The Fruholmen Formation is furthermore subdivided into three members: the prodeltaic Akkar, the fluvo-tidal Reke and the deltaic Krabbe members (Dalland et al., 1988), and is predominantly supplied with immature and fine-grained sediments from the east whereas the sandstone-dominated Tubåen, Nordmela and Sto formations comprise reworked and predominantly southerly derived coarser sediments in the NBSB (Klausen et al., 2017).

The stratigraphic onshore equivalent to the Realgrunnen Subgroup is the Wilhelmsøya Subgroup in Svalbard. While the Wilhelmsøya Subgroup is up to 300 m thick with almost complete early Norian to Aalenian stratigraphic succession in Kong Karls Land, only 5 to 20 m thick condensed or eroded units with several hiatuses are preserved on the western and central Spitsbergen (Bäckström and Nagy, 1985; Nagy and Berge, 2008) making the offshore-onshore link problematic. As for the Realgrunnen Subgroup in the Barents Sea, the base and top are defined by the early Norian flooding and the Bathonian flooding respectively (Mørk et al., 1999; Worsley, 2008; Henriksen et al., 2011; Koevoets et al., 2018) (Table 1).

The post-depositional history of the succession involves late Jurassic and Cretaceous rifting (Serck et al., 2017), and transpression between the Barents Sea and eastern Greenland in the Eocene (Faleide et al., 1993; Faleide et al., 1996; Faleide et al., 2008; Clark et al., 2014). The effects of these events are most pronounced along the western margin of the NBSB (Fig. 1c). These events therefore had relatively little impact on the present study area, but repeated regional glaciations in the Pleistocene (Vorren et al., 1989) resulted in pronounced erosion referred to as the Upper Regional Unconformity (URU) - a composite erosional feature seen across most of the study area.

3. Data and methods

Coverage and quality of seismic data, in addition to the amount of well data, varies across the study area. Data coverage is extensive in areas with ongoing hydrocarbon exploration and field development such as the Hoop Fault Complex area, where regional 2D seismic data is accompanied by conventional 3D and P-Cable seismic data combined with several recently drilled exploration wells with cores that provide high-resolution biostratigraphy (Vigran et al., 2014). Other parts of the basin remain frontier areas where interpretations have to be extrapolated from observations in areas with dense data coverage. For example, the Fingerdjuvet Subbasin in the northwestern parts of the study area is characterised by a deterioration in 2D seismic quality westward, partly due to hard sea floor above and larger burial depths. Data coverage and quality decrease north of the study area, and insight into the nature of the stratigraphic boundary in areas to the north are therefore best offered by outcrop exposures and we present one example from Agardhbukta on eastern Spitsbergen (Fig. 1a).

3.1. Well data and outcrop studies

A database of 95 exploration wells (Fig. 1) from both the Norwegian and Russian sectors of the Barents Sea has been studied. Gamma ray (GR), neutron density (NEU) and density (RHO) log signals are coupled with core data to guide interpretations of changes in gross depositional environment. In addition to standard stratigraphic information available from the Norwegian Petroleum Directorate, key wells are reviewed in terms of biostratigraphic information.

3.2. Seismic data

Regional 2D seismic data, tied to well logs (Fig. 1), are used to map the study interval across the basin. These seismic lines are spaced between 5 and 10 km, and the seismic resolution varies across the study area depending on burial depth. Limits of visibility is typically around 10 m whereas limits of separability are roughly 20 m (cf. Brown, 2011).

The formation boundaries within the Realgrunnen Subgroup are difficult to connect to and trace in seismic because the formations are thin and lithologically similar, which lead to small contrast in acoustic impedance and poor visibility in seismic data imaging. Nine seismic horizons are interpreted on a regional scale and used as a framework for evaluating the basin evolution across the Triassic-Jurassic boundary, including Lower Triassic to Upper Jurassic strata: Top of the Havert Formation, Top of the Klappmyss Formation, Top of the Kobbe Formation, Top of the Snadd Formation, Top of the Realgrunnen Subgroup, Top of the Fuglen Formation, and the Base Cretaceous Unconformity (BCU) (Fig. 1B). Horizon flattening is a powerful tool that help unravel the stratigraphic relationships between strata of different ages relative to a datum. In most of the seismic profiles presented herein, we use the Top of the Realgrunnen Subgroup as a flat datum.
This surface represents a close-to-paleohoriztonal surface formed at a maximum transgressive stage in the late Middle Jurassic and is of regional extent. In a few areas, e.g. where the Upper Regional Unconformity (URU) is truncating the Upper Jurassic or where the Realgrunnen Subgroup cannot be mapped with confidence, flattening does not work, and the seismic profiles are consequently distorted in these areas.

P-Cable seismic data is available in the Hoop area (Fig. 1c). These datasets have higher frequencies but shallower penetration depth than conventional seismic, and typically has a vertical resolution of about 5 m at the studied intervals. This high-resolution dataset provides detailed information about the Realgrunnen Subgroup, where the strata are not too deeply buried to be imaged with this method and add important knowledge about the age relationships and stratigraphic evolution of the study interval.

4. Results

Results reveal distinct thickness variations and angular unconformities that are directly tied to prolonged periods of non-
deposition and reworking, evident in exploration wells, within the Realgrunnen Subgroup (Fig. 2). In this section, we show the results from the different datasets, and how these are used to map truncation patterns throughout the study area.

4.1. Stratigraphic information from wells

The Realgrunnen Subgroup exhibits large temporal and spatial variations in thickness and provides important information relevant for this study about time of deposition and periods of non-deposition and erosion. Biostratigraphic analyses have revealed the presence of a considerable hiatus between the Norian-Rhaetian (Fruholmen Formation) and the uppermost Triassic to Middle Jurassic, Rhaetian-Bajocian (Tubåen, Nordmela and Stø formations) (Fig. 2).

In the northwestern and northern parts of NBSB, the Toarcian (Stø Formation) is unconformable overlying directly on the Norian (Fruholmen Formation) (e.g. wells 7324/2-1, 7325/1-1, 7324/10-1). The hiatus in these wells is considerable, and spans to over 40 m.y. In other wells, a thin late Pliensbachian package (Nordmela Formation) is present in between the Fruholmen and Stø formations (e.g. wells 7324/8-1, 7324/7-2), while in other parts of the platform areas, also Hettangian-Sinemurian (Tubåen Formation) is present although relatively thin, as evident in for example well 7226/2-1.

The thickness of the Norian (Fruholmen Formation) varies from c. 27 to 120 m in the northwestern and northern NBSB, which suggests, together with the biostratigraphic analysis, pronounced truncation and erosion in the late Triassic and early Jurassic (e.g. 7324/7-2; Fig. 3). The unconformity is covered by thin units of dominantly Middle Jurassic Stø Formation (maximum 27 m) and occasionally thin Lower Jurassic Tubåen and Nordmela formations are present (Fig. 3). Review of the biostratigraphic information of the wells in the northwest NBSB also reveal that reworked Triassic taxa (e.g. Kyrtomisporis gracilis, P. amicus and Cavatosporites obvius) are present in both the Nordmela and...
Stø formations (e.g. 7324/7-2 and 7324/8-1).

Towards the southeastern margin of the basin and on the Fedynsky High, for example in well 7131/4-1, the Norian is thin (c. 29 m) and is overlain by a thin Stø Formation of Aalenian age (Fig. 3). The same trend is observed along the southern part of the basin where Tubåen Formation (latest Rhaetian-Hettangian) is unconformably overlying a condensed early Norian package.

No wells are yet drilled on the Fedynsky High, but Norian deposits are overlain unconformably by condensed Lower to Middle Jurassic deposits in the adjacent Severo-Kildinskaya and Severo-Murmanskaya wells (Suslova, 2013a, 2013b; Norina et al., 2014). Although, the biostratigraphic analysis available for the Russian wells shows a considerable hiatus, it varies from study to study.

A more complete sedimentary package of the Realgrunnen Subgroup, compared to the platform areas, is present in the basins of the southern and central parts of NBSB (e.g. 7228/2-1 S; Fig. 3). The thickness of the Fruholmen Formation ranges from c. 50 m up to 220 m, while the Tubåen Formation varies in thickness from about 70 m to 150 m in the Hammerfest and Nordkapp basins (Fig. 3). In the Hammerfest Basin and parts of the Nordkapp Basin, there are seemingly no distinct biostratigraphic hiatus between the late Triassic and earliest Jurassic formations (e.g. 7228/2-1 S). However, the basal boundary of the Tubåen Formation is characterised by a general change from mudstone to sandstone – often with an erosive base.

Along the western margin of the Barents Sea, the Realgrunnen Subgroup reaches as much as c. 800 m (e.g. 7220/8-1) and is more complete with fewer and shorter hiatuses (Figs. 2 and 3). In these western wells, the formation includes thick successions of deltaic heterolithic deposits associated with the Krabbe Member of the Fruholmen Formation which is largely absent from wells on the Bjarmeland Platform.

The Tubåen Formation also reaches considerable thicknesses along the western margin. It is, however, absent in both the Hoop and Fjingerdjupet areas (Fig. 3). A similar trend is mapped for the Nordmela Formation, for which the thickest intervals are observed within in the Bjarnøyrenna Fault Complex (e.g. 7220/8-1). The Stø Formation also
shows the same thickness trends as the underlying Nordmela Formation, reaching more than 140 m along the western margin of the southwestern Barents Sea. Unlike older Jurassic sequences, the Stø Formation is present as a relatively thin succession (10 to 30 m) across most of the eastern and northern parts of the Bjarmeland Platform (Fig. 3) (Klausen et al., 2017). Biostratigraphic data suggests that the Realgrunnen Subgroup is more complete in the western areas compared to for example the wells on the margin of the Finnmark Platform and the Bjarmeland Platform (Fig. 2).

In the Eastern Barents Sea, the thickness of Jurassic strata increases to more than 1000 m, and a maximum thickness of c. 1500 m thickness is penetrated in the Arcticheskaya well in the central parts of south-eastern Barents Sea (Suslova, 2013a, 2013b). Stratigraphic unit subdivision is based primarily on biostratigraphy. However, since the palaeontological data are quite scarce and fossils are poorly preserved, sequence stratigraphic principles and stratigraphic relationships are emphasized when evaluating the Jurassic strata in seismic data from the Eastern Barents Sea. A total of nine cycles have been defined within the Jurassic strata based on logs (Suslova, 2013a, 2013b), of which the Top Realgrunnen Subgroup equivalent (Middle Jurassic) is used as a regional datum for correlation between the Russian and Norwegian sectors.

4.2. Stratigraphic development in regional 2D seismic data

Regional seismic lines, tied to well logs with stratigraphic information confirm that thickness variations and hiatuses observed in well, correspond to truncation of underlying Triassic intervals. Coincident with this truncation are often distinct angular unconformities between Triassic and Lower Jurassic strata that become evident when flattening the Top Realgrunnen or BCU seismic horizon (e.g. Fig. 4). This regional seismic cross section example shows some of the most important characteristics of the Triassic-Jurassic transition: i) Truncation of Lower to Upper Triassic strata, partially draped by Lower to Middle Jurassic deposits, along the southern margin of the basin. ii) Subtle angular unconformities between Upper Triassic strata and Jurassic strata above older basement roots within the basin, exemplified by truncation of the Norian Fruholmen Formation on the southeastern margin of the Nordkapp Basin. iii) Differential preservation associated with reactivated salt structures. iv) General northeastward thinning of Upper Triassic strata caused by truncation below the Jurassic.

The full extent of the late Triassic to early Jurassic basin inversion is however partly masked by later erosion events, e.g. the URU, in certain areas within the basin and along the southern margin. Below we show these different erosion patterns in key parts of the NBSB. Since it is not possible to distinguish between the Lower Jurassic formations (Tubåen, Nordmela and Stø) in seismic, these are grouped together. In addition to the angular unconformity between the Upper Triassic and the Lower to Middle Jurassic, mapping also include erosion of both the Triassic and Jurassic strata below URU where this applies.

4.2.1. Northwest NBSB (Hoop area)

Data coverage and quality in the northwest part is exceptional and this offers crucial insights into the importance of the Triassic-Jurassic transition in the NBSB. This area surrounds the Svalis Dome (Fig. 1) where the Realgrunnen Subgroup varies considerable in thickness (Fig. 5). In particular, the thickness of the Norian-Rhaetian Fruholmen Formation varies significantly between the Hoop area and the adjacent Maud Basin (Fig. 5). Along the margins of the Svalis Dome, abrupt decrease in thicknesses are associated with distinct angular unconformities between the Upper Triassic (Fruholmen and Snadd formations) and the overlying Lower to Middle Jurassic intervals (Fig. 5). Away from the dome, thicknesses increase and no angular unconformities are identified. In this part of the basin, the Lower Jurassic Tubåen Formation is not present (Fig. 3), instead there is a long hiatus between the Upper Triassic formations and the Nordmela and Stø formations (Fig. 2).

Regional seismic lines indicate that uplift of the Svalis Dome is coupled with diapirism of thick Permian salt (Fig. 5a). Because Lower Jurassic strata are unconformable overlying truncated Triassic successions (Fig. 5b), it is apparent that the Lower Permian salt below the Svalis Dome moved in the late Triassic to early Jurassic and came to a halt around the end of the deposition of the Realgrunnen Subgroup in the middle Jurassic.

High-resolution P-Cable seismic data provide unique insight into the truncation trends at the Triassic-Jurassic transition in the Hoop area as it provides an image of higher resolution that resolves details about the truncation pattern and internal thickness variations within the Realgrunnen Subgroup not clearly imaged in standard broadband seismic (e.g. Fig. 5b). P-Cable seismic data in Fig. 6 shows that the Lower Jurassic Stø and Nordmela formations are unconformably overlying the Fruholmen and Snadd formations with an angular unconformity, and there is pronounced incision at this boundary.

In other parts of the Hoop area and towards the northwest, there is a decrease in the overall thickness of the Snadd Formation. Regional 2D seismic lines tied to well logs (Fig. 5c) show that the Top Snadd seismic horizon converge on the base Realgrunnen Subgroup while also the stratigraphic thickness between the Top Robbe and Top Snadd horizons decreases in a basinward direction.

4.2.2. West and south NBSB (Loppa High and Hammerfest Basin)

Due to Pleistocene glaciations, all evidence for potential uplift and erosion or deposition at the Triassic-Jurassic boundary has been removed. We can observe this in Fig. 7, where both the Upper Triassic and Jurassic strata are truncated below URU. This unconformity partly obscures the mapped truncation trends within the basin. The high has been argued to have been reactivated several times during the basin evolution (Gabrielsen et al., 1993) but be the site of sediment accumulation during the late Triassic to early Jurassic (Indrevær et al., 2017). Westward thickening of the Relagrunnen Subgroup in Fig. 7a suggest that this area could have been a site of deposition during this period.

South of the Loppa High, the thickness of the Realgrunnen Subgroup increases westward (Fig. 7b) in a similar manner as we see tendencies for east of Loppa High (Fig. 7a). This complicates our understanding of the nature of the stratigraphic boundary. North of the high, Triassic strata show angular unconformities to preserved Lower Jurassic strata, whereas the Realgrunnen Subgroup gradually thicken towards the west in the Hammerfest Basin.

4.2.3. Central NBSB (Bjarmeland Platform and Nordkapp Basin)

Truncation of Triassic strata is also evident in central parts of the NBSB, including the Bjarmeland Platform and Nordkapp Basin (Fig. 1). Truncation patterns are generally much subtler on the Bjarmeland Platform than elsewhere in the basin. Angular unconformities between Norian strata belonging to the Fruholmen Formation and the Lower to Middle Jurassic intervals unconformably above are, however, clearly seen in the central parts and towards the northwest (Fig. 4). Towards the Loppa High, an increase in thickness of Norian strata contrasts the general thinning trend (Fig. 7). Although an angular unconformity is identified towards this high as well. This truncation occurs below URU and affects both Triassic and Lower Jurassic strata, and post-dates the basin inversion at the Triassic-Jurassic transition. Elsewhere on the Bjarmeland Platform, especially in eastern parts, Lower Jurassic strata are oriented parallel to Triassic intervals and there are no distinct angular unconformities (Fig. 7b). Thickness maps however indicate that there might be erosion in this part of the basin as well due to the thinning of the Fruholmen and Tubåen formations in this area (Fig. 3).

The Nordkapp Basin is divided into a NE and SW segment (Fig. 1), and salt structures are present in both but angular unconformities between Triassic and Jurassic strata are concentrated along the margins of
the basin, not the salt structures. This is different from observations on the Svalis Dome (Fig. 5a). Interestingly, although the margins of the southern segment of the Nordkapp Basin is associated with thinning of Upper Triassic strata (Fig. 4), margins of the northern segment are not.

4.2.4. Eastern Barents Sea (Russian sector)

East of the NBSB, regional 2D seismic data show that the Triassic-Jurassic transition can be tied to the uplift of Novaya Zemlya in the Russian sector of the Barents Sea basin (Fig. 8a). In addition to the previously documented thickening of Norian and Lower Jurassic strata in the foreland basin of the Novaya Zemlya Fold and Thrust Belt (Scott et al., 2010; Suslova, 2013a, 2013b), seismic transects show the results of folding and truncation of the Triassic strata immediately west of and adjacent to the Novaya Zemlya uplift (Fig. 8c). This uplift is also associated with distinct onlap of Upper Jurassic strata (Fig. 8c), showing that the uplift had ended by the late Jurassic and thus that the compressional forces creating the fold and thrust event was time-equivalent with the uplift and erosion event in the NBSB.

4.3. Regional mapping of truncation trends

When mapping the abovementioned truncation trends on a regional scale, we differentiate areas with angular unconformity between 1) Triassic and Lower Jurassic strata; and 2) URU and underlying strata, including both Jurassic and Triassic strata (e.g. Fig. 7a). There is considerable erosion even in areas without distinct angular unconformities since distinct thickness variations and hiatuses are observed in wells (Fig. 3).

The Snadd Formation is truncated below the Lower Jurassic strata in the Barents Sea basin (Fig. 9). The formation is also eroded in the area between the Hammerfest and Nordkapp basins (Fig. 7b) and juxtaposed salt domes (e.g. Figs. 4a and 5b). Truncation of the Fruholmen Formation below the Lower Jurassic is observed regionally, whereas truncation of the older Snadd Formation occurs farther to the northwest and towards the basin margins (Fig. 9). Unlike this formation, erosion of the Fruholmen Formation is also seen above older basement rooted faults such as the flanks of the Nordkapp Basin (e.g. Fig. 4). In addition, there is a distinct
belt of Fruholmen Formation truncation on the Bjarmeland Platform that is also evident in the Hammerfest Basin (Fig. 9; e.g. Fig. 7).

Our mapping reveals a pattern of intra-basinal erosion of Upper Triassic strata below the Jurassic that broadly follow N-S striking trends (Fig. 9). Except for discrete areas overlying older structural features, such as for example the Nordkapp Basin margin and areas close to the southern margin of the NBSB, angular unconformities between the Upper Triassic strata and Lower Jurassic are characterised by erosion of the Fruholmen Formation in the central part of the Bjarmeland Platform. This erosion gradually propagates lower into the older stratigraphy towards the west where the erosion penetrates down into the Snadd Formation (Fig. 5c).

4.4. Outcrop analogues in Svalbard

Important evidence for the basin-wide distribution of an unconformity near the Triassic-Jurassic boundary is evident in the stratigraphic record on Svalbard (Johannessen and Embry, 1989; Mørk et al., 1999; Smelror et al., 2009). Most of these authors related the break to faulting or tectonic uplift of the archipelago. The Norian to late Pliensbachian succession of the Wilhelmøya Subgroup in Svalbard, i.e. the onshore equivalents to Fruholmen, Tubåen and Nordmela...
formations, varies from c. 200 m thick successions in the east (Kong Karls Land) to less than 10 m condensed or eroded units with several hiatuses or lacunas in western Spitsbergen (Bäckstrøm and Nagy, 1985; Johannessen and Embry, 1989; Krajewski, 1990; Grogan et al., 1999; Nagy and Berge, 2008, Olaussen et al., In press; Rismyhr et al., In press).

The best exposure of the Triassic-Jurassic unconformity in Svalbard is found in northern Agardhbuta, East Spitsbergen (Fig. 1a). Here, condensed, shallow marine Lower Jurassic strata of Pliensbachian age rest unconformably on reworked Upper Triassic strata (Fig. 10). The Upper Triassic comprise a condensed and reworked meter-thick marine succession of the Norian Flatsalen Formation found unconformably above terrestrial deposits of the Carnian to Norian De Geerdalen Formation (Rismyhr et al., 2019). The upper part of this formation is regionally characterised by shallow marine, transgressive deposits overlain by offshore marine Flatsalen Formation (Klausen and Mørk, 2014; Paterson et al., 2016). The fact the Rhaetian to Early Toarcian are missing and that Norian Flatsalen is thin or preserved as remnant in most part of Spitsbergen, unlike the eastern islands Hopen and Kong Karls Land, Svalbard, suggests significant uplift and erosion near the Triassic-Jurassic boundary. The Svenskøya Formation above is Pliensbachian in age, and the hiatus separating it from the wave ravinement in the condensed Flatsalen Formation is substantial.

5. Discussion

Our novel observations from wells, seismic and outcrop document the presence of a regional unconformity on the Triassic-Jurassic transition in the Barents Sea, which is partly represented by a pronounced angular unconformity. This reveal that an important basin-wide tectonic regime was active in the Greater Barents Sea during the late Triassic and continued into the early Jurassic. The importance of this tectonism on the basin configuration in the western part of the Barents Sea has hitherto been overlooked by previous studies but is crucial in order to understand the overall structural and stratigraphic evolution of the basin. Although our present dataset is inadequate to constrain the full geodynamic evolution of the basin, the mapped angular unconformities and salt reactivations throughout the basin show that there was basinwide compression which are time equivalent to the protrusion of the Novaya Zemlya Fold and Thrust Belt. In the context of our findings, it is clear that the diachronous shift in basin setting from high to low accommodation is best explained as a forebulge uplift, and below, we discuss the cause for this uplift, its impact on older basin rooted faults and salt, and the implications of this important tectonic event.

Although data coverage varies across the basin, we recognize that the two broad truncation trends mapped within the study area (Fig. 9) can be tentatively traced across the Greater Barents Sea: 1) a proximal uplift and erosion trend extends from northern parts of Norway, via the Fedynsky and Fersmanovskaya highs towards Kong Karls Land; and 2) a distal trend including the N-S striking truncation pattern of Fruhholmen and Snadd formations with lower magnitude of uplift extending from the Hammerfest Basin towards Svalbard. These two distinct trends are located about 400 and 800 km away from the thrust front in Novaya Zemlya (Fig. 11).

5.1.1. Causes for regional uplift, truncation and reactivation

The mapped truncation trends in the NBSB, reactivation of older structures, and their regional extension based on outcrop data and previous studies align broadly parallel to the fold and thrust belt forming contemporaneously in the east. Correlation across the Barents Sea shows that in the east, Lower to Upper Triassic strata are folded and tilted and overlain unconformably by onlapping Lower to Middle Jurassic strata (Fig. 8c). Upper Triassic strata are less folded, but somewhat tilted relative to overlying Jurassic strata. This shows that compressional forces acted in the east, and that this folding and thrusting (Scott et al., 2010) was contemporaneous with tilting in NBSB – proving a direct link between the tectonism in eastern and western parts of the Barents Sea.

Proximal and distal truncation trends documented above (Fig. 9) suggest a forebulge-style uplift with diminishing magnitude away from the compression. Because of the basin configuration of the Barents Sea, this forebulge trend does not conform directly to standard models (e.g. Allen and Allen, 2005). Forebulge apices typically range in distance from their associated thrust front by about 200 to 600 km depending on the orogenic load and flexural strength of the lithosphere (Allen and Allen, 2005). This is exemplified by the approximately 200 to 400 km in the Western Interior Seaway (DeCelles and Giles, 1996; DeCelles, 2004); 500 to 600 km in the Amazonian Basin (Roddaz et al., 2005; Chase et al., 2009); c. 200 km in the Caucasus (Ershov et al., 1998); and c. 400 km in Himalaya (DeCelles, 2012). The distinct truncation trends in the Barents Sea are located about 400 and 800 km away from the...
thrust front, suggesting that the proximal trend conforms to the relative position of typical forebulges. The forebulge apex at approximately 400 km distance from the Novaya Zemlya Fold and Thrust belt indicates the wavelength of the forebulge (Turcotte and Schubert, 2014). The amplitude of the uplift is more complicated since it evidently varies along strike and likely responded to dynamic topography (Burgess and Moresi, 1999), but erosion rates on the order of many hundreds of metres can be inferred based on the stratigraphic relationships and erosion observed on the Fedynsky High. The dome-shaped patterns of this forebulge uplift trend are however distinct from standard forebulge trends (e.g. Allen and Allen, 2005), but can be explained by the heterogeneous nature of the lithosphere below the Greater Barents Sea basin (Klitzke et al., 2015; Gac et al., 2016; Klitzke et al., 2019) that complicate the forebulge uplift pattern (Fig. 11).

The uplifted part of the Barents Sea, including Svalbard, cover approximately 500,000 km² by conservative estimates based on shaded areas in Fig. 11. This is comparable in areal extent to other zones of uplift distal to the foreland basin, for example is the areal extent of uplifted zones in front of the Sevier forebulge in the Cretaceous Western Interior Seaway approximately 300,000 km² (based on outlines by White et al., 2002), whereas modern India has a forebulge area extent of about 450,000 km² (based on outlines by DeCelles, 2012, not including potentially uplifted back-bulge areas).

Three factors however distinguish the Barents Sea uplift from the classical setting for forebulge uplifts (e.g. Allen and Allen, 2005): 1) no pronounced underplating beneath the fold and thrust belt (Faleide...
et al., 2018); 2) a limited orogenic wedge (Stoupakova et al., 2011); and 3) a deep sedimentary basin with heterogonous basement instead of continent-continent collision, which is the basis for many conceptual models. This heterogeneity is manifested by the differential uplift and erosion along the western margin of the Eastern Barents Sea basins where highs such as Fedynsky and Fersmanovskaya, underlain by old crustal blocks (Gac et al., 2016), show signs of erosion while juxtaposed areas such as the eastern Bjarmeland and Finnmark platforms show less erosion. Nevertheless, because of the many similarities between classical foreland basins and their forebulge areas and what we observe in the Greater Barents Sea, including proximal foreland basins (Scott et al., 2010; Suslova, 2013a, 2013b) and highs bordering a broad zone of uplift (Fig. 11), we interpret forebulge uplift to be the cause of the regional uplift in the Barents Sea. Importantly, there are also no other documented compressional tectonic regime at play in the basin during this period.

Across the basin, compression is distributed along a heterogeneous basement and lithosphere by thick-skinned compression and manifested in different degrees of deformation summarized in Fig. 12. First-order deformation can be linked to large-scale variability in the lithosphere (Gac et al., 2016), whereas second-order deformation corresponds to Paleozoic graben systems. In the immediate front of the Novaya Zemlya Fold and Thrust Belt, a foreland basin accommodates several hundreds of meters of Jurassic sediments (Suslova, 2013a, 2013b). Proximal parts of the forebulge west of the foreland basin show relative large rates of uplift and erosion relative to the rest of the forebulge. Differential uplift and erosion within the forebulge seems to be controlled by faults linked to the basement. Reactivation of older basement rooted faults and a heterogeneous pattern of tectonism and relatively low rates of uplift and erosion compared to proximal parts of the compressional stress regime are classical traits of forebulge terranes (e.g. DeCelles, 2012). Truncation trends correspond to the orientation of older basement rooted normal faults that define Paleozoic rift basins (Fig. 12, Faleide et al., 2010), suggesting a link between these truncation trends and older faults - supporting thick-skinned compression. We regard it as likely that older basement rooted faults also control zones of differential uplift and erosion in other parts of the basin experiencing forebulge uplift (i.e. frontier areas around Svalbard and Franz Josef Land).

Areas overlying salt structures are differentially uplifted above local domes created either by mobilization or remobilization of underlying salt, and although no studies have evaluated salt movement at the Triassic-Jurassic transition, later salt movement has been attributed to basin shortening (Nilsen et al., 1995). The basin shortening previously assumed to post-date the Middle Mesozoic is more easily explained by
compressional forces documented in our study than basin shortening by normal fault gliding in Nordkapp Basin (Nilsen et al., 1995) or late Cretaceous compression of the Svalis Dome (Kristoffersen and Elverhøi, 1978).

5.1.2. Inversion of basin rooted faults

On the Fedynsky High, uplift and erosion exposed Middle to Upper Triassic strata during the late Triassic to early Jurassic (Figs. 11 and 12). The deep erosion is interpreted to reflect that this area was located on the forebulge of the Novaya Zemlya Fold and Thrust Belt. Crustal heterogeneities (Klitzke et al., 2015; Gac et al., 2016) and Carboniferous structural trends favoured that this area was uplifted and contributed to its distinct dome-like shape. It is also reasonable that these heterogeneities gave rise to the differential uplift rates along the distal margin of the Eastern Barents Sea foreland basin. Areas immediately south and north of the Fedynsky High are characterized by lower rates of erosion and some sediment accumulation during this period, for example the Tiddlybanken Basin (Fig. 1c). South of the Tiddlybanken Basin, the basin margin again shows similar rates of erosion deep into Triassic strata (Fig. 9). These areas of pronounced uplift and erosion of Triassic strata roughly align along the same N-S trend that more or less correspond to the distal, western boundary of the eastern Barents Sea foreland basins (Fig. 11).

Basement rooted faults that lie west of this proximal uplift trend, and distal to the thrust front, are differentially inverted but all areas show less erosion compared to the Fedynsky High. Erosion rates are difficult to quantify since the transition from the Fruholmen Formation to the Tubalen Formation is ubiquitously erosive but based on the thickness of the Fruholmen Formation along the western margin (Fig. 3), we regard it as likely that erosion was on the order of up to hundreds of meters throughout most of the basin. We also note anomalous thickness trends of Upper Triassic strata across the Asterias Fault Complex, which could be explained by reactivation and inversion of the margin of the Hammerfest Basin. Worth noting is the lack of truncation of Triassic strata along both margins of the northern segment of the Nordkapp Basins (Fig. 9), perhaps reflecting its position relative to the Fedynsky High.

In northwestern parts of the Barents Sea, the present model explains hitherto enigmatic sequence boundaries with the onset of compression from the east. The unconformable relation between sandstone-dominated Lower Jurassic intervals and the thin Norian Flatsalen Formation and deltaic De Geerdalen Formation in outcrops on eastern Spitsbergen has earlier been interpreted to be caused by multiple uplift and erosion events (Rismyhr et al., In press). Our model offers an alternative explanation to the complex stratigraphic relationship implicit in these data: Instead of multiple uplift events at different times in the same locality, a single significant uplift event caused erosion down into the Carnian/Norian strata of the De Geerdalen Formation during the Triassic-Jurassic transition (Fig. 10). This pronounced erosion reworked Norian strata and was followed by a long hiatus before strata of Pliensbachian age was deposited above. This development is similar to what is observed in the subsurface Barents Sea in the Hoop area (Fig. 5b and c). Further indications about the important tectonic event occurring at the Triassic-Jurassic transition in northwestern parts of the Barents Sea is offered by previous studies. However, the important change in sedimentation occurring at this boundary has generally been attributed...
to changes in climate or sediment supply patterns instead of large-scale tectonism. Lord et al. (2017) record multiple sites where coarse-grained deposits of the Svenskøya Formation of early Jurassic age rest unconformably on offshore marine Flatsalen Formation of Norian age, e.g. on Hopen, Wilhelmøya, Kong Karls Land and Barentsøya. Olaussen et al. (2019) suggest a link between unconformities near the Triassic-Jurassic transition in Svalbard and the formation of the Novaya Zemlya foreland basin in the Early Jurassic. The increased thickness and the more completely preserved Lower Jurassic strata of the Wilhelmøya Subgroup on Kong Karls Land is also explained in the context of a foreland to Novaya Zemlya. This hypothesis fits well with what we have documented from the NBSB in the present study and can be used to tentatively extrapolate the observed truncation trend to the north (Fig. 11). Rhaetian ages in the Svenskøya Formation on Hopen (Paterson et al., 2016) has been recorded, but attributed relative sea-level changes as opposed to tectonism. Unconformable stratigraphic relationships in other parts of the basin can also be explained by the present model: Outcrops in Franz Josef Land show an erosional relationship between Triassic and Lower Jurassic strata (Krymholts, 1972) that correlates broadly with our extrapolated trend for the truncation of the Fruholmen Formation (Fig. 11). Additionally, in the subsurface of northwestern Barents Sea, shallow stratigraphic drillings reveal a similar unconformable relationship between the Svenskøya and the Flatsalen formations (Riis et al., 2008) along this trend.

5.1.3. Salt tectonics

Salt tectonics could be triggered by contraction, extension and differential loading (Peel, 2014), and the timing of the salt evacuation and formation of the domes are reportedly highly complex in the Barents Sea (Nilsen et al., 1995; Rowan, 2014; Rowan and Lindso, 2017). The main salt movement in the Nordkapp Basin occurred in the early to middle Triassic, ending when Permian salt layers were depleted in the Middle Triassic and are believed to have remained inactive until Paleogene (Nilsen et al., 1995). The Svalis Dome (Kristoffersen and Elverhøi, 1978) was less affected by loading of Lower to Middle Triassic sediment than the Nordkapp Basin, and the main salt reactivation phase here is believed to be of late Mesozoic age (Mørk and Elvebak, 1999).

The differential thicknesses in the Nordkapp Basin and the angular unconformity above the Svalis Dome at the Triassic-Jurassic boundary presented above (Figs. 4 and 5) reveals prominent remobilization of salt structures in the NBSB which contrasts previous assumptions about the salt being inactive during the late Triassic to Cretaceous (Nilsen et al., 1995; Rojo and Escalona, 2018; Rojo et al., 2019).

Low sedimentation rates during salt remobilization in the late Triassic to early Jurassic implies relatively small buoyancy effect compared to the activation mechanism in the main phase of salt withdrawal during the early-middle Triassic when the salt responded to rapid differential loading (Bergdahl, 1989). Instead, at the Triassic-Jurassic basin shortening is the most likely driver for salt remobilization. Similar explanations are proposed for the Paleogene reactivation (Nilsen et al., 1995), where normal fault gliding is proposed to have shortened the Nordkapp Basin.

Subtle doming above other salt structures likely also affected the overall thickness of the Realgrunnen Subgroup (Fig. 4), and we furthermore note a similar tectono-stratigraphic relationship above the newly defined Veslekari and Signalhorn domes (Fig. 11).

5.2. Implications for basin infill dynamics

Regional uplift created a low accommodation setting in the Jurassic, which we have linked to a forebulge development in response to the Novaya Zemlya Fold and Thrust Belt. As emphasized by Ryseth (2014) and Klausen et al. (2017), the accumulation rate of the Jurassic succession was considerably lower than for the Triassic succession. This is a natural consequence of the large-scale uplift of the western Barents Sea and Svalbard. The subtle variations in accommodation arising from the differential uplift within the forebulge terrane documented herein have important implications for how we understand the sediment supply patterns to the basin. The present study shows that local highs, earlier hypothesized to have been possibly uplifted during this period (Faleide Fig. 10. The Triassic-Jurassic transition in Agardhbukta, eastern Spitsbergen, is characterised by thin, reworked, Flatsalen Formation unconformably overlying Upper Triassic De Geerdalen Formation with sandstone dominated Lower Jurassic Svenskøya Formation above the Flatsalen Formation. Location of outcrop is shown in Fig. 1a. The outcrop weathers back and the upper part of the Realgrunnen Subgroup is not exposed at this locality.

Fig. 10. The Triassic-Jurassic transition in Agardhbukta, eastern Spitsbergen, is characterised by thin, reworked, Flatsalen Formation unconformably overlying Upper Triassic De Geerdalen Formation with sandstone dominated Lower Jurassic Svenskøya Formation above the Flatsalen Formation. Location of outcrop is shown in Fig. 1a. The outcrop weathers back and the upper part of the Realgrunnen Subgroup is not exposed at this locality.
were indeed prominent topographic features with erosion deep into the Triassic, and likely responsible for routing sedimentation in the early to middle Jurassic. Accurate knowledge about the sediment supply fairways is important because this interval contains prolific reservoir rocks.

Pronounced truncation of Middle to Upper Triassic deposits on the southern Finnmark Platform suggest that the Norwegian mainland also experienced uplift and erosion in the latest Triassic. This supports previous analyses of uplift and denudation rates from apatite fission tracks in onshore areas to the south of the Barents Shelf (Eastern Finnmark and the Kola Peninsula) which indicate significant and rapid late Triassic to early Jurassic uplift and denudation estimated to be between 2.5 and 3 km (Hendriks and Andresen, 2002; Hendriks, 2003). The possibility for such an uplift event is also considered as an explanation for changes in sediment supply to the NBSB in Ryseth (2014) but is complicated by a similar uplift episode probably occurring further to the south (Goldsmith et al., 2003) showing that other regional tectonic regimes were active during this time interval. Areas with contemporaneous uplift in the Norwegian Mainland are located along the same trend SW-NE trend as the forebulge bordering the Eastern Barents Sea basins – suggesting a possible link in stress-regime. However, horizontal stress from fold and thrust belt induced compression is insufficient to exhume the Baltic Craton. Without more in-depth data on exhumation rates, it is difficult to know how far south this uplift and erosion effect extended, and its magnitude.

6. Conclusion

This study shows for the first time the extent, magnitude and causal mechanism of a major late Triassic to early Jurassic compressional tectonic regime that affected the Norwegian Barents Sea. We have mapped distinct truncation patterns and unconformities which formed

---

[Diagram and text not fully transcribed due to image limitations]
over a considerable time span and explain these by compressional stress regimes in the forebulge uplift distal to the Novaya Zemlya Fold and Thrust Belt east of the basin. The impact of this major compressional tectonic regime has hitherto been largely overlooked despite its importance for understanding the tectonic setting and its implications for the basin evolution and infill pattern.

Since the basement of the Barents Sea basin represents a melange of different crustal blocks and rift basins overlain by thick sedimentary successions, the forebulge uplift pattern is more complex in the Barents Sea than compressional regimes involving large and relatively homogenous cratons. The Novaya Zemlya Fold and Thrust Belt reactivated salt and older basement rooted faults inherited from the Paleozoic and caused several widespread, but discrete, zones of truncation – propa-gating as far down as the Middle Triassic.

This new understanding can be used to explain several previously enigmatic issues related to the basin evolution: the evolution of the Loppa and Fedynsky highs; sediment supply patterns and reworking; thickness variability within the Upper Triassic formations as a function of differential preservation rather than deposition; and denudation rates in northern Norway. In sum, this attest to a period which is much more affected by tectonic forces than previously assumed and this has important implications for the basin infill history of the entire Greater Barents Sea basin and future research in the area.

Acknowledgements

We first and foremost thank OMV Norway for financial support for this study, in addition to contributions from the RCN-funded ISBAR project. Seismic data were made available by TGS-Nopec, MAGE, PGS and the Norwegian Petroleum Directorate. In addition, we wish to thank VBPR, TGS, WGP Survey and Spectrum for allowing to publish their multiclient data. Schlumberger is thanked for academic software license. Frøydis Eide is thanked for evaluating the biostratigraphy in key well, and Albina Gilmullina is thanked for help with figures. We are very grateful for the many good comments and thoughtful advice provided by Roy Helge Gabrielsen and an anonymous reviewer.

References

Allen, P.A., Allen, J.R., 2005. Basin Analysis: Principles and Application to Petroleum Play Assessment. John Wiley & Sons.
Backstrom, S.A., Nagy, J., 1985. Depositional history and fauna of a Jurassic phosphorite conglomerate (the Brentskardhaugen Bed) in Spitsbergen. Norwegian Polar Inst. Trans. 183, 1–61.
Bergendahl, E., 1989. Halokinetic utvikling av Nordkappkassengerets servestre segment. Master of Science thesis. University of Oslo, Norway (120 p. (In Norwegian).
Brown, A.R., 2011. Interpretation of Three-Dimensional Seismic Data. Seventh edition. AAPG Memoir 62, SEG Investigations in Geophysics, No. 9 (Tulsa, Oklahoma, U.S.A. ISBN13: 978-0-919111-374-3).
Bue, E.P., Andreasen, A., 2014. Constraining depositional models in the Barents Sea region using detrital zircon U–Pb data from Mesozoic sediments in Svalbard. Geol. Soc. Lond., Spec. Publ. 386, 261–279.
Butrer, S.J., Torvik, T.H., 2007. Horizontal movements in the eastern Barents Sea constrained by numerical models and plate reconstructions. Geophys. J. Int. 171 (3), 1376–1389.
Burgess, P.M., Moresi, L.N., 1999. Modelling rates and distribution of subsidence due to dynamic topography over subducting slabs: is it possible to identify dynamic topography from ancient strata? Basin Res. 11, 305–314.
Chase, C.G., Susman, A.J., Coblehn, D.D., 2009. Curved Andes: Geoid, forebulge, and flexure. Lithosphere 1, 358–363. https://doi.org/10.1130/L67.1.
Clark, S.A., Glørstad-Clark, E., Faleide, J.I., Schmid, D., Hartz, E.H., Fjeldskaar, W., 2014. Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA. Am. J. Sci. 304, 105–168.
DeCelles, P.G., 2004. Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA. Am. J. Sci. 304, 105–168.
DeCelles, P.G., 2012. Foreland basin systems revisited: variations in response to tectonic settings. In: Tectonics of Sedimentary Basins: Recent Advances. pp. 405–426.
DeCelles, P.G., Giles, K.A., 1996. Foreland basin systems. Basin Res. 8, 105–123.
Ershov, A.V., Brunet, M.F., Nikishin, A.M., Boletov, S.N., 1998. Evolution of the eastern Fore-Caucasus basin during the Cenozoic collision: burial history and flexural mod-elling. In: Epicratonic Basins of Peri-Tethyan Platforms. vol. 179. pp. 111.
Faleide, J.I., Vågnes, E., Gudlaugsson, S.T., 1993. Late Mesozoic-Cenozoic evolution of the south-western Barents Sea in a regional rift-shear tectonic setting. Mar. Pet. Geol. 10, 186–214.
Faleide, J.I., Solheim, A., Fiedler, A., Hjelstuen, B.O., Andersen, E.S., Vanneste, K., 1996. Late Cenozoic evolution of the western Barents Sea-Svalbard continental margin. Glob. Planet. Chang. 12, 53–74.
Faleide, J.I., Tsikalas, F., Breivik, A.J., Mjøde, R., Ritzmann, O., Engen, Ø., Wilson, J., Eldholm, O., 2008. Structure and evolution of the continental margin off Norway and the Barents Seas. Episodes 31, 82–91.
Suslova, A.A., 2013b. УСЛОВИЯ ФОРМИРОВАНИЯ ПРИРОДНЫХ РЕЗЕРВУАРОВ ЮРСКОГО НЕФТЕГАЗОНОСНОГО КОМПЛЕКСА БАРЕНЦЕВОМОРСКОГО ШЕЛЬФА (Conditions for forming Jurassic reservoirs for oil and gas on the Barents Sea shelf). [Ph.D. thesis]. Moscow University, Moscow (183 p.).

Turcotte, D., Schubert, G., 2014. Geodynamics. Cambridge university press (636 p).

Vigran, J.O., Mangerud, G., Mørk, A., Worsley, D., Hochuli, P.A., 2014. Palynology and Geology of the Triassic Succession of Svalbard and the Barents Sea. Geological Survey of Norway Special Publication 14, pp. 269.

Vorren, T.O., Lebesbye, E., Andreassen, K., Larsen, K.B., 1989. Glacigenic sediments on a passive continental margin as exemplified by the Barents Sea. Mar. Geol. 85, 251–272.

White, T., Furlong, K., Arthur, M., 2002. Forebulge migration in the Cretaceous Western Interior basin of the central United States. Basin Res. 14, 43–54.

Worsley, D., 2008. The post-Caledonian development of Svalbard and the western Barents Sea. Polar Res. 27, 298–317.