Potential reservoirs

The principal sedimentary units of interest with respect to potential reservoirs in the Norwegian–Danish Basin are the sandstones of the Upper Triassic – lowermost Jurassic Gassum Formation and the Middle Jurassic Haldager Sand Formation. The growth of salt pillows caused local topographic relief that influenced the deposition of these two reservoir units, as well as the intervening Fjerritslev Formation. The units thicken into rim synclines as indicated, for example, by the Felicia-1/1A section, and may thin considerably over salt pillows. These principal potential reservoirs are reviewed below with respect to their gross distribution, thickness development and properties.

A number of secondary potential reservoir units are also known from the Norwegian–Danish Basin and the Fennoscandian Border Zone, including the Lower Triassic Bunter Sandstone, the Lower–Upper Triassic Skagerrak Formation, the Lower Jurassic F-II member of the Fjerritslev Formation, the Upper Jurassic Flyvbjerg Formation and the uppermost Jurassic – lowermost Cretaceous Frederikshavn Formation. These secondary reservoir units are briefly described after the principal reservoirs.

Gassum reservoir

Shoreface and fluvial–estuarine sandstones interbedded with marine mudstones, lagoonal heteroliths and mudstones, lacustrine mudstones and thin coal seams occur in the Gassum Formation (Nielsen 2003). In the Himmerland Graben, the Sorgenfrei–Tornquist Zone and the Skagerrak–Kattegat Platform, sandstones are commonly the dominant lithology, and petrophysical log evaluations typically show net-to-gross ratios of 0.3–0.7 and porosities of 15–25%. The formation is more sand-poor in the central part of the basin with net-to-gross ratios of 0.1–0.2 (e.g. Mejrup-1, Nøvling-1, Vemb-1, Vinding-1). The sandstones are predominantly well to moderately sorted, fine- to medium-grained, locally coarse-grained and slightly pebbly. The shoreface sandstones occur as widespread sheets, 4–30 m thick, separated by marine transgressive mudstones and lagoonal heteroliths. Thick fluvial–estuarine sandstones mostly overlie the major SB 5 sequence boundary (Figs 10, 12; Nielsen 2003).

The formation is 50–150 m thick in central parts of the Norwegian–Danish Basin, its thickness being influenced by proximity to salt structures and faults. The formation thickens to 170–200 m in the fault-bounded Himmerland Graben and the northern part of the Sorgenfrei–Tornquist Zone. It thickens further to more than 300 m in the southern part of the fault zone where deposition of sand continued from the Triassic until the Early Sinemurian (Nielsen 2003). The thickness ranges from 69–205 m in the F-1, K-1, Felicia-1/1A and J-1 wells (Fig. 1). The large thickness (205 m) of the formation in Felicia-1/1A, with thick mudstones in the middle part of the formation, probably reflects an excess of accommodation space in the rim syncline associated with the nearby large salt pillow. The thickness decreases to 10–80 m on the Skagerrak–Kattegat Platform.

It is generally assumed that the siliciclastic material was mainly supplied from the Baltic Shield to the north and east. However, the dominance of mineralogically mature and better sorted sandstones in the Stenlille area and in the Ullerslev-1 well suggests that sand may have been supplied from the erosion of older sediments, such as the Triassic Bunter Sandstone on the Ringkøbing–Fyn High (Larsen 1966; Nielsen 2003).

The Gassum Formation is utilised in geothermal energy installations onshore Denmark at a depth of *c.* 1200 m (Thisted, northern Jylland) and is used for storage of natural gas in a structure at *c.* 1550 m depth in the eastern part of the basin (Stenlille area; Fig. 1).

Haldager Sand reservoir

The Haldager Sand Formation consists primarily of sandstones interbedded with thin mudstones. The sandstones are medium- to coarse-grained, slightly pebbly, commonly well to moderately sorted but locally poorly sorted. Sandstones are the dominant lithology, and petrophysical log evaluations typically show net-to-gross ratios of 0.4–0.8 and porosities of 15–30%. In the Sorgenfrei–Tornquist Zone, where subsidence continued despite regional uplift, the formation consists of four thick fluvial–estuarine to shallow marine sandstone units separated by marine and lagoonal–lacustrine mudstones (Nielsen 2003). Beyond the fault-bounded graben, in areas that experienced uplift in the early part of the Middle Jurassic, sandstones were mainly deposited by braided rivers, and the sand bodies are expected to be laterally coherent without significant primary hydraulic barriers. Anomalies with respect to facies and thickness occur locally in rim synclines associated with salt structures.

The distribution and thickness of the Haldager Sand reservoir are strongly influenced by regional syndepositional tectonism, local faulting and salt structures. Sediments were supplied from the north and east, but deep erosion of Triassic and older strata on the Ringkøbing–Fyn High and Lower Jurassic mudstones along the northern flank of the high added a substantial amount of material. As a result of the uplift of the Ringkøbing–Fyn High, high-energy braided rivers shed erosion products into the Sorgenfrei–Tornquist Zone, which experienced slow fault-controlled subsidence. Between the Fjerritslev and Børglum Faults, the formation attains a thickness of 30–175 m. Outside the Sorgenfrei–Tornquist Zone, the thickness and number of sandstone units decreases. On the Skagerrak –Kattegat Platform, the formation is 15–50 m thick and in the central part of the basin it is 25–50 m thick. In the southern and south-western part of the study area, the formation is thin and has a patchy distribution with thicknesses below 10 m.

Additional reservoirs

The Lower Triassic Bunter Sandstone and the Lower–Upper Triassic Skagerrak Formations constitute additional potential reservoir units in the study area. The Bunter Sandstone Formation consists of orange, red-brown and yellow-brown, medium- to fine-grained, moderately to well-sorted, cemented sandstones deposited mainly in braided ephemeral rivers and by eolian dunes. The Skagerrak Formation consists of interbedded sandstones, siltstones, claystones and anhydrites. The sandstones are arkosic, grey, red, orange-brown, fine- to coarse-grained, poorly sorted, angular–subangular and partly cemented, and were deposited on alluvial fans or braided river plains. Both formations are dominated by sandstones and potential internal barriers or seals are rare.

Another potential reservoir unit is represented by a muddy sandstone unit, 20–30 m thick, in the upper part of the Lower Jurassic F-II member (Fjerritslev Formation) on the Skagerrak–Kattegat Platform; the muddy sandstones were deposited by coastal progradation and ensuing transgression (sequences Fj 4, Fj 5; Figs 8, 12; Nielsen 2003). The sandstones are only well developed north-east of the Børglum Fault, where they show good porosity.

In the south-eastern part of the study area, a series of Lower Jurassic (Sinemurian–Pliensbachian) shoreface sandstones were encountered in the Lavø-1 and Margretheholm-1 wells, where they interfinger with marine mudstones of the Fjerritslev Formation. The sandstone unit is 30–70 m thick with porosities of 10–25%.

The shoreface sandstones present in the lower and upper parts of the Upper Jurassic Flyvbjerg Formation are also considered potential reservoir rocks; these sandstones show a general thinning from north to south and from east to west (Figs 8, 13).

On the Skagerrak–Kattegat Platform, the uppermost Jurassic – lowermost Cretaceous Frederikshavn Formation includes shallow marine and fluvial sandstones that possess reservoir properties, although the shale content increases rapidly towards the basin.

Discussion

The evaluation presented here of potential source rocks in the Danish portion of the Norwegian–Danish Basin, together with a review of potential reservoirs, suggests that a Mesozoic petroleum system may be present. Two primary plays are possible: the Upper Triassic – lowermost Jurassic Gassum play and the Middle Jurassic Haldager Sand play, both relying on charge from Lower Jurassic (Toarcian) or uppermost Jurassic – lowermost Cretaceous source rocks. Both plays have, however, been tested with negative results in a number of wells. It is generally proposed that the main reason for the failure of these plays so far has been the insufficient maturation (burial depth) of the potential source rocks. In the light of this study, then, it is useful to revisit the important elements of the Mesozoic petroleum system.

Source-rock quality and distribution

The regional petroleum generation potential and thermal maturity of the pre-Upper Cretaceous succession in the study area have been assessed by evaluating the stratigraphic units drilled by 33 wells both onshore and offshore in the Skagerrak and Kattegat areas (Fig. 1). It is generally accepted that the Upper Cretaceous – Cenozoic strata have no source-rock potential in the study area. Within the Lower Palaeozoic – Lower Cretaceous succession, only the Lower Jurassic (Toarcian) F-III and F-IV members of the Fjerritslev Formation and the uppermost Jurassic – lowermost Cretaceous Frederikshavn Formation contain intervals that qualify as potential oil-prone source rocks in the successions drilled to date (Figs 25–27, 34–38). None of these potential source rocks have a basinwide distribution. It is further emphasised that only parts of the lithostratigraphic units have a good to excellent petroleum generation potential and the potential source-rock units have highly variable generation potentials depending on the interaction of a number of geological processes during their formation. An overall upwards increasing petroleum generation potential is observed from the F-I member to the upper F-III and F-IV members of the Lower Jurassic Fjerritslev Formation (Figs 23, 24, 26, 27). This difference in generation potential is partly attributed to a change in depositional conditions through Early Jurassic times (Thomsen *et al.* 1987; Michelsen 1989b; Nielsen 2003). The F-I and F-II members were deposited in more oxic and shallow marine environments with a higher contribution of Type III kerogen, whereas the F-III and F-IV members were deposited under more reducing bottom conditions with a higher contribution of oil-prone Type II kerogen (Figs 28, 33).

The generation potential of the Toarcian part of the F-III and F-IV members shows significant lateral changes, with the best-developed source-rock units occurring in the basin centre (Fig. 35A; Table 2). The source quality of the F-III member seems to be particularly well developed in the Mors-1, Kvols-1, Hyllebjerg-1 and Farsø-1 wells, where the average HI values indicate a gas/oil generation potential (Fig. 34A). The Mors-1 well is located close to a major salt diapir (Fig. 3), which may suggest that the good source-rock quality is related to deposition in the deeper rim syncline of the diapir. It is likely that development of rim synclines adjacent to salt structures influenced source-rock formation, and it may thus be possible to infer the presence of source-rock intervals based on the analysis of lateral changes in seismic attributes in the rim synclines. Indeed, Thomsen *et al.* (1987) suggested that the increased HI values and TOC contents in Kvols-1 were the result of anoxic depositional conditions in a rim syncline; note, however, that this well was drilled adjacent to a minor salt pillow rather than a diapir. Michelsen (1989b) proposed that the organic-rich section in the Kvols-1 well resulted from reduced siliciclastic influx and constant organic deposition (i.e. a condensed section) as reflected in the relatively thin succession between TS 15 and the base of the F-IV member compared to other wells; this interpretation is compatible with the fact that the highest HI values seem to be related to MFS 15 (Fig. 29A). The Hyllebjerg-1 and Farsø-1 wells were not drilled close to salt structures, but both wells are located in the deepest part of the Himmerland Graben (Figs 2, 3). In Hyllebjerg-1, the highest HI values actually occur in the basal part of the F-IV member immediately above SB 16, which may suggest a relationship to a transgressive surface (Fig. 32A). The Rønde-1 well is located on the eastern flank of the Voldum structure, but the F-III member is not developed as a good source rock in this well. In contrast, the well-developed source rocks occur in the F-IV member and they do not seem to be associated with either maximum flooding or transgressive surfaces (Fig. 29B). It is commonly assumed that the formation of marine black mudstones with high values of HI is associated with initial flooding of lowstand systems creating sediment-starved environments with sufficient nutrients for high organic production (e.g. Wignall & Maynard 1993). During continued transgression, organic-rich black shales may be preserved. The formation of oil-prone shales is also considered to occur at the time of maximum marine flooding, and they are often best developed in the upper part of the transgressive systems tract close below the maximum flooding surface (Bohacs 1993; Robison & Engel 1993; Pasley *et al.* 1993). It is clear, however, from Figs 29–32 that no simple relationship exists in this case between the sequence stratigraphic key surfaces and high HI values.

The data from the wells analysed in this study thus indicate that the potential oil source rocks occur in different intervals within the Toarcian part of the F-III and F-IV members. These intervals may be locally developed, and 2–4 stacked intervals occur in some areas. The combined F-III and F-IV members in the Rønde-1, Kvols-1 and Haldager-1 wells, for example, possess oil-prone net source-rock intervals (i.e. HI >200 mg HC/g TOC) with average HI values ranging from 294–404 mg HC/g TOC, whereas the net source-rock interval in other wells is less oil-prone (Fig. 35A). The large variation in net/gross ratio shows that sedimentation rate was not the sole controlling parameter (Fig. 35A), but rather that optimum conditions required the right combination between sedimentation rate and organic productivity. Local depressions in the basin may further have favoured preservation of the organic matter by promoting stratification of the bottom waters. A detailed analysis of outcrops and cores from the Lower Toarcian Posidonia Shale in south-west Germany has shown that the formation of this rich source rock was governed by a complex interplay of factors, important amongst which was water column stratification controlled by sea-level changes (Röhl *et al.* 2001). Stratigraphic subdivision of the Danish well sections (Michelsen 1989a; Nielsen 2003) indicates that the two lower intervals of organic-rich mudstones in the F-III member are similar in age to the organic-rich shales in the Falciferum and Bifrons Zones of the Posidonia Shale. This suggests that, in addition to local factors, external factors such as regional/global anoxic events and sea-level changes may have played an important role in the formation of organic-rich shales at this time in the Norwegian–Danish Basin and the Fennoscandian Border Zone. The regional or global anoxia in the Early Toarcian that seems to have favoured the formation of organic-rich mudstones at some stratigraphic levels in parts of the basin, was apparently not a significant factor in other areas, possibly owing to high clastic input or shallow water depth that prevented the development of oxygen-deficient conditions and thus masked the event. It is intriguing, however, that the anoxic event appears to have influenced deposition along the basin margin in shallow marine/lagoonal areas on Bornholm (Koppelhus & Nielsen 1994; Hesselbo *et al.* 2000). The implication is, therefore, that the deposition and preservation of marine organic matter in the basin was a complex interplay between a number of factors probably including bottom topography and depth, variation in primary organic productivity, sedimentation rate, bottom-water oxygenation and distance to fluvial sources and coastlines; the relative importance of these different factors in influencing source-rock formation in the area is poorly understood in detail.

In contrast to the uncertainty related to regional prediction of source-rock quality, the present-day geographical occurrence of the stratigraphic interval spanning the F-III and F-IV members is well understood (Fig. 15). Their occurrence is primarily dependent on the regional early Middle Jurassic uplift event that caused deep widespread erosion, with truncation of the source-rock interval over large parts of the study area. Indeed, even within the central area where the F-III and F-IV members are typically preserved (Figs 15, 25B), this interval may be absent over local structural highs such as salt structures. To assess the distribution of this interval, it is necessary to map seismically both the base Middle Jurassic unconformity (base Haldager Sand Formation or Bryne Formation) and the seismic reflector corresponding to top F-II member. The latter coincides with a significant Upper Pliensbachian flooding surface typically situated 100–200 m below the best source-rock intervals. If possible, reflectors between these two horizons should also be mapped out in order to further constrain the position of the potential source rocks.

Parts of the uppermost Jurassic – lowermost Cretaceous Frederikshavn Formation, which is dominated by siltstones and sandstones in most wells, possess a petroleum generation potential in the Hyllebjerg-1, Skagen-2, Terne-1 and Voldum-1 wells, with the Terne-1 well having a particularly rich *c.* 160 m thick oil-prone interval with an average HI of 478 mg HC/g TOC (Fig. 38A; Table 3). The Type I kerogen composition of this Terne-1 interval (Fig. 39) indicates, however, freshwater to slightly brackish lacustrine depositional conditions in contrast to the marine and paralic conditions that characterised the regional depositional environment of the formation; the unit may thus be only a local development in the Terne-1 area in the Kattegat.

Source-rock maturity

Regional maturation profiles constructed from VR measurements corrected for post-Early Cretaceous exhumation yield a likely depth to the top of the oil window (VR of 0.6%R_o) of *c.* 3050–3100 m, based on the regional coalification curves principally derived from onshore wells (Figs 20A, 22A). Accepting this depth, the potential source rocks

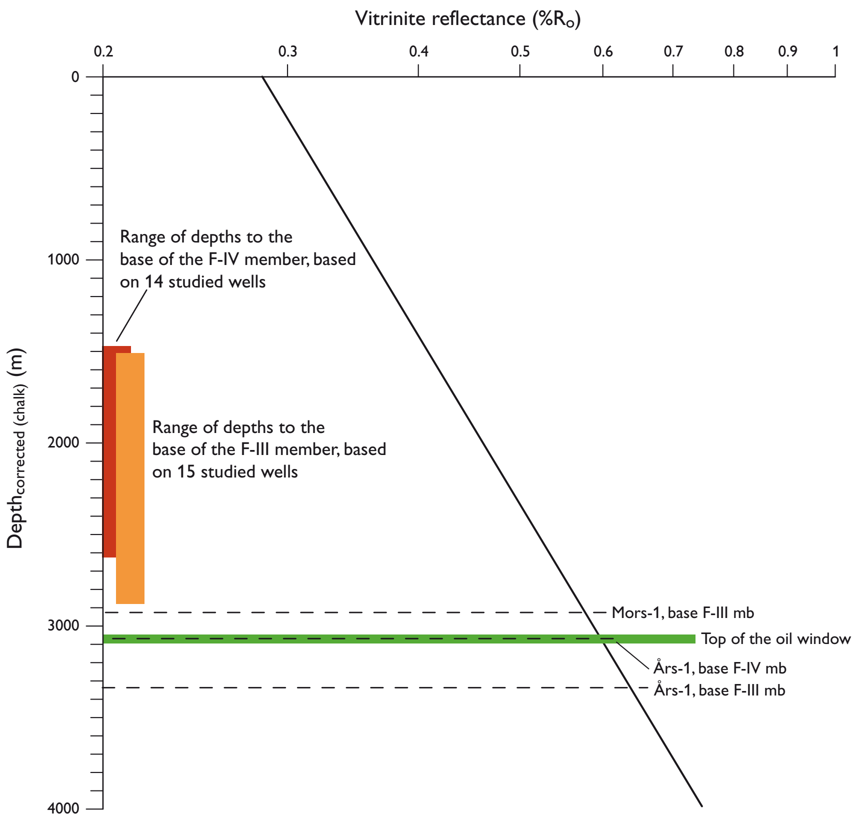
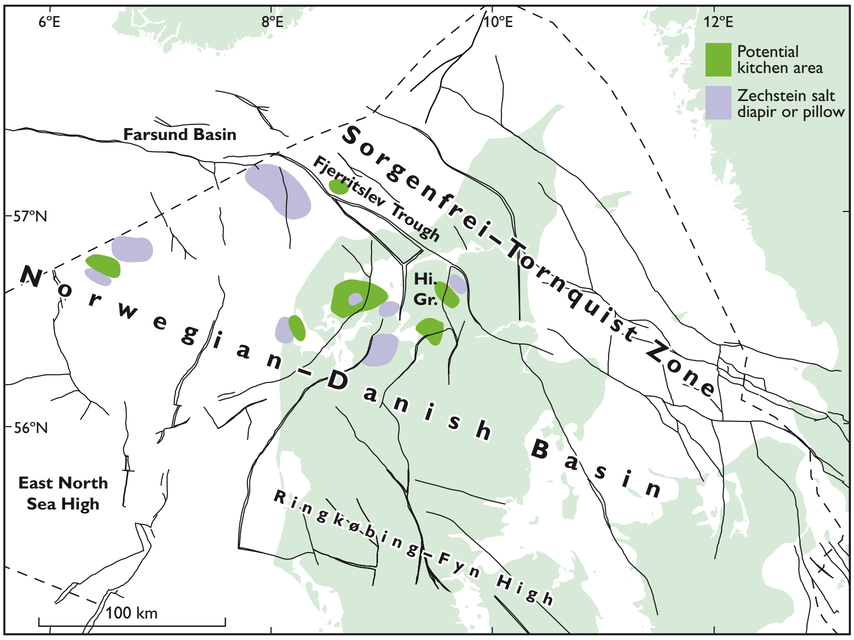


Fig. 40. The regional VR curve based on chalk velocity corrected depth (see Fig. 22A). The depth to the top of the oil window at 0.6%R_o is indicated together with the range of depths to the base of the F-III and F-IV members before post-Early Cretaceous exhumation in the studied wells. In the Mors-1 well, the base of the F-III member has been buried slightly deeper, but still above the top of the oil window. Only in the Års-1 well has the F-III member been within the top part of the oil window before exhumation. The thickness of the F-III member ranges from 30–279 m in the 15 studied wells, whereas the F-IV member ranges from 9–127 m in 13 of the 14 studied wells. In Gassum-1, the F-IV member is considerably thicker, namely 320 m.

need a burial depth of *c.* 1.75–2 sec. TWT to reach the oil window if velocity data from the Års-1 well, placed centrally in the basin, are used as guidelines (Nielsen & Japsen 1991). The shales of the Frederikshavn Formation are thus regionally thermally immature in the study area. The Toarcian shales of the F-III and F-IV members of the Fjerritslev Formation constitute the most obvious potential source rocks, but over most of the study area they have not been buried sufficiently to have entered the oil window (Fig. 40). Of the investigated wells, only in the Års-1 well, on the flank of the Himmerland Graben immediately west of a major salt structure, has the F-III member been within the uppermost part of the oil window prior to post-Early Cretaceous exhumation. The source-rock quality of the F-III member in this well, however, is poor with a maximum HI value of 186 mg HC/g TOC and an average HI of only 113 mg HC/g TOC. Hence, occurrence of mature source rocks in the study area requires local burial anomalies, such as local grabens or rim synclines adjacent to salt diapirs, to reach thermal maturity for oil generation.

A map showing the depth to the base of the Middle Jurassic (i.e. the base Middle Jurassic unconformity) in the Danish part of the Norwegian–Danish Basin was constructed by Bidstrup *et al.* (2002). This surface corresponds to the top of the F-IV member, i.e. the top of the stratigraphic unit with the most promising source rocks (F-III and F-IV members) in the Fjerritslev Formation. If the present-day depths are corrected for post-Early Cretaceous uplift (Table 1; Japsen 1998) and information of the combined thickness of the F-III and F-IV members (Fig. 25) is included, it is possible to locate potential areas with mature source rocks (Fig. 41). These potential, locally developed petroleum kitchens are mainly located in the central part of the study area (central–northern Jylland), where they are associated with rim synclines of salt structures. Offshore, in the Skagerrak, a minor kitchen may be present in the Fjerritslev Trough close to the Fjerritslev Fault. Farther to the west, a kitchen may occur between two salt structures (Fig. 41) although in this area the F-III member is probably very thin and the F-IV member is absent (Fig. 25). The onshore petroleum kitchens indicated on Fig. 41 correspond to the possible kitchens in the Harboør–Uglev, Mors and Tostrup rim synclines mapped by Thomsen *et al.* (1987); apart from the kitchen area in the Mors rim syncline, however, the kitchens identified in the present study are areally smaller. The potential kitchen in the Vejrum rim syncline suggested by Thomsen *et al.* (1987) cannot be confirmed in the present study, principally due to very thin source-rock units (e.g. Mejrup-1 well; Fig. 25A) or the absence of the F-III and F-IV members (Fig. 15).

Fig. 41. Map showing the location of potential petroleum kitchen areas with mature source rocks of the F-III and F-IV members of the Lower Jurassic Fjerritslev Formation. The kitchens are locally developed and are principally associated with salt structures. The most westerly kitchen in the Skagerrak is highly uncertain due to the absence of the F-IV member and possibly only a very thin (or absent?) F-III member. Note that only salt structures associated with potential kitchen areas are shown (cf. Fig. 3). **Hi. Gr.**, Himmerland Graben.



The Mors-1 well is located adjacent to the northern flank of the largest potential kitchen area. The main targets of this well were the Zechstein and Rotliegend, but the well reached TD in Lower Triassic sandstones at a depth of 5303 m. The well intersected 123 m of net source rock with gas and oil generation potential (average HI = 221 mg HC/g TOC) and the source rocks are close to being early mature (Fig. 35). The well encountered only small traces of asphalt in the Haldager Sand Formation, and the poor hydrocarbon indications may be explained by the lack of structural closure (Thomsen *et al.* 1987; GEUS, unpublished data).

Reservoirs and migration

Both reservoirs, the Gassum and Haldager Sand Formations, are proved to be present regionally and sealed by Lower Jurassic and Upper Jurassic mudstones, respectively. The Haldager Sand reservoir conformably overlies the Lower Jurassic potential source rocks in the relatively deep Fjerritslev Trough and presumably also in the Farsund Basin (Fig. 2). In contrast, in the remaining parts of the study area, where the F-III and F-IV members and the Haldager Sand Formation are present, the Haldager Sand reservoir unconformably overlies the succession with the potential source rocks. Migration of hydrocarbons to the Haldager Sand reservoir is thus simple. Migration to the Gassum reservoir requires stratigraphic downward migration of the hydrocarbons and may thus require structural components, i.e. faulting or salt domes.

Thin fine-grained shoreface sandstones formed during short-lived regressive events occur within the Lower Jurassic marine mudstones in the Fjerritslev Trough and Skagerrak–Kattegat Platform. These sandstones can be traced relatively far into the basin as thin silty sandstone intercalations in the mudstones and may function as conduits for hydrocarbon migration.

The Gassum Formation reservoir is overlain by the laterally consistent, thick marine mudstone succession of the Fjerritslev Formation. Sandstone or siltstone units up to 5–10 m thick are present in the basal Fjerritslev Formation in places, but their influence on seal integrity over the Gassum Formation reservoir is generally expected to be limited. Close to the basin margin, however, for example on the Skagerrak–Kattegat Platform in the eastern part of Kattegat and Sjælland, Hettangian–Pliensbachian sandstones are common and constitute an additional potential reservoir, overlain by marine mudstones of the upper Fjerritslev Formation. The Haldager Sand reservoir is overlain by marine mudstones of the Flyvbjerg and Børglum Formations. Sandstones are present in the lower and upper part of the Flyvbjerg Formation in places, and their thickness and grain size are expected to increase towards the northern and eastern basin margin, where they may form an additional reservoir section. The middle part of the Flyvbjerg Formation is dominated by marine mudstones with some seal capacity, and the Flyvbjerg Formation itself is overlain by the thick, regionally continuous, marine mudstone succession of the Børglum Formation.

Active Mesozoic petroleum system?

In agreement with the general immaturity of the potential source rocks in the study area, very few oil shows have been reported. One exception is the K-1 well (Fig. 1), in which weak shows in sandstone and sandstone stringers were noted at several depths. The well was, however, drilled with diesel that was added several times during drilling operations; geochemical data of cuttings samples from the K-1 well show the presence of a low-boiling distillation cut such as diesel, with a minor contribution representing indigenous immature organic matter (GEUS, unpublished data). Thus, reports of thermally generated petroleum in this well cannot be confirmed. The well was also drilled in an area in which the presence of mature source rocks is deemed unlikely (Fig. 41). The presence of generated petroleum in the Danish part of the Norwegian–Danish Basin thus still has to be documented, although it cannot be excluded that petroleum has been generated in localised potential kitchen areas (Fig. 41).

Conclusions

Two primary plays are possible in the study area: the Upper Triassic – lowermost Jurassic Gassum play and the Middle Jurassic Haldager Sand play, both relying on charge from Lower Jurassic (Toarcian) or uppermost Jurassic – lowermost Cretaceous source rocks. Both plays have, however, been tested with negative results. This study shows that two main uncertainties are present in the Danish part of the Norwegian–Danish Basin and the Fennoscandian Border Zone: (1) the patchy distribution of well-developed, oil-prone, potential source rocks, and (2) the thermal maturity of the potential source rocks. The latter factor is considered here to be the most significant uncertainty in proving the integrity of this Mesozoic petroleum system.

The evaluation of source-rock quality, thermal maturity and distribution allows the following principal conclusions to be drawn:

1. Lower Palaeozoic rocks are overmature in the study area and Upper Cretaceous – Cenozoic strata possess no petroleum generation potential.

2. Toarcian marine shales of the Lower Jurassic F-III and F-IV members of the Fjerritslev Formation and the uppermost Jurassic – lowermost Cretaceous shales of the Frederikshavn Formation constitute oil-prone potential source rocks in parts of the basin. The generation potential of these potential source rocks is highly variable geographically, and the F-III and F-IV members in the centre of the basin possess the best-developed source potential. The highly oil-prone lacustrine mudstone interval of the Frederikshavn Formation in the Terne-1 well is probably only a local development.

3. Based on interpretation of regional coalification curves, the top of the oil window (vitrinite reflectance = 0.6%R_o) is located at *c.* 3050–3100 m depth. The uppermost Jurassic – lowermost Cretaceous Frederikshavn Formation had not been buried to this depth prior to post-Early Cretaceous exhumation, and the potential source rocks of the formation are thermally immature in terms of hydrocarbon generation. Similarly, the potential source rocks of the Lower Jurassic F-III and F-IV members of the Fjerritslev Formation are generally immature to very early mature. However, potential kitchen areas with mature source rocks of the F-III and F-IV members may occur in the central part of the study area (central–northern Jylland) and a few places offshore. These potential petroleum kitchens are considered to be of local development, mainly associated with salt structures and grabens (Fjerritslev Trough and Himmerland Graben).

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