Finnmark Platform Composite Tectono-Sedimentary Element, Barents Sea

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Abstract: The Finnmark Platform Composite Tectono-Sedimentary Element (CTSE), located in the southern Barents Sea, is a northward-dipping monoclinal structural unit. It covers most of the southern Norwegian Barents Sea where it borders the Norwegian mainland. Except for the different age of basement, the CTSE extends eastwards into the Kola Monocline on the Russian part of the Barents Sea.

The general water depth varies between 200 and 350 m, and the sea bottom is influenced by Plio-Pleistocene glaciations. A high frequency of scour marks and deposition of moraine materials exists on the platform areas. Successively older strata sub-crop below the Upper Regional Unconformity (URU), which was formed by several glacial periods.

Basement rocks of Neoproterozoic age were heavily affected by the Caledonian Orogeny, and previously by the Timanide tectonic compression in the easternmost part of the Finnmark Platform CTSE.

Depth to crystalline basement varies considerably and is estimated to be from 4–5 to 10 km. Following the Caledonian orogenesis, the Finnmark Platform was affected by Lower–Middle Carboniferous rifting, sediment input from the Uralian Orogen in the east, the Upper Jurassic–Lower Cretaceous rift phase and the Late Plio-Pleistocene isostatic uplift.

A total of eight exploration wells drilled different targets on the platform. Two minor discoveries have been made proving the presence of both oil and gas, and potential sandstone reservoirs of good quality identified in the Visean, Induan, Anisian and Carnian intervals. In addition, thick sequences of Permo-Carboniferous carbonates and spiculitic chert are proven in the eastern Platform area. The deep reservoirs are believed to be charged from Paleozoic sources. A western extension of the Domanik source rocks well documented in the Timan–Pechora Basin may exist towards the eastern part of the Finnmark Platform. In the westernmost part, charge from juxtaposed downfaulted basins may be possible.

Due to the influence of several tectonic phases and a variety of depositional environments, the Finnmark Platform has been treated as a Composite Tectono-Sedimentary Element (CTSE), outlined geographically in Figure 1 and stratigraphically in Figure 2. The Finnmark Platform CTSE, located in the southern Barents Sea, extends almost from the Atlantic Margin in the west, to the Kola–Kanin Monocline in the east (Enclosure A, B and C).

In the western area, west of the Nordkapp Basin, the platform area is defined as a narrow 30–50 km-wide NNE–SSW-trending structural element between the Norwegian mainland to the south, and the Hammerfest Basin (Henriksen *et al.* 2021) towards the north. To the east, a much broader, more than 100 km wide, ESE–WNW-trending platform exists, bordering the Nordkapp and Tiddlybanken basins towards the north (Doré *et al.* 2021), and the Kola Monocline to the east (Drachev and Shkarubo 2022). The general water depth varies from 200 to 350 m. The topography of the sea bottom is influenced by numerous Plio-Pleistocene glaciations. A high frequency of scour marks and deposition of moraine materials have been mapped in detail over large areas (Vorren *et al.* 1991; Andreassen *et al.* 2008; Chand *et al.* 2012; Laberg *et al.* 2012; Knies *et al.* 2014 and others).

A few wells and shallow stratigraphic boreholes on the Finnmark Platform confirm the general stratigraphy (Fig. 2), the major unconformities and the minor oil and gas discoveries. Depth to the Paleozoic succession varies from almost zero in the southernmost part to more than 3500 m in the NE part of the platform. The Jurassic section occurs at around 1500 m, at its deepest.

A regional sub-crop map of older strata below the Quaternary succession indicates a similar geological development for the Finnmark and the Kola platforms after the Caledonian Orogeny (Fig. 3). Based on different tectonic influences and age of basement, the Kola–Kanin Platform and the Finnmark Platform CTSEs are described separately (Drachev and Shkarubo 2022).

Age

The general stratigraphy of the Finnmark Platform CTSE is represented by rocks from the Lower Carboniferous to the Paleocene (Fig. 2). Paleozoic and part of the Mesozoic sequences dominate the sediment fill. Significant glacial erosion and uplift removed large parts of the Cenozoic and Mesozoic rocks, and successively older stratigraphy sub-crops the Upper Regional Unconformity (URU) towards the south on the platform (Fig. 3).

Geographical location and dimension

The Finnmark Platform CTSE comprises 65 000 km^2, limited by the Norwegian mainland to the south. In an east–west direction, the platform extends for 530 km. The north–south extension of the platform varies from 30 to 140 km. Towards the north, the platform is limited by the Tromsø, Hammerfest, Nordkapp and Tiddlybanken basins. In the north and eastern directions, the platform borders the South Barents Depression, the Fedinsky High and the Kola Monocline (Fig. 1; Enclosures A, B and C).

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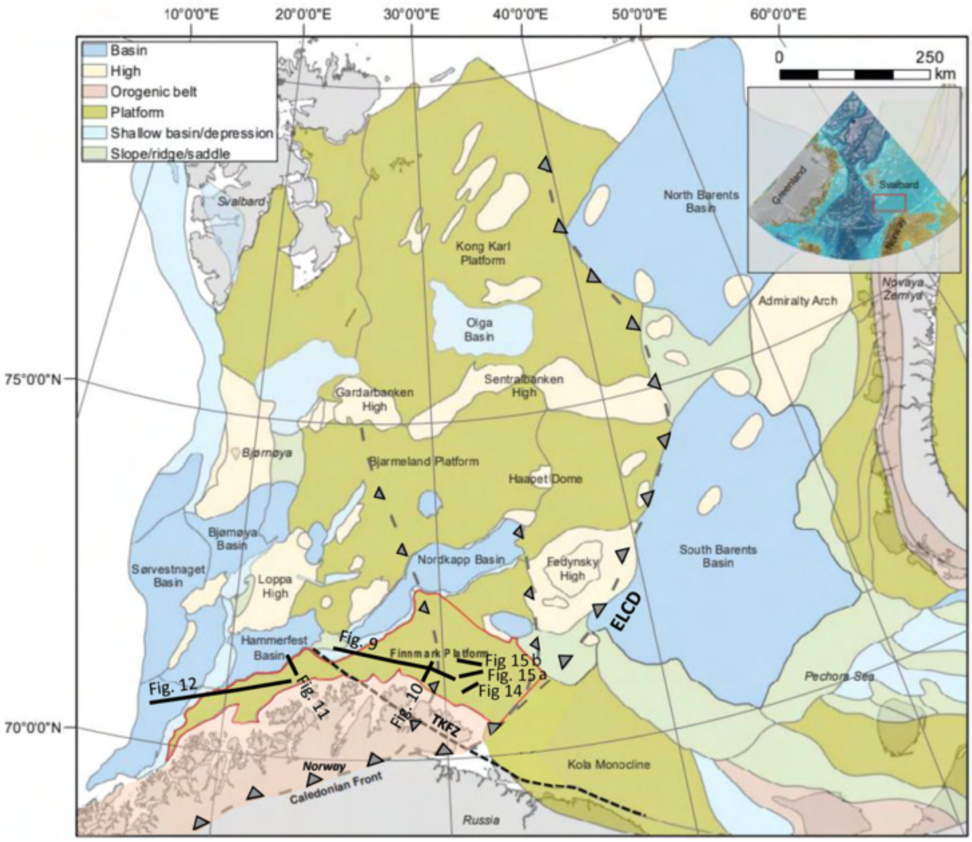

Fig. 1. Outline of the Finnmark Platform CTSE (red contour) in a regional context of the Barents Sea tectonics. Orientation of seismic profiles and geoseismic sections are marked with black lines. The Eastern Limit of Caledonian Deformation (ELCD), other Caledonian deformation boundaries of the nappe complexes farther west and the Trollfjord–Komagelv Fault Zone (TKFZ) are marked on the map. Map modified from Henriksen *et al.* (2011*a*).

Principal datasets

The data coverage, including wells and seismic, varies from the east (good coverage) towards the SW, where the data coverage is sparser (Fig. 4, Enclosure F).

Wells

A total of eight exploration wells were drilled on the platform (Table 1; Fig. 4). Of these, four wells are located on the eastern Finnmark Platform area targeting the Paleozoic section. The most recent wells were drilled by ENI in 2017 south of the Goliat Field, and by Lundin Norway AS in 2016 close to the Russian maritime border. A significant amount of data has been gathered from the wells. In well 7128/6-1, *c.* 400 m of continuous core was collected in the Paleozoic section.

In addition to the conventional wells, eight shallow (maximum of 580 m depth) stratigraphic boreholes (diamond coring) drilled by the IKU (Continental Shelf Institute, now SINTEF) from 1987 to 1988 provided important information about the subsurface. In the westernmost part of the Finnmark Platform, three additional cores were taken (Bugge *et al.* 1995). The shallow drilling cored 640 m of Paleozoic stratigraphy in total. Oil and gas were tested in well 7128/4-1(Upper Permian), and minor gas was discovered in well 7130/4-1 (Lower Carboniferous).

Seismic data

Since 1975, several vintages of 2D seismic of different quality were acquired by the Norwegian Petroleum Directorate and the petroleum industry on the Finnmark Platform. Large areas along the Troms–Finnmark Fault Complex and NE part of the platform area are covered by high-quality 3D seismic data (Fig. 4). To the west, in the transition towards the Tromsø Basin and the Harstad Basin, the general seismic data are of poor quality. Towards the Norwegian mainland, where basement exist at shallow levels, a limited amount of data has been acquired and the quality is generally poor. In the coastal area, shallow 2D seismic of high quality has been acquired.

The Finnmark Platform CTSE area is covered by magnetic and gravimetric data (Fichler *et al.* 1997; Gaina *et al.* 2011; Werner *et al.* 2011; Gernigon and Brönner 2012; Gernigon *et al.* 2014, 2018) (see also Enclosures B and C).

Tectonic setting, boundaries and main tectonic/erosional/depositional phases

Finnmark Platform CTSE represents a north-dipping east–west-elongated monocline offshore the Norwegian coast (Enclosure D; Figs 1 & 3). The platform area and its relationship to the adjacent basins has previously been described by Rønnevik *et al.* (1982), Faleide *et al.* (1984), Rønnevik and Jacobsen (1984), Spencer *et al.* (1984), Riis *et al.* (1986), Gabrielsen *et al.* (1990), Dengo and Røssland (1992), Bugge *et al.* (1995), Henriksen *et al.* (2011*a*, *b*, 2021) and others. Its structural style results from Paleozoic and Mesozoic rifting and recent post-glaciation rebound. The general outline of the platform is controlled by major normal fault complexes along the margins of the Hammerfest–Nordkapp rifts (Ringvassøy Loppa, Troms Finnmark and Måsøy fault complexes) in the NW and by the Tiddlybanken Rift in the NE (Fig. 1). Late Cenozoic uplift finally created the monoclinal dip and erosional border where the sedimentary rocks sub-crop towards the Norwegian mainland (Fig. 3). The regional setting of the CTSE in the circum-Arctic context is shown in Enclosures A, B, C and E.

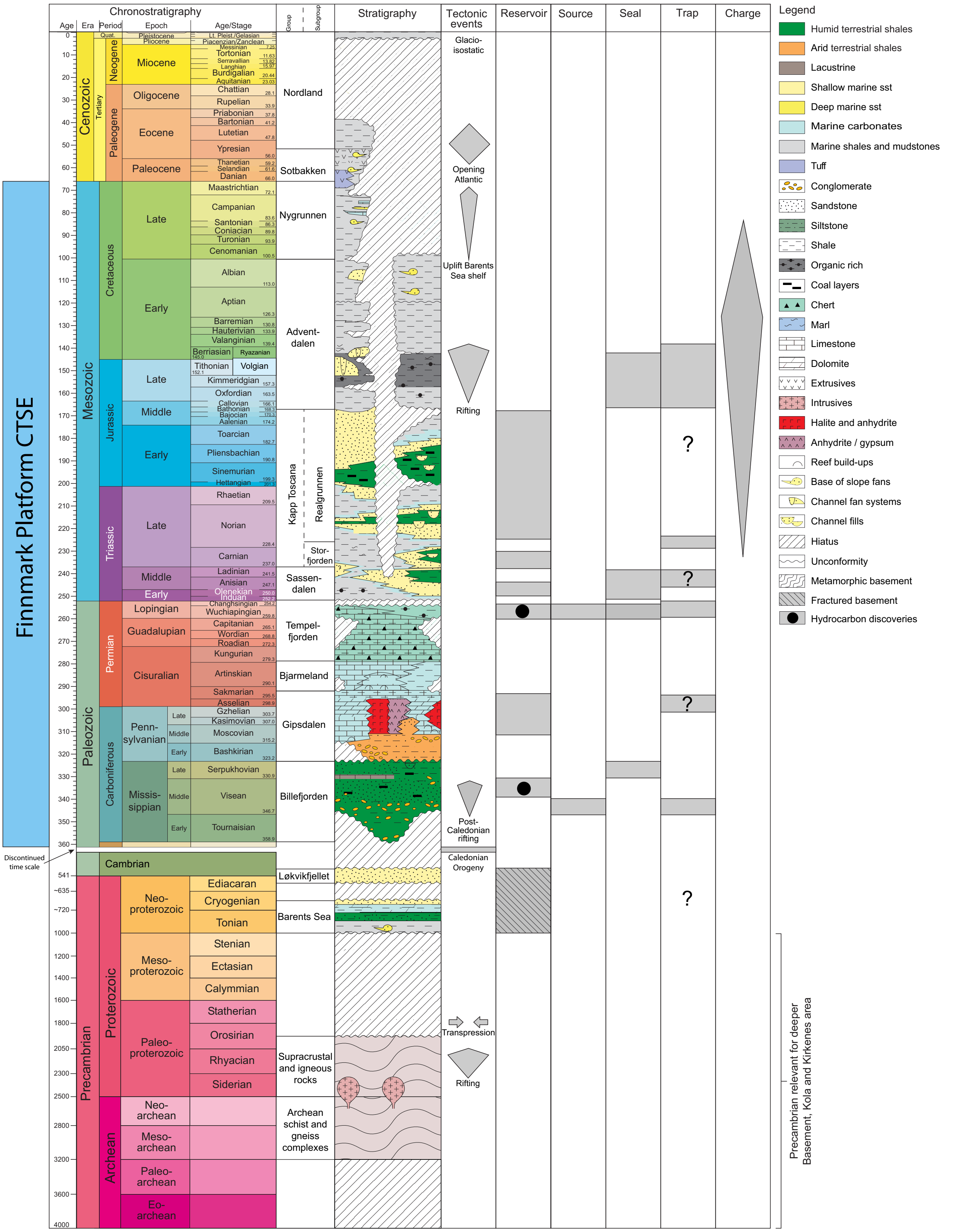

Fig. 2. Regional lithostratigraphy of the Finnmark Platform and surrounding areas, modified from Gabrielsen *et al.* (1990) and Cohen *et al.* (2013), showing tectonic events, reservoir intervals, potential source rocks, charge and traps. The preserved stratigraphy varies considerably along the monoclinally dipping platform.

The Finnmark Platform has undergone several tectonic phases:

- Timanian compressional/transpressional deformation (Neoproterozoic);
- Caledonian compressional deformation and orogeny (Silurian–Devonian);
- Lower–Middle Carboniferous rifting (possibly Devonian in the east);
- Permian Uralian compressional deformation and orogeny;

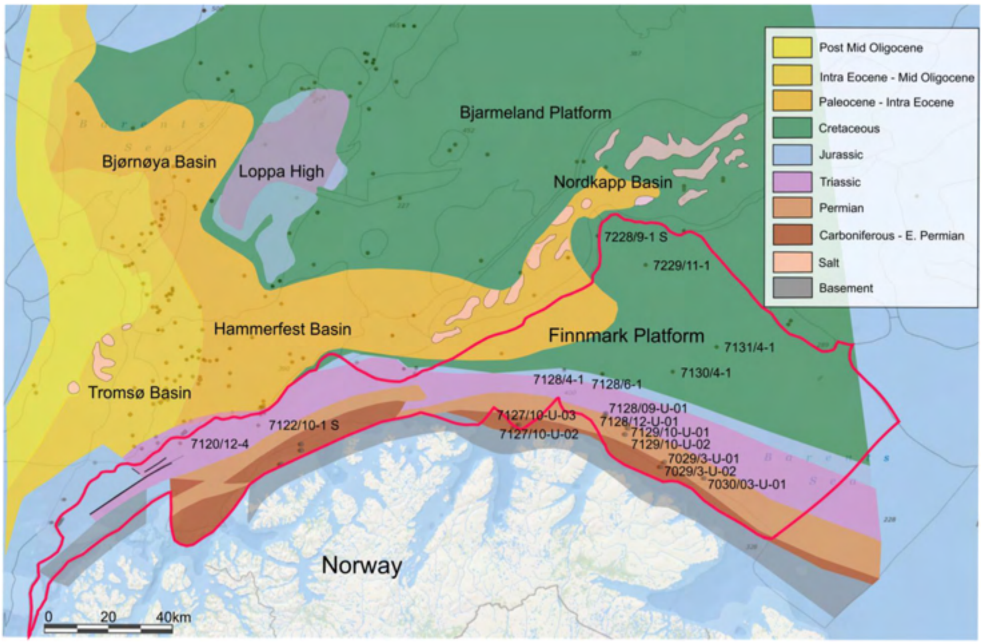

Fig. 3. Sub-crop map showing the truncated layers towards the south on the platform, below the Plio-Pleistocene Unconformity (URU). Modified from Doré (1991), Bugge *et al.* (1995) and Henriksen *et al.* (2011*a*).

- Middle–Late Jurassic rifting;
- Cretaceous tilt of platform;
- Cenozoic rifting, opening of the Atlantic and uplift (Eocene–Oligocene);
- Glacial isostatic uplift (Plio-Pleistocene).

Corresponding sedimentary units represent the following individual tectono-sedimentary elements (TSEs):

- Lower –Middle Carboniferous (possibly includes Devonian in places) synrift TSE;
- Permian–Jurassic post-rift sag TSE;
- Upper Jurassic–lower Cretaceous synrift TSE (where preserved);
- Cretaceous post-rift sag TSE;
- Paleocene–Eocene pre-rift TSE (before the opening of the North Atlantic Ocean).

Neoproterozoic tectonic movements around 570–560 Ma (Gee and Pease 2004; Herrevold *et al.* 2009) are represented onshore by the WNW- and ESE-trending Trollfjord–Komagelv Fault System. The fault trend localized on the Varanger

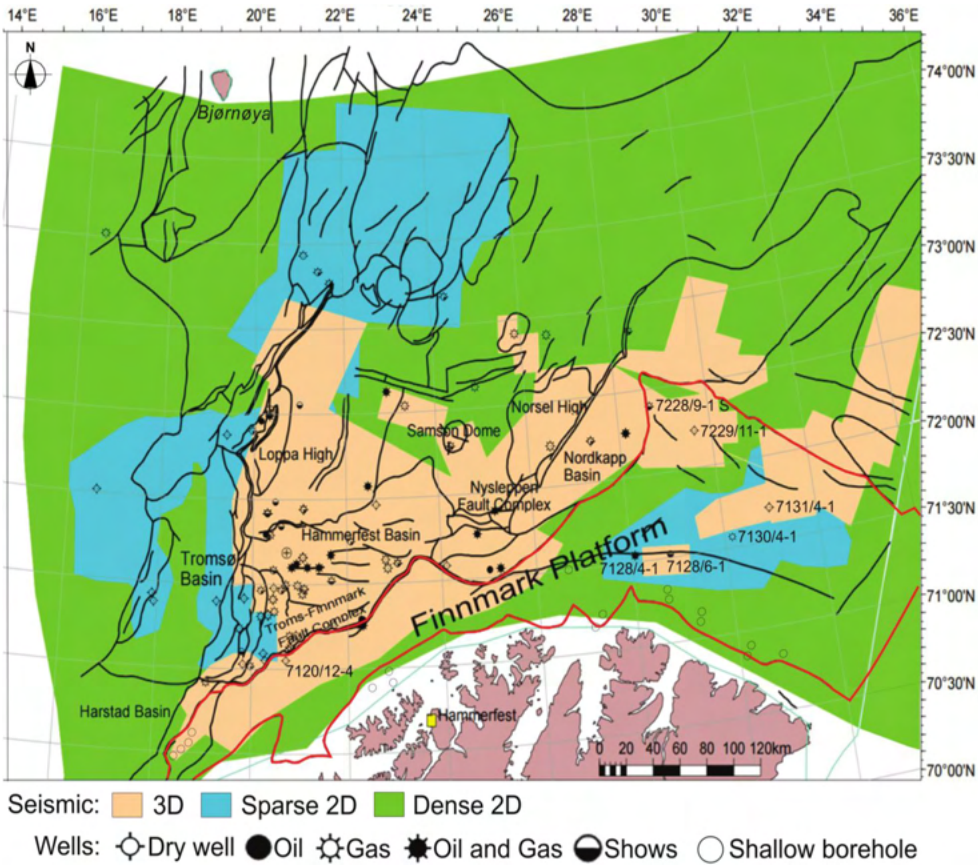

Fig. 4. Seismic and well database for the Finnmark Platform and surrounding areas.

Table 1. *Wells and shallow stratigraphic boreholes located on the Finnmark Platform*

Wells		Shallow boreholes on Finnmark East
Name	**Year drilled**	
7122/10-1	2017	7127/10-U-02 and 7127/10-U-03
7130/4-1	2015–16	7128/09-U-01
7131/4-1	2005	7128/12-U-01
7128/4-1	1993–94	7129/10-U-01 and 7129/10-U-02
7128/6-1	1991	7029/03-U-01 and 7029/03-U-02
7229/11-1	1993	7030/03-U-01
7228/9-1	1989–90	
7120/12-4	1984	

Peninsula continues further west offshore (Fig. 1). The basement adjacent to the Finnmark Platform (Fig. 5) can be studied in very good exposures in the Varanger–Porsanger areas (Fig. 6). Geology of this area plays a key role in hypothesizing offshore projection of the Caledonian deformation front.

The Caledonian Orogeny, a result of the collision between Baltica and Laurentia, was active in Silurian–Devonian time. The offshore extension of the Caledonian suture is still under debate and different interpretations exist (Fig. 1) (Roberts 1975; Doré 1991; Gee and Pease 2004; Faleide *et al.* 2008, 2018; Gee *et al.* 2008; Henriksen *et al.* 2011*b*; Gernigon *et al.* 2014, 2018; Klitzke *et al.* 2015; Doré *et al.* 2021). The offshore wells 7128/4-1 and 7128/6-1 penetrated 27 m into acoustic basement that is represented by Eocambrian–Neoproterozoic metasediments with recrystallized, granoblastic quarts and kaolinized feldspars, which indicate Caledonian deformation (Henriksen *et al.* 2011*b*; and well completion reports found at http://www.npd.no) in the eastern area (Figs 3 & 7). In general, the Neoproterozoic section is reported to thin considerably from east to west (Fossen *et al.* 2008).

Systematic mapping of the Varanger Peninsula and surrounding areas was carried out by Siedlecka and Siedlecki (1972), Roberts (1975, 2011), Siedlecka (1975), Rice (2014), Siedlecka and Nordgulen (1996), Gee and Pease (2004), Nasuti *et al.* (2015 and references therein). Bedrock outcrops demonstrate a gradual decrease in Caledonian influence going eastwards in Finnmark County (eastern Varanger Peninsula), where almost undeformed rocks of the Vadsø, Tanafjord and Vestertana groups in the Tanafjord–Varangerfjordregionen occur (Figs 5 & 6). The offshore Finnmark Platform mirrors the well-documented onshore basement trends that have been discussed in numerous papers (Roberts 1975; Ulmishek 1982; Harland and Dowdeswell 1988; Gabrielsen *et al.* 1990; Doré 1991; Fossum *et al.* 2001; Ivanova 2001; O'Leary *et al.* 2004; Ritzmann and Faleide 2007; Smelror *et al.* 2009; Henriksen *et al.* 2011*a*, *b*; Gernigon *et al.* 2014, 2018; Drachev 2016; Zhang *et al.* 2016; Koehl *et al.* 2018; Doré *et al.* 2021; Drachev and Shkarubo 2022).

In this chapter, we tentatively place the eastern border of the Caledonian basement (Eastern Limit of Caledonian Deformation (ELCD)) east of the Varanger Peninsula, where it coincides with the eastern flank of the Lower Allochthon, the Gaissa Nappe Complex and the Tanafjord–Varangerfjord region. East of the front, Neoproterozoic and Archean basement crops out on the southern flank of the Varangerfjord, on the Rybachi Peninsula and on the Kola Peninsula correspondingly (Siedlecka and Nordgulen 1996; Adatte *et al.* 2020; Drachev *et al.* 2022).

On an east–west profile (Fig. 1), a regional domal feature, later modified by Carboniferous extensional faults, may fit with the main onshore Caledonian front.

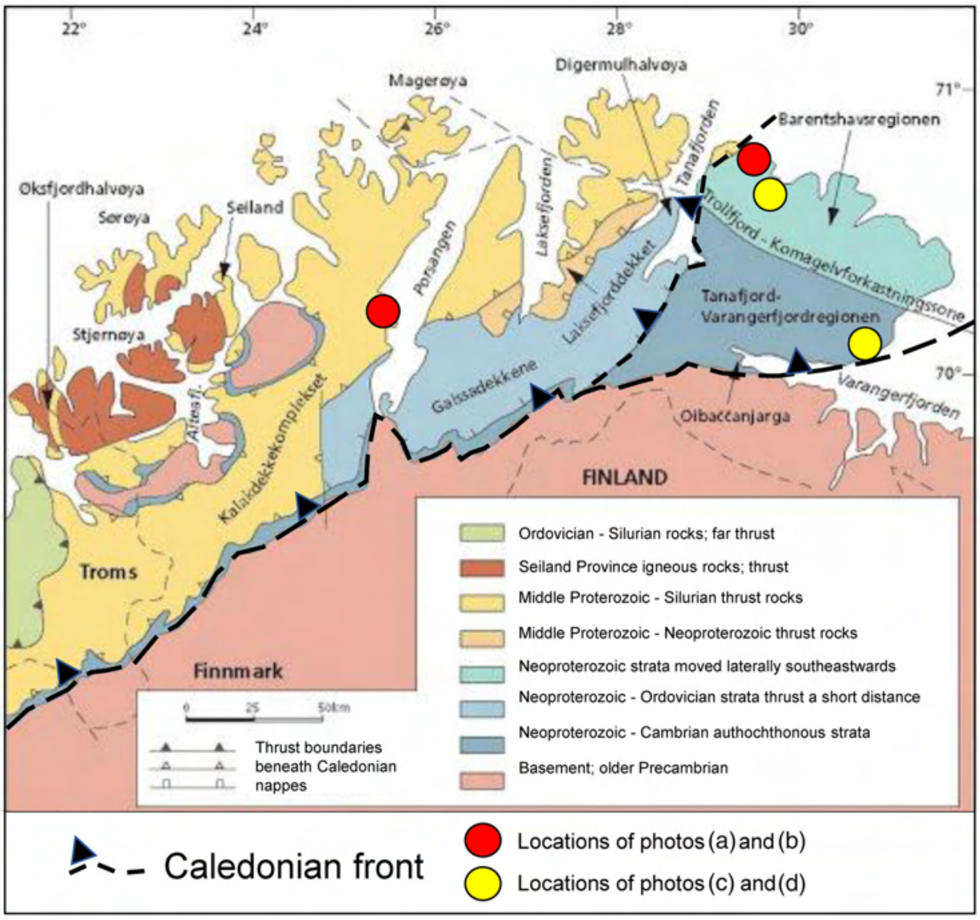

Fig. 5. Onshore basement structure adjacent to the Finnmark Platform CTSE, and the front of the Caledonian thrusts. Modified from Nystuen (2008 and references therein). The locations of field examples in Figure 6 are marked on the map.

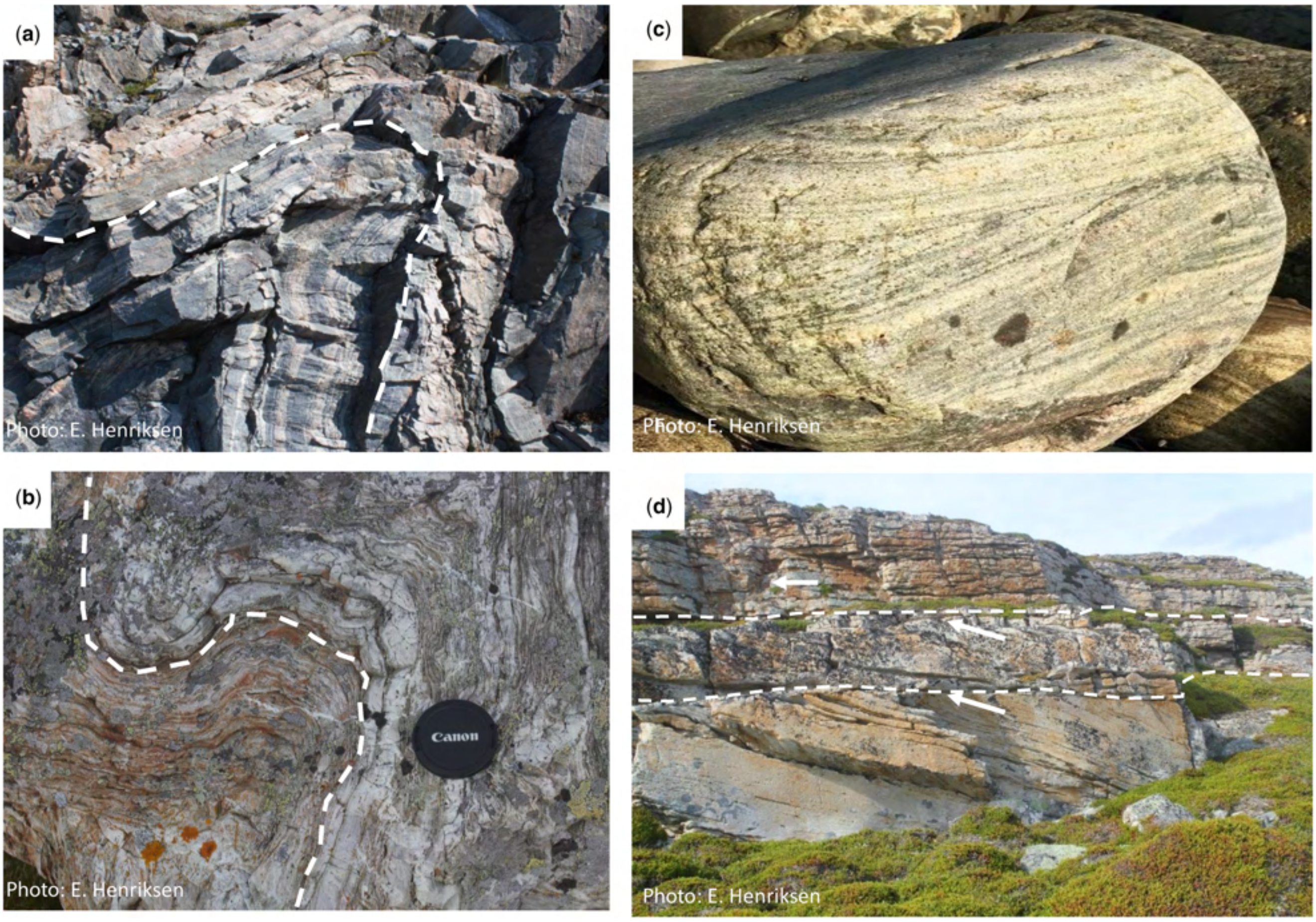

Fig. 6. Onshore field examples of (**a**) folded and deformed Neoproterozoic sand and shale layers and (**b**) dolomites from the Porsanger and Varanger area, in contrast to the undeformed cross-bedded fluvial sediments (**c**) and (**d**) farther east on the Varanger Peninsula.

Sediments from the Ordovician to the Devonian, not found in the Norwegian part of the Barents Sea, are well documented in the Timan–Pechora area (Schenk 2011; Stoupakova *et al.* 2011; Prishchepa *et al.* 2021). Possible analogues of the Timan–Pechora successions (including Upper Devonian sediments) may be present in a distinct gravimetric low informally named the 'Varanger–Kola Basin' (Fig. 8a); the oldest undeformed rocks documented in this basin in wells 7128/4-1 and 7128/6-1 are Visean. The 'Varanger–Kola Basin' is approximately parallel to the Trollfjord–Komagelv Fault and probably predates the Caledonian Orogeny. Farther to the west, a NNE–SSW-orientated structure, informally named

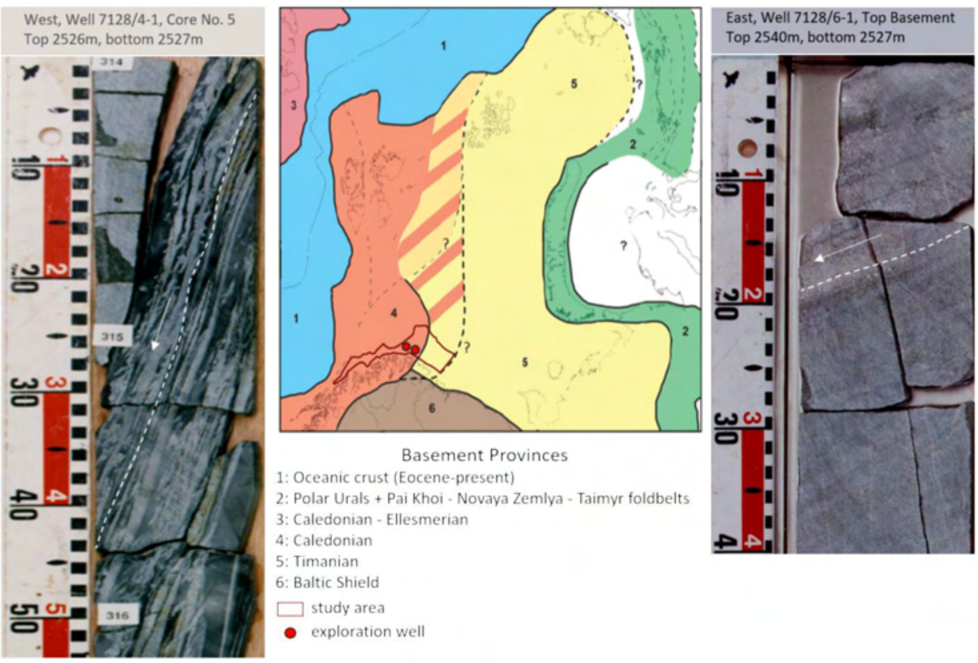

Fig. 7. Moderately deformed and tilted sedimentary rocks (Neoproterozoic) from offshore wells on the Finnmark Platform seem to follow the same deformational trend as onshore. Map showing basement provinces, modified from Faleide *et al.* (2018). Core data are from the Norwegian Petroleum Directory (NPD: http://www.npd.no).

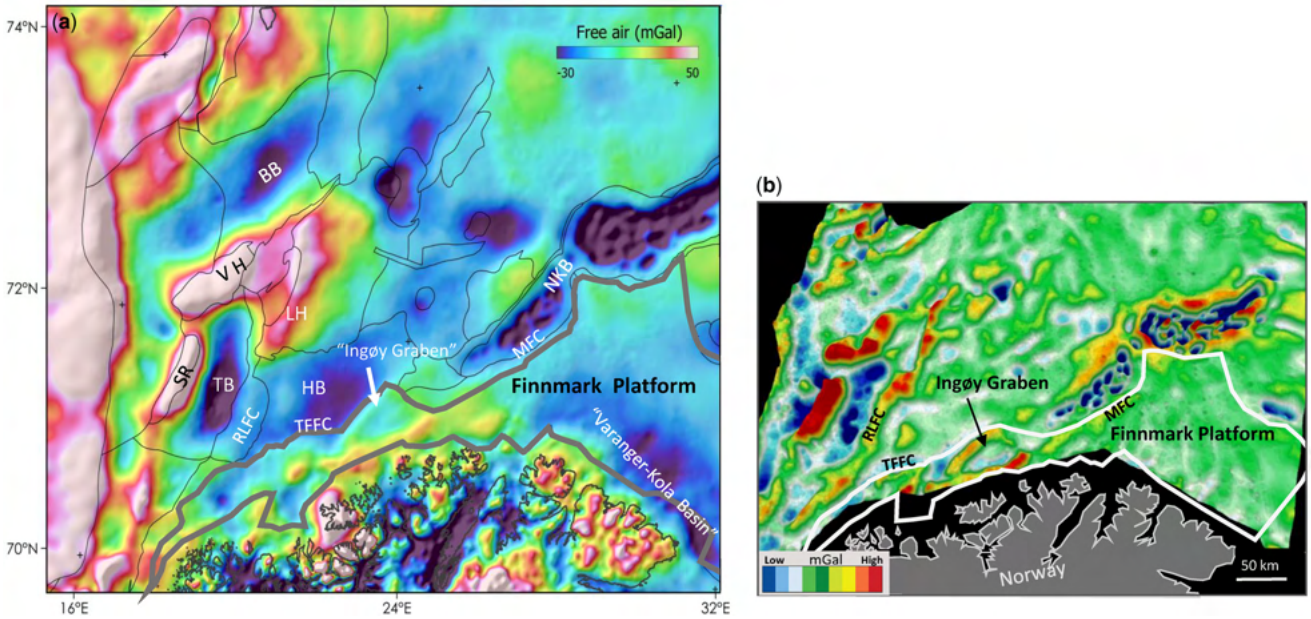

Fig. 8. Gravimetric maps. Free-air anomalies with (**a**) 200 km and Bouger anomalies (**b**) 100 km filters over the SW Barents Sea, showing internal structural elements on the Finnmark Platform represented by gravimetric lows. To the east, on the regional map (a), a potential sedimentary basin is observed (informally called the Varanger–Kola Basin). It follows the land contour from the Varanger Peninsula to the Kola Peninsula. Farther west, a distinct low can be seen, in particular on the close-up map, informally called Ingøy Graben. The gravimetric data are courtesy of NGU and TGS. BB, Bjørnøya Basin; HB, Hammerfest Basin; LH, Loppa High; MFC, Måsøy Fault Complex; NKB, Nordkapp Basin; RLFC, Ringvassøy–Loppa Fault Complex; SR, Senja Ridge; TB, Tromsø Basin; TFFC, Troms–Finnmark Fault Complex; VH, Veslemøy High.

the Ingøy Graben, is evident along the flank of the Finnmark Platform (Fig. 8b). Thick siliciclastic-dominated sequences (Figs 9–12) developed in graben and half-graben at a more local scale on the Finnmark Platform. This is also described by Gudlaugsson *et al.* (1998) and Johansen *et al.* (1993).

Reactivation of faults took place in latest Visean–Serpukhovian/Bashkirian time with thickening of the sequences in local half-graben (Figs 9 & 10). Dolerite dykes mapped in eastern Finnmark and onshore Magerøy (Roberts *et al.* 1991; Lippard and Prestvik 1997; Roberts 2003, 2011) gave both Devonian and Carboniferous ages. The 340–266 Ma Carboniferous intrusions (Nasuti *et al.* 2015) and the confirmation of Carboniferous mafic intrusions from offshore drilling on the Loppa High CTSE dated at 342 Ma (Brunstad and Rønnevik 2022) fit very well with a period of rifting in Visean–Serpukhovian time predating a major Carboniferous unconformity (Fig. 10). Evidence of different diagenetic processes observed in wells offshore (Henriksen *et al.* 2011*b*) may indicate a magmatic influence in the earliest Carboniferous. Excellent magnetic data presented by Nasuti *et al.* (2015) clearly show the outline of dolerite swarms along Finnmark County. Fluorspar encountered in the IKU shallow core 7029/03-U-02 support hydrothermal activity in the area. Intrusive bodies on the Finnmark Platform CTSE could have raised the heat flow locally and thereby influenced the reservoir quality.

The tectonic activity ceased in upper Carboniferous–Permian time. An overall marine transgression occurred, and a carbonate platform developed. As the northern margin of Pangaea drifted northwards, a dramatic change towards a cooler climate took place in the Late Permian (Stemmerik 2000). This is documented by a major change in deposition from carbonates and siliceous sponges to siliciclastic rocks, with the Ural Mountains and the Fennoscandian Shield as provenance areas. Only a few signs of compression are seen

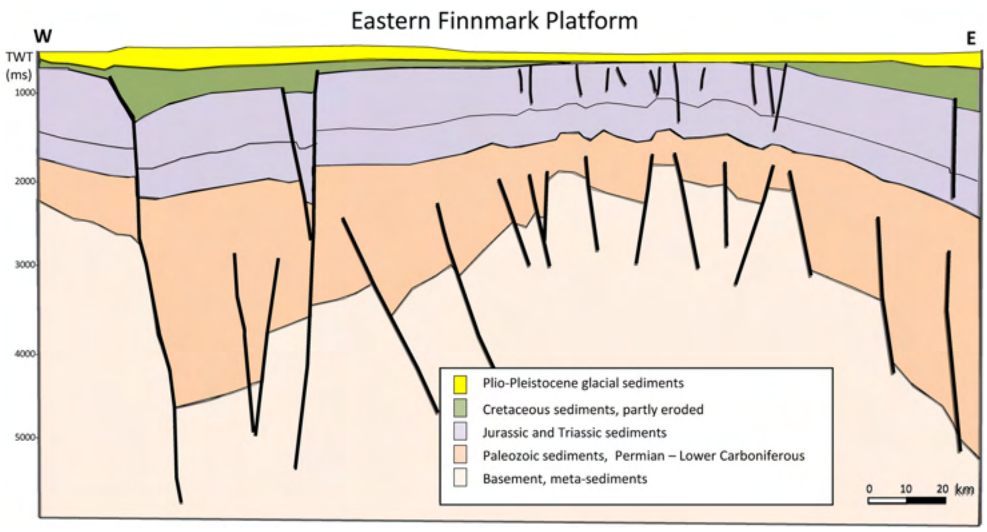

Fig. 9. Geoseismic east–west profile across the eastern Finnmark Platform. Three distinct tectonic phases can be observed: (1) basement-involved faults of Middle Carboniferous rifting, they control significant local thickness increases; (2) Upper Jurassic faulting; and (3) Late Cenozoic isostatic uplift and erosion that formed the Upper Regional Unconformity (URU) at the base of Late (Plio-Pleistocene). For the locations, see Figure 1. TWT, two-way time.

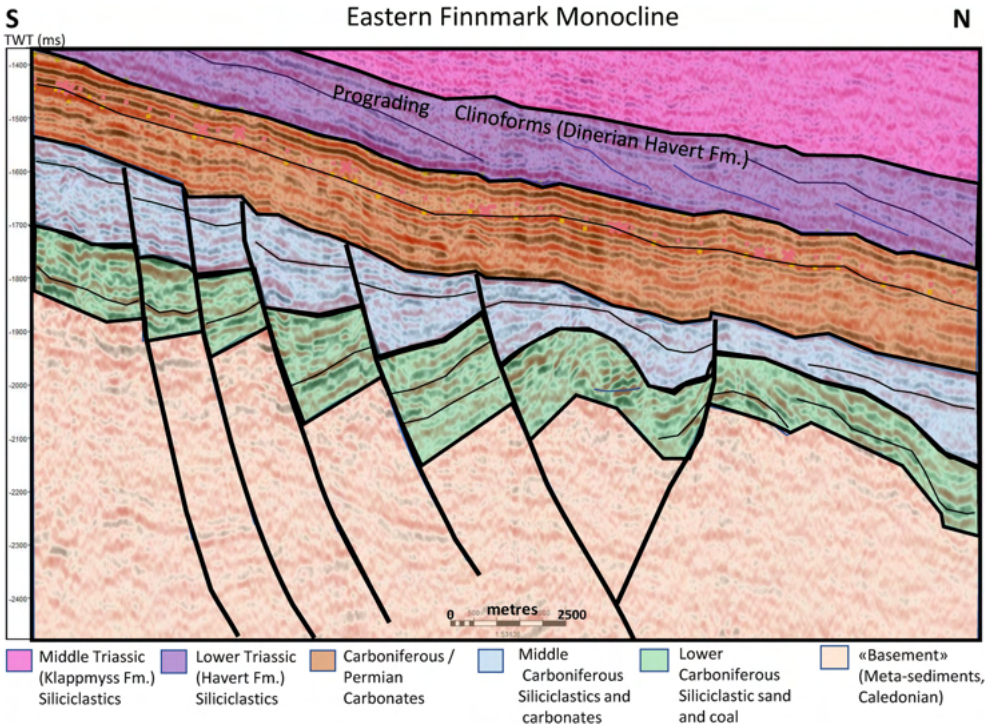

Fig. 10. Seismic section showing the Paleozoic and Lower Triassic sections, Carboniferous faulting, and the development of half-graben systems. 100 m of reservoir sand is proven at the base of the Visean interval. The Middle Carboniferous–Upper Permian planar sub-parallel reflection represents a carbonate platform. On top of the carbonate rocks, Triassic clinoforms represent silty–sandy sediments prograded towards the north. For the locations, see Figure 1. TWT, two-way time.

on the seismic sections at the Finnmark Platform as minor domal features in the Triassic interval.

The Triassic is characterized by a quiet tectonic period in the area. A response to the Uralides further to the east and local uplift of the Norwegian mainland to the south resulted in marine and terrestrial transport of sediments towards the WNW.

The eastern Finnmark Platform was little affected by Upper Jurassic–Lower Cretaceous rifting, and only small extensional faults are observed. In the western area, however, Late Jurassic rifting is manifested in the adjacent Harstad, Tromsø and Hammerfest rift basins (Fig. 1). Due to the opening of the Canadian basin and the oblique rifting of the northern Atlantic, local compressional and transpressional events are suggested along the margin (Kairanov *et al.* 2021).

Uplift and exhumation of the entire Barents Sea represented the major event of the Cenozoic. The timing and amount of uplift have been the subject of intense discussions based on different methods and approaches, and have been considered in many papers over the last few decades (Doré 1991; Doré

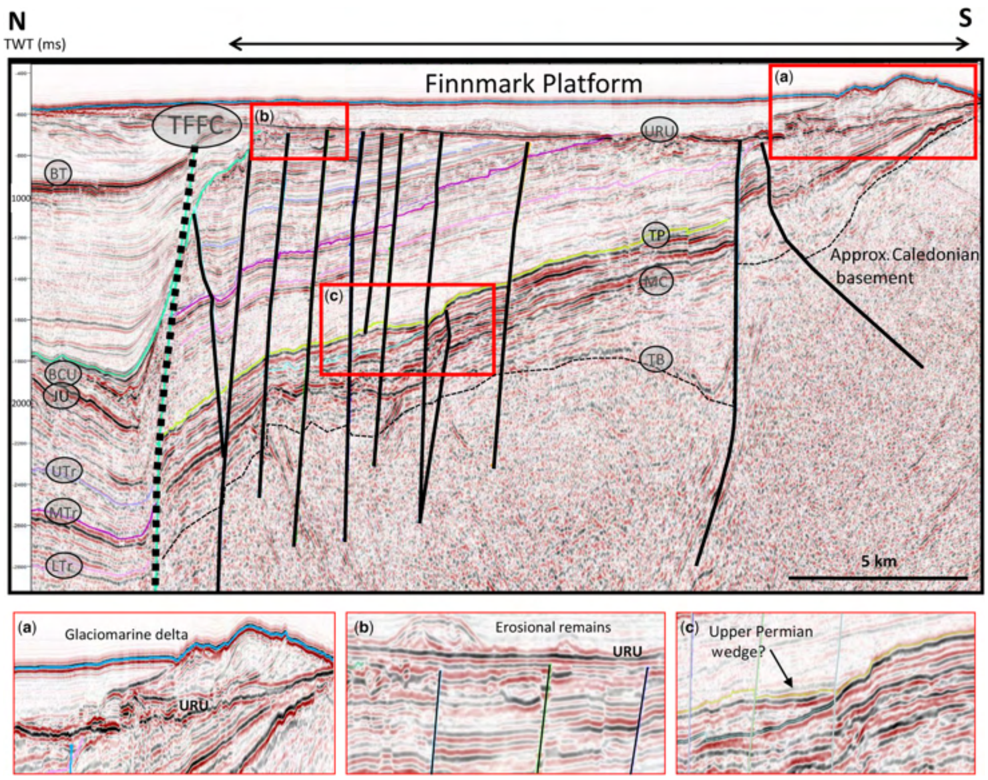

Fig. 11. Seismic section showing the Troms–Finnmark Fault Complex (TFFC), which represents the transition between the Finnmark Platform CTSE and the Hammerfest Basin CTSE. Note the major updip truncation of older sedimentary sequences below the URU. The bold dotted line represents the major TFFC. The minor dotted line represents the Top Basement (TB). Abbreviations in the grey circles are main seismic reflectors: TB, Top Basement; MC, Middle Carboniferous; TP, Top Permian; LTr, Lower Triassic; MTr, Middle Triassic; UTr, Upper Triassic; JU, Jurassic; BCU, Base Cretaceous Unconformity; BT, Base Tertiary; URU, Upper Regional Unconformity. Close-up (**a**) shows the URU in detail and the glaciomarine delta. Close-up (**b**) shows the erosional remains from glacial activity. Close-up (**c**) indicates the development of an Upper Permian fan system onlapping the platform towards the south. For the locations, see Figure 1. TWT, two-way time.

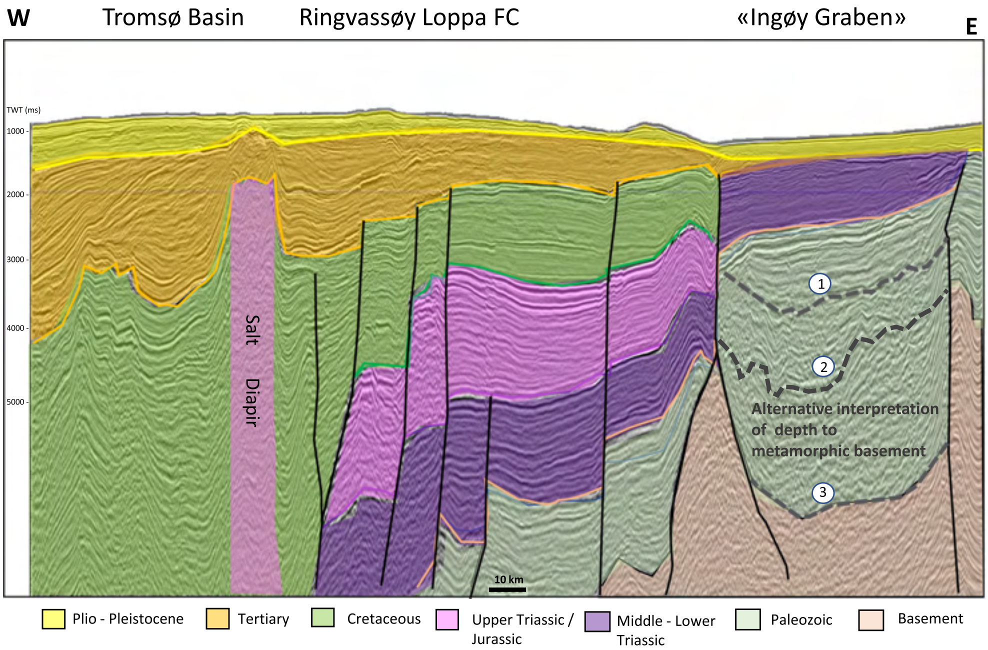

Fig. 12. Seismic profile in the transition between the Finnmark Platform and the Tromsø Basin. To the east, an increased thickness of Carboniferous sediments may be present in the Ingøy Graben. Note how progressively younger sequences appear towards the west. For the locations, see Figure 1. TWT, two-way time.

et al. 2002; Vorren *et al.* 1991; Nyland *et al.* 1992; Riis and Fjeldskaar 1992; Doré and Jensen 1996; Richardsen *et al.* 1993; Henriksen *et al.* 2011*a*; Ktenas *et al.* 2017, 2019; Amantov and Fjeldskaar 2018; Doré *et al.* 2021; Lasabuda *et al.* 2021; Drachev *et al.* 2022). It seems that several episodes related to the opening of the Atlantic Ocean and the glacial episodes affected the platform in different ways. The early Cenozoic, Paleogene, extensional faulting (Eocene) reactivated the Mesozoic fault pattern (Fig. 1). Shear movements and compressional tectonics resulted from the change in the spreading axis in the Atlantic Ocean at magnetic anomaly 13 (Oligocene). The latest Plio-Pleistocene glacial event, however, seems to have had a major impact on the regional tilt and massive erosion of pre-glacial units of the entire platform and the Norwegian mainland (Figs 3 & 11).

Underlying and overlying assemblages

Age of underlying basement or youngest underlying sedimentary unit

The CTSE rests unconformable on Neoproterozoic rocks deformed to various degrees during the Caledonian Orogeny in Silurian–Early Devonian time (Enclosure D). On top of the 3002–2900 Ma Archean crystalline basement observed in the Kirkenes area located in the southern part of the Varangerfjord (Fig. 5) (Siedlecka and Nordgulen 1996; Nystuen 2008) and the Lakselv area (Setså 2019), different basement types exist. A compilation of relevant studies was published in Corfu *et al.* (2014). In the west, the metamorphic basement (gneiss) is dominant as a result of the Caledonian Orogeny (420–400 Ma). However, windows of older Neoproterozoic deformed rocks are identified locally (e.g. dolomites of the Tanafjord Group, middle allochthon in the Lakselv area) (Fig. 6b). The Caledonian metamorphic basement has been encountered by offshore wells 7128/4-1, 7128/6-1 and 7226/11-1 (see above).

Age of the oldest overlying sedimentary unit

In most places, the Cenozoic sediments are lacking due to late glacial erosion, and the Finnmark Platform CTSE is overlain by 50–200 m-thick lenses of Plio-Pleistocene glaciomarine sediments (Figs 3, 11 & 12). Characteristic morphological features seen on high-resolution bathymetric maps clearly indicate deposition of end moraines (Vorren *et al.* 1991; Andreassen and Winsborrow 2009; Laberg *et al.* 2012; Bellwald *et al.* 2019). High-quality seismic data resolve many characteristic details of the glacial and glacimarine sediments (Fig. 11).

Subdivision and internal structure

The structure of the platform interiors is shaped by extensional faults that define half-graben and conjugated horst, as well as tilted monocline segments (Figs 9–12). Anomalous gravity field data allow major structural elements and trends within sedimentary basins to be defined. Based on these data (Fig. 8; Enclosures C and E), internal structures within the Finnmark Platform CTSE are defined as sets of local anomalies. Two distinct gravity lows stand out:

1. To the east, on the Norwegian–Russian border, a gravity low may correspond to a deeper basin, probably a westerly extension of lower Carboniferous and possibly Devonian structural trend in the Taman–Pechora province (Prishchepa *et al.* 2021). Informally this has been named as the Varanger–Kola Basin (Fig. 8). Separation of Carboniferous sediments from older Devonian–Neoproterozoic sediments in the area is very uncertain.
2. In the western part of the Finnmark Platform, a gravity low corresponds to a WSW–ENE graben of Paleozoic age informally named the Ingøy Graben after the nearest island (Figs 8 & 12). The structure may coincide with what has previously been described as the Gjessvær Low (Johansen *et al.* 1994). The age and the thickness of the sediments in the graben are uncertain. Gernigon *et al.* (2014) suggested a much shallower basement compared to a deeper basement shown as the 'deeper alternative' in Figure 12. Based on the structural trend, similar to that of the Nordkapp Basin farther to the east and the Carboniferous structure trends described by Faleide *et al.* (2008) and Gudlaugsson *et al.* (1998), it is assumed that the Ingøy Graben is part of the same Carboniferous rift system. Although there are limited data in the SW part of the Finnmark Platform CTSE, there are indications of several minor basins in the platform interior.

In the far SW, the Finnmark Platform area is affected by the Ringvassøy–Loppa Fault Complex, which merges with the Troms–Finnmark Fault Complex at the boundary between the Tromsø Basin and the Harstad Basin.

Sedimentary fill

Total thickness

Due to the monoclinal dip of the platform area, the sediment thickness varies considerably from 0 along the basement cropline to 10 km estimated by gravity modelling (Klitzke *et al.* 2015; Smelror *et al.* 2009; Faleide *et al.* 2018). Exhumation and uplift of the Norwegian mainland resulted in a regional tilt of the platform, and deep erosion down to the metamorphic basement. Consequently, in the southern areas, no sediment exists below the Quaternary cover. Towards the north, the sediment thickness increases. Wells 7128/4-1 and 7128/6-1 encountered metamorphic basement at 2526 and 2540 m, respectively. In other parts of the platform, the sediment thickness is less, except in the Varanger Kola Basin and the Ingøy Graben, which potentially contain thicker sediment packages. Gravimetric studies (Smelror *et al.* 2009; Gernigon *et al.* 2011, 2014) indicate around 4 km thickness in the southern platform area, and as much as 10 km to 'basement' in the NE part of the platform. Seismic data confirm a much thicker sediment package in the NE area, and well 7229/11-1 reached the Upper Carboniferous at 4630 m.

Lithostratigraphy/seismic stratigraphy

The general lithostratigraphy of the Finnmark Platform has been described by a number of authors (Di Lucia *et al.* 2017; Gerard and Buhrig 1990; Nilsen *et al.* 1993; Larssen *et al.* 2002; Smelror *et al.* 2009; Henriksen *et al.* 2011*a*, *b*; Stoupakova *et al.* 2011; NPD 2020). Extensive coring of deep wells 7128/4-1 and 7228/6-1 gave valuable information on the stratigraphy down to the metamorphic basement. Based on these data and comprehensive seismic interpretation, the lithostratigraphy (Fig. 2) of the Finnmark CTSE is described.

Lower–Middle Carboniferous TSE. The lowermost unit of Visean–Serpukhovian age is characterized by rotated high-amplitude reflectors representing thick (300 m) sandy and coaly sequences. Based on wells 7128/4-1 and 7128/6-1, and the IKU shallow boreholes, the Lower Visean succession of the Billefjorden Group consists of thick fine- to coarse-grained fluvial, alluvial and lacustrine sediments (Ehrenberg *et al.* 1998*a*, *b*; Larssen *et al.* 2002; Smelror *et al.* 2009; Henriksen *et al.* 2011*b*), most likely derived from the erosion and redeposition of Neoproterozoic rocks. Characteristic seismic amplitudes on top of the Visean sandstones represent an interval of interbedded coal, shale and silt.

Middle Carboniferous–Jurassic post-rift TSE. The megasequence contains a mixture of different lithologies deposited in different climatic and depositional environments. A well-defined seismic marker, the Middle Carboniferous Unconformity, represents the transition from the lower sandy–coaly unit to the overlying marine shale and the alternation of evaporites and carbonate depositions. High-frequency alternation proves rapid sea-level changes in the Upper Carboniferous–Lower Permian interval. A distinct seismic package seen on the platform-margin area and farther to the north represents a thick evaporite sequence. The sequence is penetrated by wells 7228/9-1 and 7229/11-1, and was previously mapped and described by Gerard and Buhrig (1990), Nilsen *et al.* (1993), Samuelsberg *et al.* (2003), Colpaert *et al.* (2007) and Rafaelsen *et al.* (2008). In the inner platform area, the sequence thins. In wells 7128/4-1, 7128/6-1 and 7130/4-1, only a few metres of anhydrite were present.

The Gzhelian–Sakmarian interval of the Ørn Formation (Gipsdalen Group) drilled by wells 7128/4-1 and 7128/6-1 encountered an approximately 100 m-thick succession of partly dolomitized phylloid–*Palaeoaplysina* algal build-ups interbedded with lagoonal sabkha facies.

In the basinal setting, parallel high-amplitude reflectors represent carbonate mud. On the structural highs, discontinuous reflectors outline thick carbonate build-up trends. On top of the succession, a thin unit of cherty spiculites exists (Figs 13 & 14). The transition between Permian carbonates and Triassic siliciclastic rocks is characterized by a very-high-amplitude reflector.

The Lower–Upper Triassic section has been previously described by Mørk (1999), Sollid *et al.* (2003), Hadler-Jacobsen *et al.* (2005), Glørstad-Clark *et al.* (2010), Henriksen *et al.* (2011*b*), Eide *et al.* (2018) and references therein. The

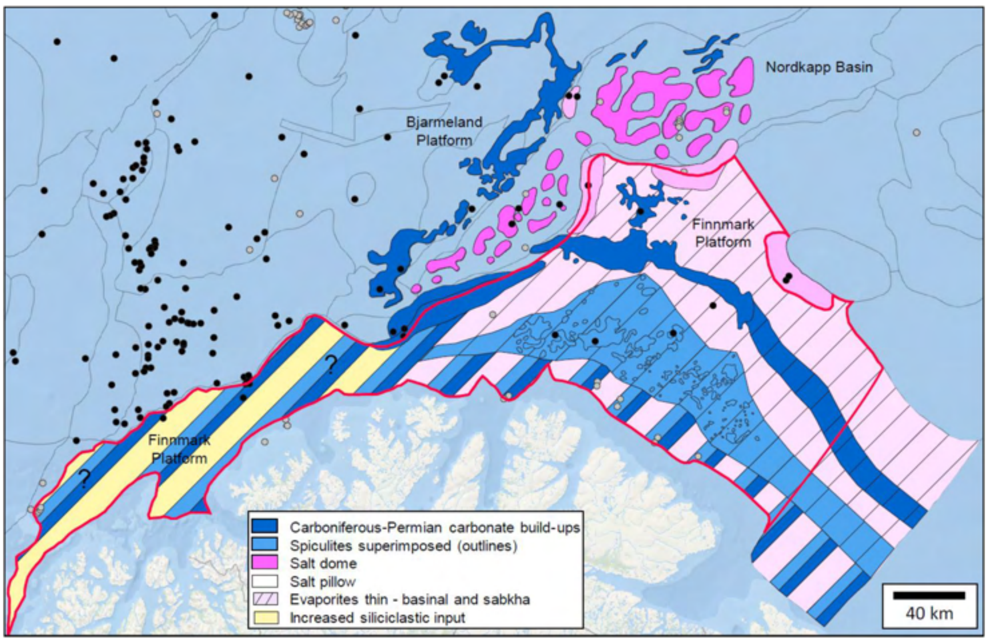

Fig. 13. Palaeogeography of the Middle Carboniferous–top Permian carbonate succession. Extension of carbonate build-ups, evaporites, spiculites and sandstones. A compilation of our own seismic mapping and published data from Gerard and Buhrig (1990), Nilsen *et al.* (1993) and Ehrenberg (2004).

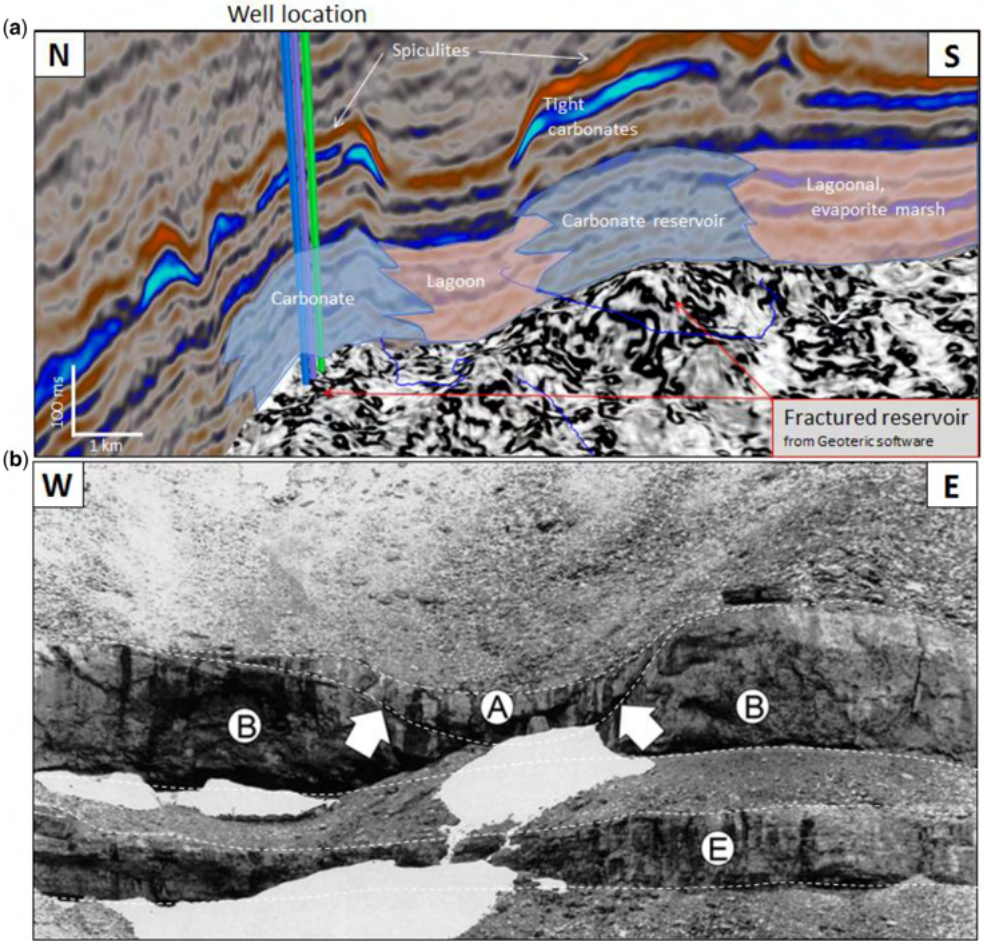

Fig. 14. Detailed seismic image (**a**) and field analogue from Svalbard (**b**) of the stacked tabular carbonate build-ups. Amplitude variations represent a change in lithologies and porosities in the carbonate and spiculite sections. A fracture pattern in the carbonate is shown at the base of (a). B and E represent carbonate build-up facies. A represent lagoonal facies (b) is modified from Hanken and Nielsen (2013). For the location, see Figure 1.

interval includes the Havert, Klappmyss, Kobbe and Snadd formations of Induan–Norian age. Triassic progradational sequences started to develop above the Paleozoic succession as a result of a colder climate and increased input of siliciclastic material. The Anisian interval, represented by the Kobbe Formation (Sassendalen Group), consists of both marine reservoir sands, as seen in the Goliat Field and in platform well 7122/10-1, and anoxic mudstones proven in wells next to the Finnmark Platform.

The Upper Triassic sandy interval grades into Jurassic marginal-marine sands that show low–moderate amplitudes on the seismic data. The interval is represented by the Realgrunnen Group, including the Fruholmen, Tubåen, Nordmela and Stø formations of Norian–Bathonian age.

Upper Jurassic–Lower Cretaceous synrift TSE. A distinct seismic marker at the top of the Jurassic sand corresponds to the top of the organic-rich shale of the Hekkingen Formation in the Upper Jurassic section. This Base Cretaceous marker represents a major unconformity frequently used for the construction of regional depth–structure maps. The organic-rich shale is mostly absent on the Finnmark Platform. The shaly sequence, with potential thin sandbodies interbedded, is limited to the northern, less eroded, part of the platform. Most of the platform area to the SW acted as provenance to sediments deposited in the neighbouring basins.

Cretaceous post-rift sag TSE. Low-angle clinoforms of Lower–Middle Cretaceous are dipping and onlapping the Base Cretaceous Unconformity towards the south. The gentle dipping clinoforms indicate a shaly sequence with a provenance area towards the north. A thin unit (12 m) of Hauterivian carbonate was observed at the bottom of the shaly interval in well 7229/11. The sequence is only present in the NE part of the platform, with a thickness of up to 1000 m.

Paleocene–Eocene pre-rift TSE. In a limited area in the northern part of the Finnmark Platform CTSE, thin Paleocene lenses of bathyal mudstone sequences are present on top of the Base Tertiary Unconformity. These sequences can be seen as parallel low-amplitude reflectors, confirming a low energetic depositional environment.

Depositional environment and provenance

An approximately 100 m-thick coaly sequence developed over most of the inner platform area on top of the Visean reservoir sandstones, proving a terrestrial depositional environment. Towards the north, the sedimentary environment is more uncertain, although a similar depositional environment is expected and documented on Svalbard.

Towards the Middle Carboniferous Unconformity there was an increased onset of marine environments, and lenses of carbonates (Bugge *et al.* 1995) alternating with sandstones and claystones have accumulated above the coaly sequence. A gradual deepening of the area is assumed, and IKU core 7029/03-U-02 documents a late Visean transgression. Further to the east, in the Timan–Pechora Basin, a transgressive event took place in early–late Visean times with carbonate deposition (Ulmishek 1982; Prishchepa *et al.* 2021). In the following Visean regressive event, marine carbonates, black shales and coastal-plain deposits in the Tettegras and Blærerot formations of the Billefjorden Group were deposited (Stemmerik and Worsley 1989, 2005; Gerard and Buhrig 1990; Nilsen *et al.* 1993; Bugge *et al.* 1995; Ehrenberg *et al.* 1998*a*, *b*; Larssen *et al.* 2002; Hanken and Nielsen 2013).

A massive carbonate sequence developed in the eastern Finnmark Platform from the Bashkirian–Moscovian to the Late Permian (Figs 2, 13 & 14). Carbonates of the Middle–Upper Carboniferous succession were deposited in a tectonically quiet period in a shallow platform shelf environment (Stemmerik and Worsley 1989; Larssen *et al.* 2002; Lønøy 1988; Smelror *et al.* 2009; Henriksen *et al.* 2011*b*). The Carboniferous warm-water carbonates of the Gipsdalen Group developed as stacked low-relief *Palaeoaplysina*–phylloid algal mats combined with crinoids and brachiopods. A platform margin started to develop in the NE part, separating the build-up facies from the laminated evaporites that increased in thickness further north towards the Nordkapp Basin (Fig. 13). The high-frequency eustatic sea-level changes that occurred during the deposition of the carbonate and evaporite sections is believed to be related to glaciations in other continents (Elvebakk *et al.* 1990; Ehrenberg *et al.* 1998*a*; Stemmerik *et al.* 1999; Nilsen *et al.* 1993; Stemmerik and Worsley 2005; Stemmerik 2008; Hanken and Nielsen 2013). Onshore analogues on Svalbard support the seismically mapped elongated ridges, ring-shaped to polygonal carbonate build-up complexes encircling lagoonal environments encountered offshore, with their distribution predominantly controlled by faults and the underlying topography in a context of climate and sea-level fluctuations (Rafaelsen *et al.* 2008; Hanken and Nielsen 2013).

A major change in climate occurred in Artinskian time with the deposition of thick cool-water carbonates (Bjarmeland Group) with abundant bryozoans, tubiphytes and brachiopods. This graded into cherty sediment (Ehrenberg *et al.* 2001) with a dominance of sponge spicules of the Røye Formation and marine shales of the Ørret Formation (Tempelfjorden Group) in the latest Permian (Fig. 14). In the SW narrow part of the Finnmark Platform TSE, it appears that siliciclastic input was more frequent, with interbedded siliciclastic and carbonate units, in Carboniferous–Permian time.

The general depositional environment varied from shallow-marine conditions, marine shelf to shoreface in the lower Triassic to tidal-flat estuarine–coastal plain deposits in the Upper Snadd Formation of Carnian age. The Uralian mountain range represented an important provenance for the Triassic depositional sequences further west in the Barents Sea (Ritzmann and Faleide 2007; Sømme *et al.* 2018; Doré *et al.* 2021). After the mass extinction and climate change at the Permian–Triassic transition (Stemmerik 2000; Vigran *et al.* 2014; Uchman *et al.* 2016), a distinct progradational marine sequence in the Lower Triassic interval (Havert Formation of the Sassendalen Group) developed with the main provenance area from the Norwegian mainland. Silty sediment and mature clean sandbodies 60–80 m thick (wells 7128/4-1 and 7128/6-1) developed on the shelf (Henriksen *et al.* 2011*b*). The progradational direction indicates fan systems sourced from the south (Fig. 15). Eide *et al.* (2018) suggested an extension of the Tana palaeoriver system as the source of the fluvial, shallow-marine and turbidite fan sediments on the platform area. Based on detailed mapping, several entry points for lower Triassic fan deposits are found along the palaeoshelf.

In the Upper Triassic, more sand was transported into the area through a widespread network of fluvial channels. These channels can in places be easily detected by high-resolution 3D seismic.

A gradual change from prodelta, delta plain to fluvial depositional environment took place from Olenekian to Carnian time. The Carnian sequence, deposited in fluvial, tidal and coastal-plain environments (Henriksen *et al.* 2011*b*), also

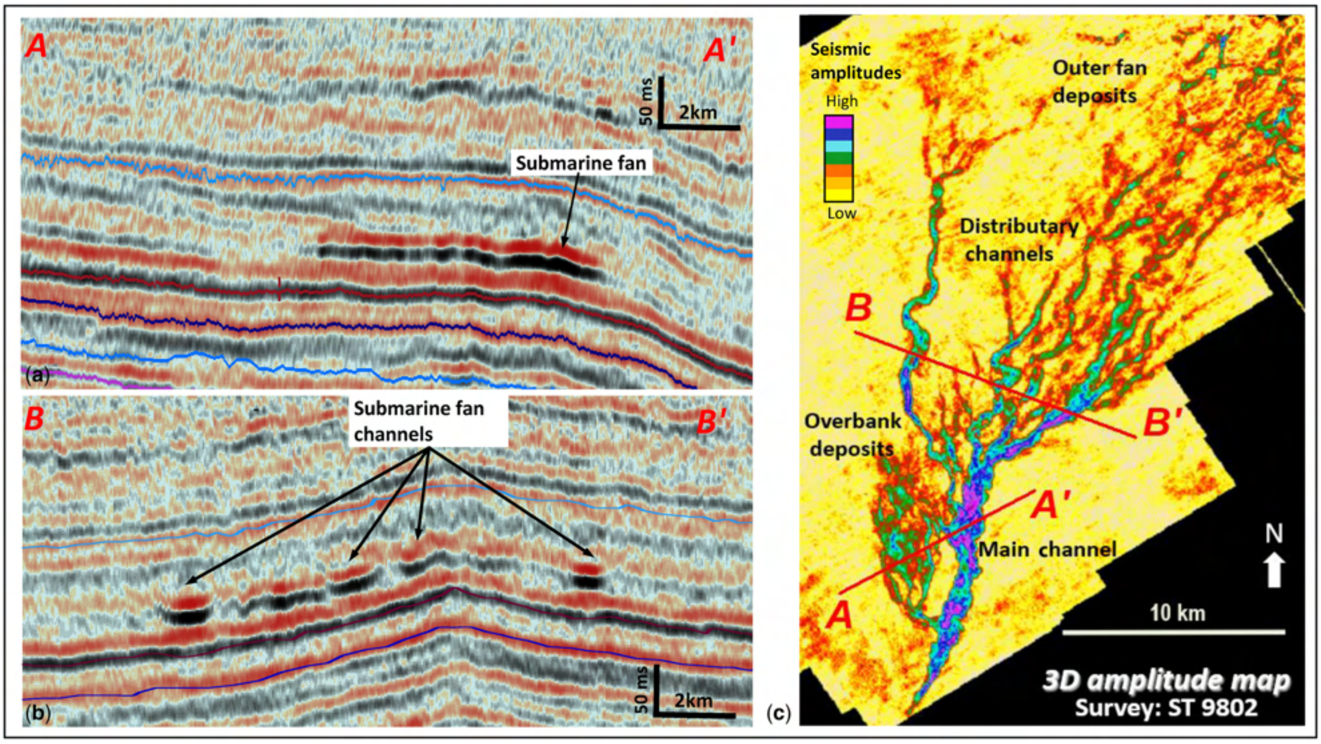

Fig. 15. Lower Triassic delta fan prograding from the Norwegian mainland. High amplitude (acoustic impedance) in the toes of the clinoforms represents submarine sandy channels (**a**), (**b**) and (**c**). Submarine fans were deposited towards the north (c). The channel–fan system was originally discovered in 1998 by Nicholas Ashton, Statoil exploration team, and later published by Hadler-Jacobsen *et al.* (2005), Eide *et al.* (2018) and presented by Henriksen (2009). Such clear seismic imaging of depositional features contributes to valuable information of the hydrocarbon plays existing on the Finnmark Platform. For the location of the seismic, see Figure 1.

shows characteristic anomalies on seismic sections, confirming the fluvial-dominated environment at a regional scale (Henriksen *et al.* 2018).

The Upper Triassic and Jurassic section contain the most important reservoirs of the Norwegian shelf, deposited in shoreface to marine-shelf environments. Increased tectonic activity in the Late Jurassic changed the basin configuration (Gabrielsen *et al.* 1990; Dengo and Røssland 1992), and a more restrictive depositional environment resulted in the deposition of the Upper Jurassic (Kimmeridgian–Ryazanian) Hekkingen Formation organic-rich shale. Most of the Upper Triassic–Lower Cretaceous sequences are absent on the Finnmark Platform mainly due to later erosion (Figs 3, 11 & 12).

Due to a general deepening of the shelf and exhumation of the Barents Shelf towards the north (Worsley 2008), low-angle deep-marine progradational Lower–Middle Cretaceous sequences, as observed in well 7229/11-1, onlapped the underlying sequences on the Finnmark Platform. A stable provenance area to the NE is demonstrated by Marín *et al.* (2018).

Magmatism

Several generations of intrusions of Neoproterozoic age (580–560 Ma: Seiland Igneous Province) and Paleozoic (355 Ma and perhaps even younger) are observed onshore (Siedlecka 1975; Lippard and Prestvik 1997; Roberts 2003, 2011). There is no direct evidence for magmatic activity on the Finnmark Platform. However, dolerite intrusions of Neoproterozoic and Paleozoic age are observed onshore on Varanger Peninsula (Siedlecka and Nordgulen 1996) and on the Magerøya in the west (Corfu *et al.* 2006; Roberts 2011; Roberts *et al.* 2011; Zhang *et al.* 2016) (Fig. 5). These may have affected the rocks of the Finnmark Platform CTSE. On the Loppa High, a mafic intrusion was drilled and dated to 342 Ma (Brunstad and Rønnevik 2022). Different diagenesis of reservoirs observed on structures of similar origin and depth indicate the influence of high temperatures in some areas.

Heat flow

The heat flow varies considerably in the Barents Sea, from extreme maxima of 1000 mW m^{-2} in the NW area with oceanic crust to 60 ± 10 mW m^{-2} on the platform areas measured in IKU shallow stratigraphic wells (Smelror *et al.* 2009). Wells on the Finnmark Platform indicate a temperature gradient of around 38°C km^{-1}. A general decrease from western to northwestern areas towards the east into Russian waters is observed (Henriksen *et al.* 2011*a*, *b*). Local variations may exist: for example, where the effects of salt domes and pillows in the Nordkapp Basin and along the margin of the Finnmark Platform (Fig. 13) may account for increased thermal conductivity and thereby impact source-rock maturation.

Petroleum geology

Major uncertainties exist regarding trap integrity due to the monoclinal nature of the Finnmark Platform. Several reservoir intervals of Paleozoic and Mesozoic ages have been identified as having hydrocarbon potential. Another major uncertainty for most of the platform areas is the access to a rich kitchen area with enough source-rock potential to charge the stratigraphic traps.

Discovered and potential petroleum resources

There are no commercial discoveries of hydrocarbons made in the Finnmark Platform CTSE. Exploration wells have tested several Carboniferous–Jurassic plays on the platform. Only minor hydrocarbon resources have been discovered and tested in the Upper Permian spiculitic chert play (oil and gas) and in the Lower Carboniferous Visean (gas) sandstone play. The spiculite discovery proved a stratigraphic trapping mechanism. The well 7128/4-1 discovery was tested, and produced minor gas and oil from the Paleozoic section. The tiny structural closure may contain 5–15 Mbbl recoverable oil equivalents, with an additional potential estimated to 50–100 Mbbl for the stratigraphic component. Many prospects and leads do exist on the platform (Fig. 13). Due to technical problems, production potential remains uncertain for the interval. Although undiscovered potential may exist, the exploration results have been disappointing.

Current exploration status

A total of seven exploration wells have been drilled on the Finnmark Platform, starting in 1984. The latest well was drilled in 2017, south of the Goliath Field. Extensive 2D and 3D seismic surveys of different vintages from the 1970s to 2018 were acquired. In the inner platform area, only parts of the CTSE are covered by seismic data due to governmental restrictions related to the regeneration of marine species. (Figs 1 & 4). The area of restriction limits the available exploration acreage to the south and additional limitations exist due to the restricted seasonal time window for the petroleum exploration.

There are currently no awarded exploration licences in the area of the Finnmark Platform CTSE. The SW part of the platform area acreage can be applied for in the yearly Award in Predefined Areas (APA) concession rounds. For the Eastern Finnmark Platform, application follows numbered rounds defined by the ministries (Four licence blocks were awarded in the 25th concession round in Norway, June 2021. Three of the awards are located in the Barents Sea. However, no areas awarded within the Finnmark platform.).

Hydrocarbon systems and plays

A summary of the petroleum plays observed in the eastern Finnmark Platform CTSE is presented in Figures 2 and 16.

Source rocks. The classical Upper Jurassic Hekkingen Formation source rocks are only present in the NE part of the Finnmark Platform. Due to a thin overburden, these rocks have never reached thermal maturity. Long-distance migration from the Tromsø Basin and Harstad Basin is the only possibility for sourcing hydrocarbons from the Hekkingen Formation. Potentially limited remigration from structures in the Hammerfest Basin may have occurred.

Potential local source rocks for charging the reservoirs are identified in the Carboniferous coaly–shaly sequence, in the carbonate bioclastic sequences of Carboniferous–Permian age and in the Lower–Middle Triassic (Fig. 17).

Hydrocarbon to source rock correlation indicates that the oil encountered in the Upper Permian spiculites in well 7128/4-1 and the oil shows in the same interval found in well 7128/6-1 have biomarker signatures, isotope values, Pr/Ph ratios and wax content suggesting a contribution from the Upper Permian source rock. However, traces of oil in the deeper carbonate sections of Gzhelian age show the same biomarker signature as in the Upper Permian spiculites, and thus may support

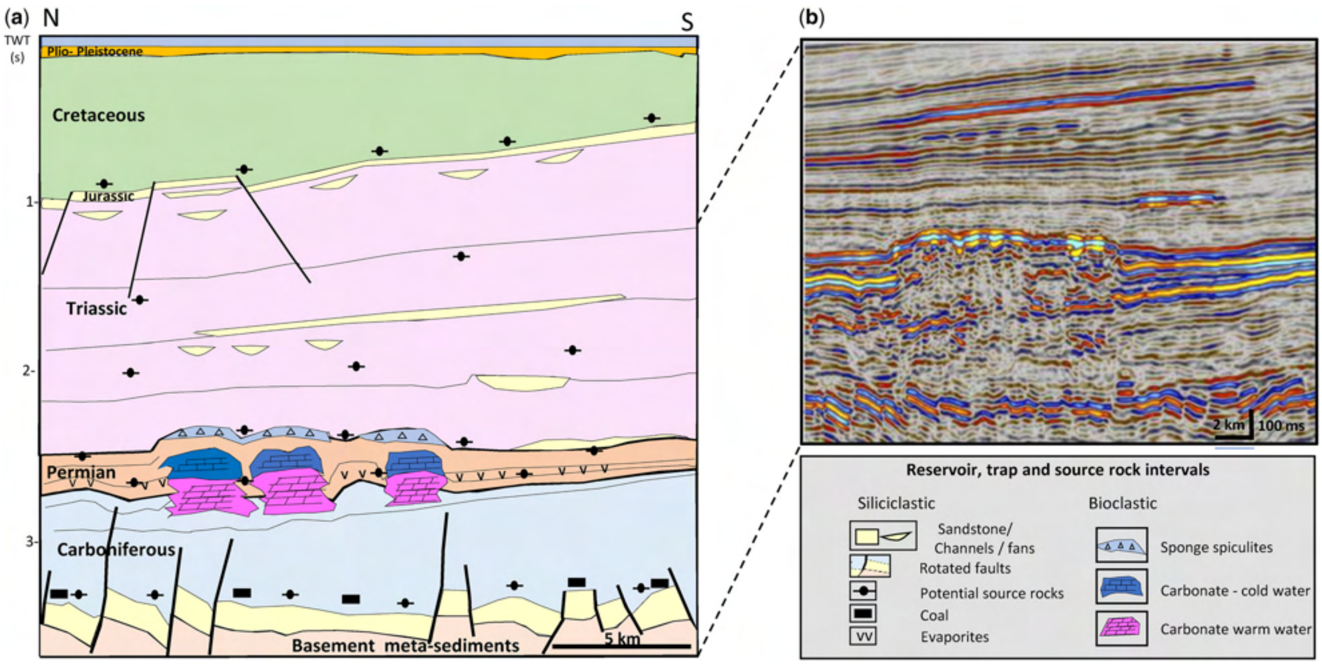

Fig. 16. Conceptual diagram (**a**) and a seismic example (**b**) showing potential plays in the Finnmark Platform CTSE. Reservoir intervals from basement to Middle Jurassic have been proven by drilling. TWT, two-way time.

deeper oil source rock units presently in the oil window (Fig. 17) (Ohm *et al.* 2008; Killops *et al.* 2014). Suggestions of oil source also include the Lower Carboniferous Tettegras coals and coaly shales, with a possible marine as well as lacustrine influence (Van Koeverden *et al.* 2010), or even Upper Devonian–Lower Carboniferous 'Domanik type' source rocks known in the Timan–Pechora Basin. The Varanger–Kola Basin (Fig. 8) may be a possible area for the preservation of Devonian sediments.

Gas discovered in well 7130/4-1, and tight gas seen in well 7128/4-1, clearly show that a deeper source rock is working. The most likely candidate is the 10–50 m-thick Lower Carboniferous (Visean) coaly–shaly unit within the 100–200 m-thick Tettegras Formation (Fig. 17) (Ohm *et al.* 2008). In

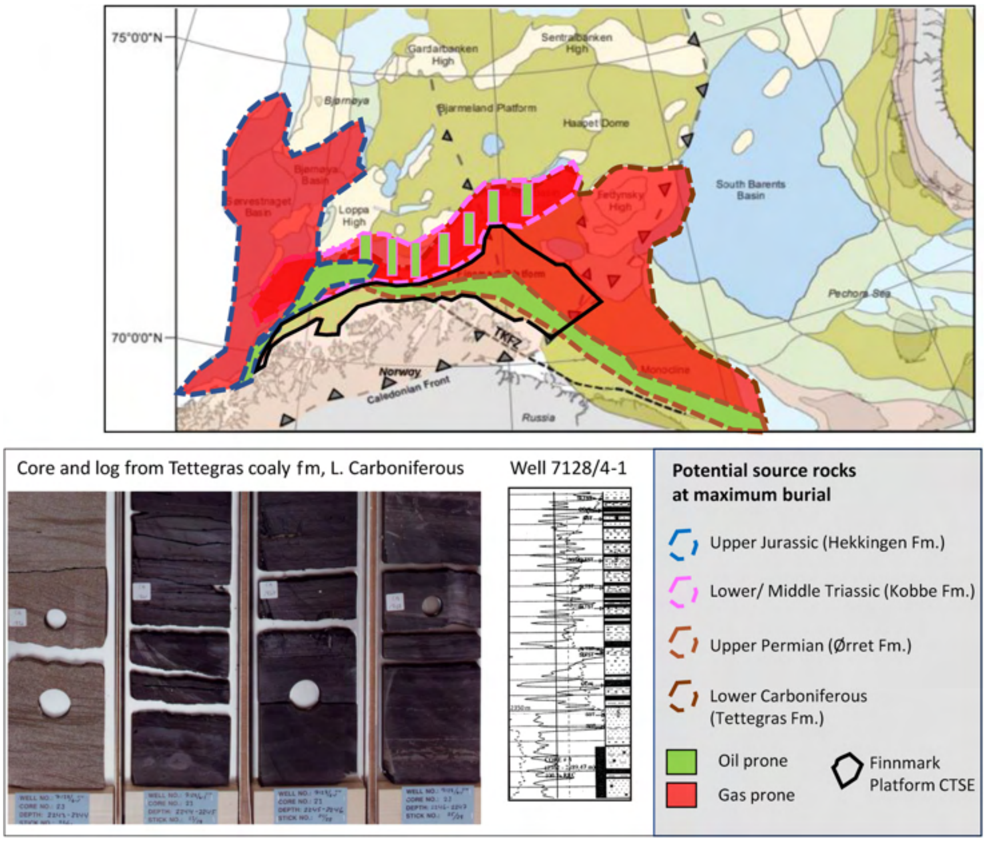

Fig. 17. Potential petroleum systems working in the Finnmark Platform and neighbouring areas. The Upper Jurassic interval is immature on the platform. Upper Permian shale, Lower Carboniferous coaly–shaly sequences or even deeper Devonian shales may be the most likely candidates for an early charge of the platform prospects and leads. TKFZ, Trollfjord–Komagelv Fault Zone.

the Ingøy Graben to the west (Figs 8 & 12), a potential source rock may have been developed in the graben area with restricted water circulation. Only the Lower Carboniferous Tettegras Formation is expected to be a candidate for significant oil and gas sourcing on the Finnmark Platform. In the western area of the Finnmark Platform CTSE, the charge from neighbouring basins is more likely, since the Upper Jurassic and Triassic source rocks are oil and gas mature in those areas, and the drainage distance to the Finnmark Platform is rather short.

Most of the discovered oils in the Hammerfest Basin area represent various mixtures of hydrocarbons that originate predominantly from a Late Jurassic Hekkingen source with minor contributions from older, probably Triassic, sources. Charging traps with pre-Jurassic reservoirs along the southern margin of the basin, like the Goliat Field and Tornerose discovery, probably resulted from long-distance migration predominantly of Triassic oils with a minor contribution from a Late Jurassic source (Ohm *et al.* 2008; Duran *et al.* 2013*a*, *b*; Killops *et al.* 2014). The area of the Finnmark Platform bounding the Hammerfest Basin to the south probably has to rely on charge by long-distance migration through the basin and/or from deeper, older proximal sources.

Due to the previous deeper burial depth of the Paleozoic succession, the oldest and deepest source rocks on the Finnmark Platform may have already started to generate petroleum in Permian–Triassic times. Potential intrusions, or longer-lived lithospheric processes in Carboniferous time, may have changed the geothermal gradient and petroleum generation locally (Henriksen *et al.* 2011*b*).

Reservoirs. Several reservoir intervals have been identified on the Finnmark Platform ranging from Carboniferous to Jurassic age (Fig. 16). In the shallow southern part of the platform, fractured basement may also act as reservoir rock.

Lower–Middle Carboniferous. Three conventional wells and shallow drillings have proven a rather good reservoir quality of sandstones in the Visean Soldogg Formation. The gross thickness of the sandstone reservoir unit in wells 7128/6-1 and 7128/4-1 is 130 and 100 m, respectively (Fig. 10). Thicker sandstone sequences are expected to be developed in half-graben areas (Ehrenberg *et al.* 1998*a*, *b*; Larssen *et al.* 2002; Henriksen *et al.* 2011*b*). Average porosities up to 17% and net/gross values of up to 60% have been recorded. However, the net/gross ratio may vary considerable laterally due to different diagenesis. Well 7128/6-1 penetrated 100 m of rather high-quality reservoir. At similar depth and 25 km away, well 7128/4-1 drilled completely tight and cemented sandstone of similar thickness. It is believed that the presence of intrusions or hydrothermal vents may have locally affected the area (Henriksen *et al.* 2011*b*). The Lower Carboniferous sandstone sequence is expected to exist over a large part of the platform. A minor gas discovery was made in well 7130/4-1, and tight gas was observed in well 7128/4-1.

Middle Carboniferous–Upper Permian. The Carbonate section ranges from Moscovian to Tatarian age. The upper section (Røye Formation, Ufimian–Kazanian age) is gradually more dominated by cherty–spiculitic rocks (Figs 2, 14 & 16). The main carbonate reservoir facies discovered so far is represented by low-relief amalgamated colonies of *Palaeoaplysina*–phylloid algal mounds. In well 7128/6-1, more than 400 m of cored Paleozoic section documents the reservoir potential (Nilsen *et al.* 1993; Bugge *et al.* 1995; Stemmerik *et al.* 1995; Ehrenberg *et al.* 1998*a*, *b*; Stemmerik 2000; Larssen *et al.* 2002; Samuelsberg *et al.* 2003; Nielsen *et al.* 2004; Colpaert *et al.* 2007; Rafaelsen *et al.* 2008; Henriksen *et al.* 2011*b*; Hanken and Nielsen 2013).

The best reservoir interval is represented by a 100 m zone of warm-water carbonates of Gzhelian–Sakmarian age (Middle Carboniferous–Lower Permian). Porosities of up to 30% and highest permeabilities of more than 500 mD were encountered. However, the reservoir parameters may vary considerably laterally due to different diagenesis and depositional environments. Both the shallow drilling (Elvebakk *et al.* 1990; Bugge *et al.* 1995) and the conventional wells (Ehrenberg *et al.* 1998*a*, *b*; Larssen *et al.* 2002; Ehrenberg 2004; Henriksen *et al.* 2011*b* and references therein) show that the reservoir is expected to exist over large areas.

The bryozoan carbonate build-up (Isbjørn and Polarrev formations of Artinskian–Kungurian age) has so far proved to be very tight with no reservoir quality (Fig. 14). The shape of the build-ups varies quite significantly, dependent on the water depths during deposition. The inner-shelf tabular build-ups are, due to limited accommodation space during deposition, sometimes hard to see on seismic data. Further north on the platform, a barrier build-up complex developed where the palaeowater depth allowed the build-up to grow. For the whole complex, only one well, 7229/11-1, penetrated the bryozoan build-up (Figs 3, 4 & 13).

The uppermost Permian reservoir interval is represented by the spiculitic section of the Røye Formation (Kazanian age). Three wells were drilled into the spiculite reservoir, and a small oil and gas discovery was made in a 20 m zone of moderate to good reservoir in well 7128/4-1. Well 7128/6-1 proved a 50 m reservoir zone with oil shows in the same interval. The average porosity of the spiculite reservoir is 22%, with permeabilities ranging from 35 to around 800 mD (Henriksen *et al.* 2011*b*).

Lower–Upper Triassic. On seismic data, a clear progradation with a Fennoscandian provenance is mapped in the lowermost Triassic (Havert Formation, Induan time). In wells 7128/4-1 and 7128/6-1, thick potential reservoir sands (60–80 m) were penetrated on top of the prograding clinoforms. Average porosities of around 17% are seen with net/gross values of around 0.6. Shaly and silty sequences were found within the clinoforms (Henriksen *et al.* 2011*b*). Eide *et al.* (2018) postulated that the sand distribution of a palaeo-Tana river system existed in earliest Triassic time. In eastern Finnmark, seismic data clearly indicate drainage patterns from the south, including complex channel systems and marine fan deposits (Figs 15 & 16). The channels found in several places along the eastern platform can easily be detected on attributes from 3D seismic data.

The Kobbe Formation (Anisian–Ladinian age) has generally proved to be a rather tight interval, with a silty–shaly development (reference to well 7229/11-1). However, in the Goliat Field, where a significant part of the production comes from the Kobbe Formation, it proved to be rather good (Klausen *et al.* 2018). Well 7122/10-1, which is located south of the Goliat Field on the Finnmark Platform, proved around 30 m of sandstones. This indicates that it might be productive to look for potential entry points for the sediments derived from the Norwegian mainland (Henriksen *et al.* 2018).

In the eastern part of the platform, well 7131/4-1 proved a giant fluvial point-bar system in the Snadd Formation of Carnian age (Henriksen *et al.* 2011*b*) with the presence of more than 40 m of high-quality reservoir sand. Porosities of up to 30% and permeabilities up to Darcy levels were proven. In the Snadd Formation, amalgamation of fluvial, tidal and coastal-plain sediments is dominant.

Upper Triassic–Jurassic. The Upper Triassic–Jurassic Realgrunnen Group deposits only exist in the NE part of the Finnmark Platform (Figs 3 & 16). The reservoir-quality sandstone (up 50 m thick, found at a depth of around 1250 m) was deposited in a shallow-marine to fluvial setting. Porosities range from around 20% up to 30%.

Cretaceous. No Cretaceous reservoir was found on the Finnmark Platform. Along the Troms–Finnmark Fault Complex, several fan systems derived from the Finnmark Platform do exist and may represent reservoir potential along the flanks.

Seals. A challenge for most of the plays defined on the Finnmark Platform is the monoclinal dip, which requires lithologically defined lateral seals (Figs 11, 15 & 16). The potential top seals for all reservoir zones are summarized in Figure 2. For the fractured basement and the Visean sandstones, the shales in the Tettegras Formation may represent the sealing lithology. At this level, lateral seals are not that critical due to structural closures. The Tettegras shale was proven in well 7130/4-1 with a minor gas discovery. Although proven in wells on the eastern Finnmark Platform, the regional extent and efficiency of the Visean shale is unclear.

In the Gzhelian–Sakmarian interval, tight carbonate rocks may represent the top seal. Sedimentary facies and diagenesis define the lateral seals within the carbonate system. Reservoir build-up facies, grading laterally into tight evaporite and lagoonal facies, are frequently observed in carbonates (Fig. 14).

A shaly sequence in the uppermost Permian contains the Røye Formation draping over the Upper Permian spiculite reservoir. Laterally, the wells have proved that the formation becomes tight moving away from the most exposed high-energy environments (Ehrenberg *et al.* 1998*a*, *b*; Henriksen *et al.* 2011*b*). The oil and gas discovery in well 7128/4-1 may have proved a lateral sealing mechanism in the spiculite play, which increases the exploration potential considerably.

For the Lower and Middle Triassic sandstones, shaly sequences have proved to work in the Hammerfest Basin (Goliat discovery) and the Nordkapp Basin (Dumbo discovery). Some of the sealing sequences were deposited in anoxic environments.

In the uppermost Triassic–Jurassic sequence, the Upper Jurassic anoxic Hekkingen Formation is the most obvious seal candidate where present. In addition, Cretaceous marine shale may have a good sealing potential. The upper shaly overbank deposits in the fluvial systems of the Upper Triassic also represent potential internal seals (Henriksen *et al.* 2011*b*).

Traps. Rifting and establishment of a horst and half-graben structural style in the basement and the Visean sequences have created numerous structural closures (Figs 9, 10, 11 & 16).

Due to a lack of structural closures, the carbonate and the spiculite plays are dependent on stratigraphic trapping towards the south. This may have been proven in the well 7128/4-1 discovery. However, the trapping mechanism remains a major uncertainty and risk for the carbonate and the spiculite plays.

Little structuring of the Lower–Upper Triassic section means that stratigraphic traps are required for this play to be valid. One of the most interesting stratigraphic leads in the Lower Triassic is still undrilled. Thanks to good seismic resolution, it is now possible to map out these sandbodies and sealing lithologies in detail (Fig. 15).

The Jurassic sequence is only present and potentially prospective on the NE part of the Finnmark Platform CTSE and transitions to the Harstad Basin in the south. In the east, the sequence is faulted and low-relief structures have developed. The Hekkingen Formation represents a good seal for the structure. In all these areas, the migration pathways into the structures may represent a major uncertainty.

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Data availability The data that support the findings of this study are available from North Energy ASA but restrictions apply to part of the study and the availability of these data, which were used under licence for the current study and so are partly not publicly available. Data can be made available from the authors upon reasonable request and with permission of North Energy ASA, Henriksen Maritime Consultancy AS, NPD, NGU and TGS.

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