Structural setting of two Mesozoic half-grabens off the coast of Trøndelag, Mid-Norwegian shelf

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Regional setting

Two small half-grabens containing sedimentary rocks of proposed Mesozoic age are found in the northeastern parts of Folla, the ocean region between Vikna and Frøya (Fig. 1). The half-grabens are bounded by NE-SW trending normal faults, which partly coincide with major submarine escarpments. In a regional context, the half-grabens are situated in crystalline basement rocks, on the innermost part of the Mid-Norwegian shelf (Fig. 1), along the southeastern margin of the Trøndelag Platform. The presence of sedimentary rocks in the northern half-graben was first demonstrated by Bugge et al. (1976), while the southern half-graben has not previously been described. Similar, though larger half-grabens containing Mesozoic sedimentary rocks are known from other places in the Trøndelag region (Fig. 1), such as Frohavet (Oftedahl 1975, Bøe 1991), Beitstadfjorden (Oftedahl 1972, Bøe & Bjerkli 1989) and Edøyfjorden (Bøe & Bjerkli 1989).

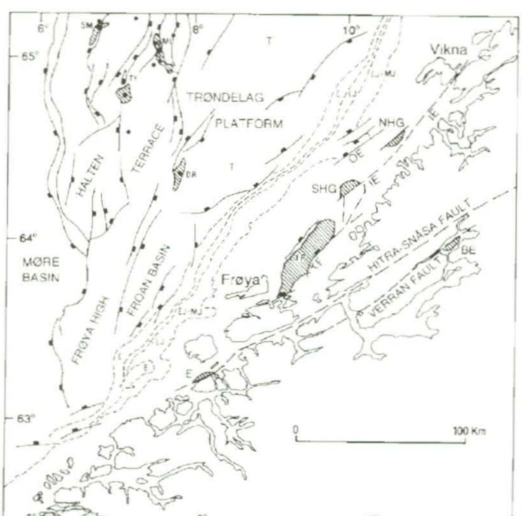

Fig. 1. Main structural elements on the Mid-Norwegian shelf and onshore between 63°and 65° N. (SHG) Southern half-graben; (NHG) Northern half-graben; (IE) Inner escarpment; (OE) Outer escarpment; (B) Basement; (BE) Beitstadfjord Basin; (E) Edøyfjord Basin; (FR) Frohavet Basin; (TF) Tarva Fault; (EJ-MJ) Early Jurassic - Middle Jurassic; (LJ) Late Jurassic; (C) Cretaceous; (T) Tertiary; (DR) Draugen Field; (MI) Midgard Field; (SM) Smørbukk Field; (TY) Tyrihans Field. Modified from

Methods and bathymetry

The Folla region was investigated by shallow reflection seismic profiling (Fig. 2), using a 20 cubic inch Bolt air gun as acoustic source, filtered at 60-600 and 220-1100 Hz. Positioning was performed by a GPS satellite navigator, and a total of 670 km of seismic profiles were collected.

The bathymetry of Folla (Fig. 2) shows several interesting features which can be used to supplement the structural interpretation of the region. Along the coast, there is a 2-10 km broad zone of shallow waters (0-100 m deep) with numerous skerries, incised by NW-SE trending troughs up to 400 m deep. These shallow waters are separated from a coast-parallel depression with water depths exceeding 500 metres, by a major, submarine escarpment (inner escarpment - IE) running parallel to the coast. The northern half-graben (NHG) and the southern half-graben (SHG) are located within this depression. The escarpment forms an anastomosing bathymetric lineament which towards the southwest links with the prominent Tarva Fault (Bøe 1991), and towards the northeast can be traced to Vikna (Fig. 3), i.e. a total distance in excess of 150 km.

In the central and northern parts of Folla, seawards of the inner escarpment, the sea bottom steadily rises from in excess of 500 m to c. 200 m. This rise is terminated by a second escarpment (outer escarpment - OE) where the sea bottom drops to c. 400 m (Fig. 2). The outer escarpment coincides with a major normal fault, offsetting Middle Jurassic rocks.

Structure and stratigraphy of the northern half-graben

The northern half-graben (Fig. 3), c. 3.5 x 13 km,

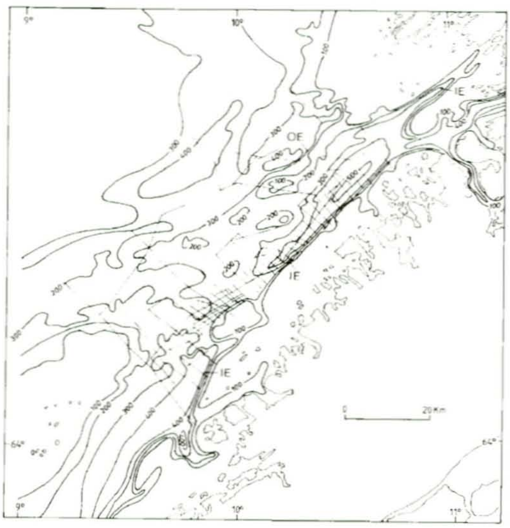

Fig. 2. Bathymetry and seismic grid in the Folla ocean region. (IE) Inner escarpment; (OE) Outer escarpment.

is bounded towards the northwest by a NE-SW trending normal fault. Towards the southeast, the sedimentary rocks wedge out due to Quaternary erosion (Fig. 4). The crystalline basement (Proterozoic basement gneisses, Sigmond 1992)

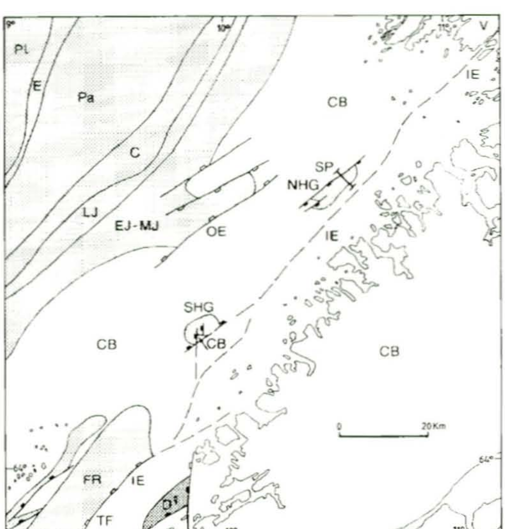

Fig. 3. Location of the southern (SHG) and northern (NHG) half-grabens, and main structural and bathymetric lineaments. (V) Vikna, (SP) Seismic profile in Fig. 4, (IE) Inner escarpment; (OE) Outer escarpment; (TF) Tarva Fault, (CB) Crystalline Basement, (D) Devonian rocks on Asenøya, (FR) Frohavet Basin; (EJ-MJ) Early Jurassic - Middle Jurassic, (LJ) Late Jurassic, (C) Cretaceous, (Pa) Palaeocene, (E) Eocene, (Pl) Pliocene.

is usually easily recognised on the seismic registrations due to low penetration and a characteristic diffraction pattern; however, the lower boundary of the sedimentary succession may be indistinct and difficult to define. The sedimentary rocks can be divided into two units:

- an upper unit, c. 100 ms two-way travel time (TWT) thick (i.e. c. 90 m), with strong, parallel, continuous reflections.
- a lower unit, c. 200 ms TWT thick (c. 180 m), showing weak, discontinuous reflections.

The upper unit is locally eroded, e.g. in Fig.4, where only the lower unit is present. The reflectors of the sedimentary rocks are locally weakly undulating, probably due to tectonic movements along the marginal fault, and are truncated by the base of the overlying Quaternary cover (Fig. 4). The throw on the marginal fault bounding the half-graben is estimated to be at least 400 metres. In addition, a smaller fault is present in the southwestern part of the northern half-graben (Fig. 3).

Structure and stratigraphy of the southern half-graben

The southern half-graben (Fig. 3) is smaller than the northern (4 x 8 km), but has a similar NE-SW orientation. However, it differs with regard to structural setting; the marginal fault bounding the SHG is on the southeast side, downthrowing the sedimentary rocks towards the northwest. This marginal fault forms part of the inner escarpment, which is present from Frohavet to Leka. In addition, there are two, minor, N-S trending normal faults, with downthrows on their western sides. These faults are aligned parallel to a N-S trending normal fault affecting Devonian metasedimentary rocks on Asenøya (Sigmond 1992) (Fig. 3). Close to the faults, the reflectors of the sedimentary sequence are tilted and openly buckled.

The stratigraphy of the sedimentary rocks in the SHG is broadly similar to that in the NHG, with a lower unit showing weak, discontinuous reflections, and an upper unit with strong, parallel, continuous reflections. The thickness of the lower unit is less than in the NHG, with a maximum thickness of 100 ms TWT (c. 90 m). The upper unit is only locally present, due to Quaternary erosion, and reaches a maximum thickness of c. 80 ms TWT (i.e. c. 70 m).

Stratigraphy of the Quaternary sediments overlying the NHG and SHG

The base of the Quaternary overlying the sedimentary rocks in the NHG is a distinct, low-angle unconformity. The deposits have a maximum

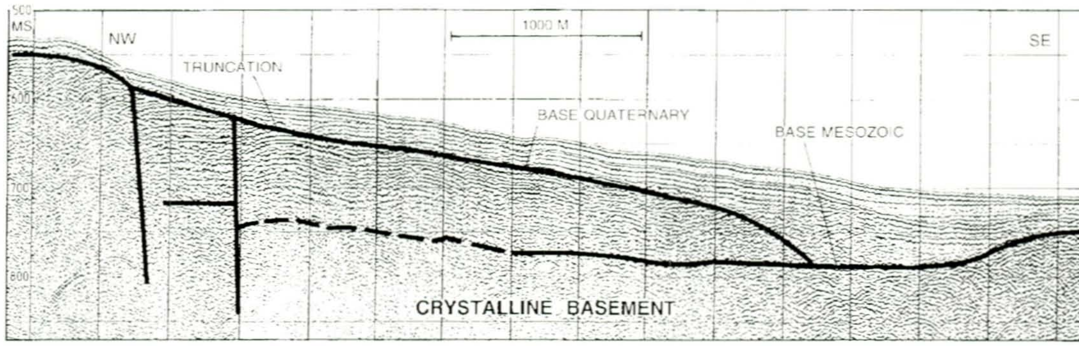

Fig. 4. Seismic cross-section of the northern half-graben (for location, see Fig. 3). (MS) - two-way travel time in milliseconds; (SE) - southeast; (NW) - northwest.

thickness of c. 140 ms TWT (c. 125 m) in the depression formed where the sedimentary rocks wedge out towards the southeast (e.g. Fig. 4), but generally the thickness is 20 - 50 ms TWT. The Quaternary deposits overstep the small, c. 20 ms TWT high escarpment associated with the marginal fault bounding the sedimentary rocks towards the northwest. The level difference on this escarpment varies from 20 to 100 ms TWT.

The base of the Quaternary deposits overlying the SHG is a low-angle unconformity, locally truncating the reflectors of the underlying sedimentary sequence. The Quaternary is generally thin, 20 - 50 ms TWT, but can locally be up to 130 ms TWT thick. At the southern end of the SHG, two units can be separated:

-- a lower unit, forming a more than 2 km long ridge, flat-topped, up to 120 ms TWT thick, with chaotic or weak internal reflections, provisionally interpreted as morainic sediments. Northeastwards the ridge grades into an up to 70 ms TWT thick sequence with strong, parallel reflections.

-- an upper unit with slightly irregular, weak reflections, up to 60 ms TWT thick, which postdates the proposed morainic sediments.

Age of the sedimentary sequences and faulting

The age of the sedimentary rocks is uncertain. However, the half-grabens are located in the strike continuation of the Frohavet Basin (Oftedahl 1975, Bøe 1991) which, based on a number of Middle Jurassic erratics found on the Froan Islands (Nordhagen 1921), and seismic correlation with dated Middle Jurassic sequences offshore (Bøe 1991), has been proposed to be of Middle Jurassic age. Consequently, a Middle Jurassic age is suggested for the sedimentary rocks in the half-grabens.

Widespread extensional faulting on the Mid-Norwegian shelf, giving rise to NE-SW trending normal faults during the Middle Jurassic and the Late Jurassic - Early Cretaceous, is well documented (Gabrielsen et al. 1984, Brekke & Riis 1987). In the Frohavet area, the Tarva Fault (Oftedahl 1975), bounding the Frohavet Basin towards the southeast, was probably active during sedimentation in Middle Jurassic times, relating to the initiation of Atlantic sea-floor spreading and rifting in the Møre Basin (Bøe 1991). During a later phase of extension, probably during the Late Jurassic - Early Cretaceous, extensive tectonism related to offshore rifting processes led to the evolution of a horst-and-graben terrain in the region, including post-depositional movements in excess of 1000 metres in the Frohavet Basin (Bøe 1991). As the Tarva Fault forms the southern part of the 'inner escarpment', it is suggested that the main faulting activity responsible for the formation of the northern and southern half-grabens dates to these periods.

Conclusions

Shallow seismic profiling in the Folla region has shown the presence of two half-grabens containing pre-Quaternary sedimentary rocks of proposed Middle Jurassic age. The half-grabens are situated in the crystalline basement of the innermost part of the Mid-Norwegian shelf, along the southeastern margin of the Trøndelag Platform. They are bounded by NE-SW trending normal faults, associated with a more than 150 km long bathymetric lineament running from Frohavet to Vikna. The main faulting activity probably relates to a phase of extensive horst-and-graben development during the period of Late Jurassic - Early Cretaceous extensional movements which affected the Mid-Norwegian shelf.

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