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Deep seismic reflection profiles across the western Barents Sea

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Summary. The continental crust beneath the western Barents Sea has been acoustically imaged down to Moho depths in a large scale deep seismic reflection experiment. A first-order pattern of crustal reflectivity has been established and the thickness of the crust determined. A number of features with important implications for the tectonics of the area have been discovered. The results are presented in the form of two transects.

1. Introduction

A large scale deep seismic reflection survey was carried out in the western Barents Sea by the Continental Shelf Institute (IKU), Norway, during the summers of 1984 and 1985. The main objective was to map reflections from the crystalline crust and to determine the depth to its base. The survey grid was designed to cover the main geological provinces in the area. The preliminary results are encouraging and a first order picture of crustal reflectivity down to Moho depths has been obtained. The data set is being interpreted and prepared for publication jointly by the University of Oslo, IKU and Esso Norway which financed the project. In this paper the interpretation of two long transects across the western Barents Sea will be presented.

2. The data

The location of the seismic lines is shown in Fig. 1. The survey consists of eight regional profiles with a total length of 3200 km. The acquisition systems included a powerful, areally extensive airgun array (5560 cu.in.) and a 4000 m streamer. The data were recorded 40 fold to 16-18 s two-way time. A fairly conventional processing sequence was applied. Excellent results were obtained in many areas but problems with multiples and signal strength were encountered in others. Further testing and reprocessing will be carried out in order to enhance deep events.

3. Geological setting

The Barents Sea (Fig. 1) covers the northwestern corner of the Eurasian continental shelf. It is bounded by young passive margins in the west and north that developed in response to the Cenozoic opening of the Norwegian-Greenland Sea and the Arctic Eurasian Basin, respectively. The western Barents Sea is underlain by a several km thick succession of Upper Palaeozoic to Cenozoic rocks. The nature and age of the basement is largely unknown

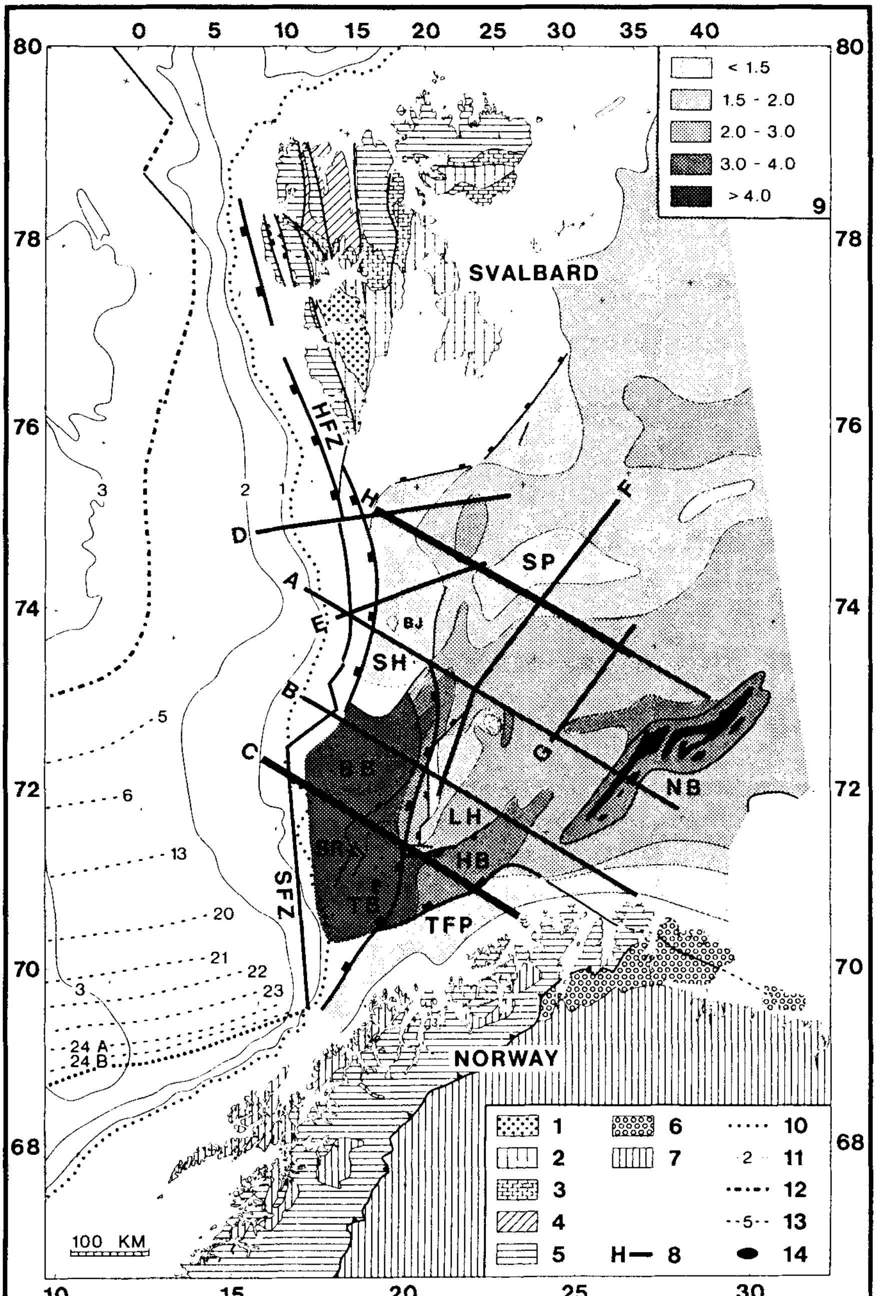

Figure 1: Geology of the western Barents Sea and surrounding areas. Onshore geology: 1: Tertiary; 2: Mesozoic; 3: Permo-Carboniferous; 4: Devonian; 5: Caledonian/Hecla Hoek basement; 6: Late Precambrian sediments; 7: Precambrian basement. Offshore: 8: location of the IKU deep seismic lines; 9: depth in two-way-time to top Permian; 10: shelf edge (500 m); 11: water depth (1000 m. contours); 12: active spreading center; 13: magnetic seafloor spreading anomalies; 14: salt. Main structural elements: BB: Bjørnøy Basin; HB: Hammerfest Basin; HFZ: Hornsund Fault Zone; LH: Loppa High; NB: Nordkapp Basin; SFZ: Senja Fracture Zone; SH: Stappen High; SP: Svalbard Platform; SR: Senja Ridge; TFP: Troms-Finnmark Platform; TB: Tromsø Basin. BJ: Bjørnøya (Bear Island).

although a continuation of the Caledonides some distance into the western Barents Sea seems likely.

Fig. 1 summarizes the regional geology. Offshore, the structural relief is illustrated by simplified contours (twt) at the top Permian level. The area investigated covers three main geological provinces: (1) the Svalbard Platform in the north with a flat-lying cover of Late Palaeozoic and Triassic sediments, (2) an east-west trending basinal province between the Svalbard Platform and the Norwegian coast, where Jurassic-Tertiary sediments are also preserved and (3) the continental margin in the west which is composed of sheared and rifted segments and is covered by a thick Cenozoic sedimentary wedge.

The structural geology and stratigraphy of these provinces is well known from a dense grid of multichannel seismic lines which has been tied to several commercial wells. A detailed discussion is found in Rønnevik & Jacobsen (1984) and Faleide *et al.* (1984).

The post-Paleozoic geological history of the western Barents Sea is dominated by a number of tectonic phases related to crustal extension between Greenland and Norway. Some of the stretching extended into the southwestern Barents Sea where deep basins formed in the Cretaceous, but part of it was probably taken up by continental transform faults in a strike-slip belt between NE Greenland and Svalbard. Apart from epeirogenic movements which produced the present day elevation differences between them, the Svalbard Platform and the eastern part of the regional basin have been largely stable since Late Palaeozoic times.

4. The transects

We have chosen two lines from the data set for presentation. The lines IKU-H and C are two long NW-SE oriented transects which cross the main geological provinces. They are typical for the deep seismic results obtained. The interpretation, presented in Fig. 2, is based on unmigrated time sections.

Line H crosses the Svalbard Platform from its western boundary at the margin to the regional basin in the SE, an area which has largely been stable since Late Paleozoic times. Triassic sediments subcrop at the seafloor for most of its length. On the western Svalbard Platform an unconformity at approximately 3 s defines the base of the undeformed sedimentary sequence. It probably corresponds to the Hecla Hoek basement which outcrops on Svalbard and Bjørnøya. In general crustal reflectivity decreases eastwards along line H. Systematic lateral differences in the reflection pattern define three crustal provinces. The westernmost province (0-150 km) is characterized by high reflectivity throughout the crust. Short reflection segments define horizontal layering. However, some steep dips and diffractions indicate tectonic deformation. A well defined downward cutoff in reflectivity places the Moho at approximately 10 s. A number of strong subhorizontal reflections are present at the base of the crust.

A reflection-free upper and middle crust is characteristic for the easternmost province (275-390 km). Reflectivity in the lower crust is variable. A cluster of lower crustal reflections shows that acoustic energy is returned from Moho depths. The apparent lack of reflections above is therefore geologically significant. The depth to Moho is less well defined here but is probably close to 11 s.

Dipping reflections characterize the central zone (150-275 km). Especially prominent is a band of westward dipping reflections which seems to define a continuous feature (A, Fig. 2) from 5 to 10 s. Further east a single continuous reflection (B) dips westward from 10.5-11 s to 12.5 s. Sandwiched between these two features are a number of westward dipping reflections in the middle and lower crust. Clear definition of the Moho is lost.

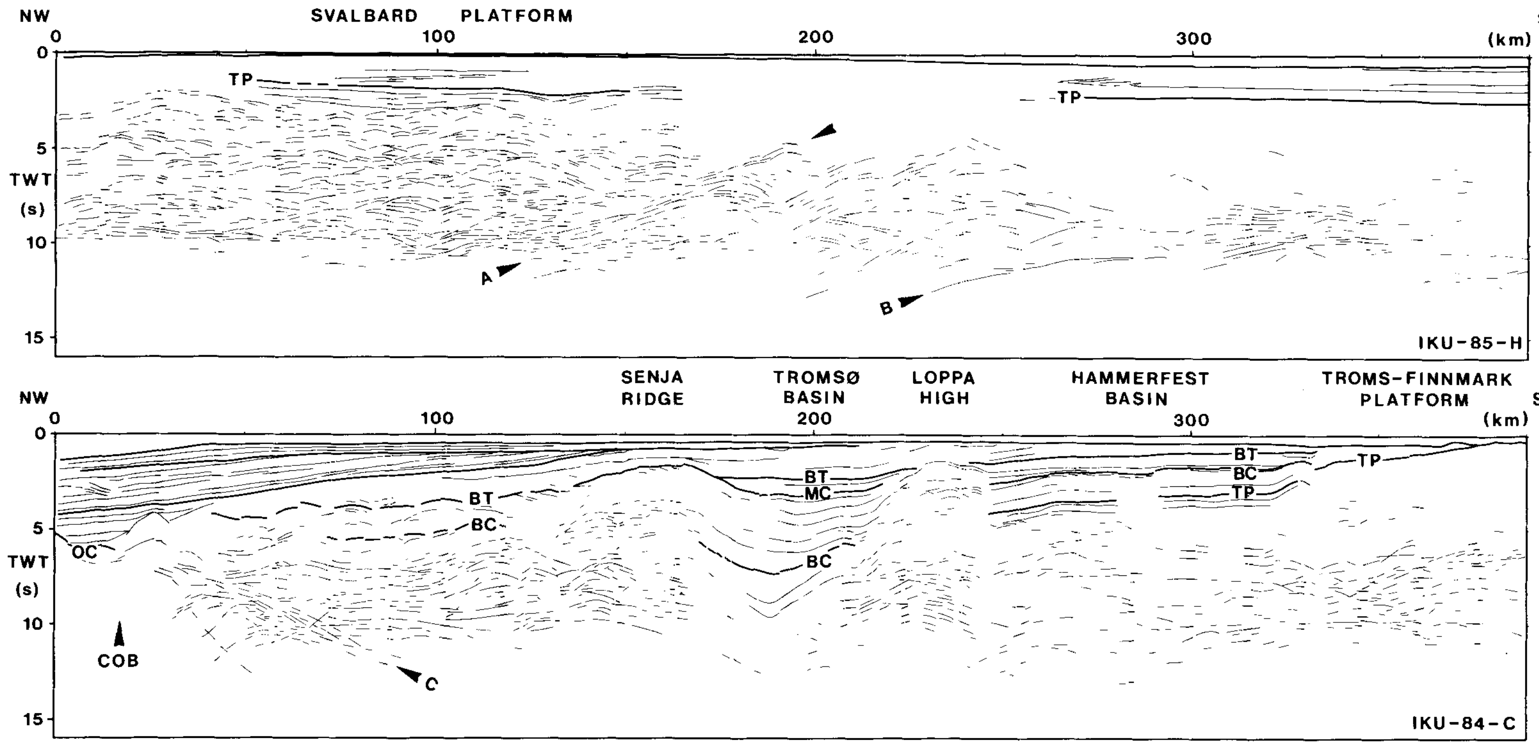

Figure 2: Line drawings of IKU lines 84-C and 85-H. Location of the seismic lines in Fig. 1. Interpretation based on unmigrated time sections. BT: Base Tertiary; MC: Mid-Cretaceous; BC: Base Cretaceous; TP: Top Permian; COB: continent-ocean boundary; OC: oceanic crust; A-C: features referred to in the text.

The central zone is a transitional zone between different crustal terranes. The asymmetric nature of the reflector pattern is consistent with eastward directed overthrusting. It is possible that this feature dates back to the closure of the Iapetus Ocean and represents the main suture.

Line C is a transect across the southwestern Barents Sea from the continental slope to the Norwegian coast. The main structural elements are, from NW to SE the continental margin, Senja Ridge, Tromsø Basin, Loppa High, Hammerfest Basin and the Troms-Finnmark Platform. Line C contrasts markedly with Line H. The sedimentary sequence is much thicker and more structuring has taken place.

The area west of the Loppa High subsided during Early Cretaceous in response to crustal extension. The Senja Ridge is a product of local inversion in the Late Cretaceous. The depth to the Base Cretaceous reflector is approximately 5 s in this area, with the exception of the Tromsø Basin where it reaches 7.5 s. The Hammerfest Basin, which was initiated as a rift between the Loppa High and the Troms-Finnmark Platform in the Middle-Late Jurassic, was shielded from further extension in the Early Cretaceous by the development of a NNE trending fault zone further west. It is therefore much shallower than the Tromsø Basin. The Top Permian reflector subcrops on the Troms-Finnmark Platform.

Deep reflections are observed down to 10-11 s along the transect. Between the continent-ocean boundary (COB) and the Tromsø Basin the whole crust is reflective beneath the Base Cretaceous reflector. The Moho is not sharply defined but its depth may be estimated within 1 s. The reflections, many of which are unusually continuous, define horizontal layering without major discontinuities.

The area immediately east of the COB is an exception. Here a band of reflections dips steeply eastwards from 7 s at the COB to the base of the crust (C, Fig. 2). The reflectors apparently cut across the horizontal layering which terminates a short distance further west in a zone of diffractions and steep westward dips. It seems reasonable to associate these features with structural discontinuities in the lower crust, possibly combined with intrusions, as it thins towards the COB.

The seismic data combined with results from wells drilled on the Senja Ridge show the Tromsø Basin to be extremely deep. From the regional geology there is good reason to believe that a substantial section of Triassic sediments is present beneath the Base Cretaceous reflector. If one allows for partial isostatic compensation of the basin very little room is left for a pre-Mesozoic crustal column. The Bjørnøy Basin north of the Tromsø Basin reaches similar depths. It seems likely therefore that the crust came close to break-up in the Cretaceous along a northerly oriented axis centered on the two basins. Final break-up occurred further west.

Below the Loppa High and the Troms-Finnmark Platform a band of reflections is observed in the lower crust. The upper crust is less reflective. These two structural elements were not affected by Mesozoic rifting. Below the Hammerfest Basin primary reflections are severely degraded by multiples.

5. Conclusions

Crustal reflectivity has been successfully mapped to the base of the crust in the western Barents Sea. The results throw new light on the large-scale tectonics of the area. On the Svalbard Platform a first-order pre-Mesozoic tectonic feature was discovered. A deep-seated zone of thrust faulting separates highly reflective crust in the west from a province of lesser reflectivity in the east. In the southwestern extensional province extremely deep basins overlie a narrow zone where the crust must have come close to break-up in the Cretaceous.

Depth migration combined with a velocity model from refraction, and gravity modeling will be needed to fully utilize the potential of the data.

References

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