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Offshore prolongation of Caledonian structures and basement characterisation in the western Barents Sea from geophysical modelling

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ABSTRACT

This study interprets the potential field of the western Barents Shelf at a crustal scale and characterises the basement underlying the deep basins in the southwestern Barents Sea. Comparing potential fields with onshore geology shows that Archaean to Palaeoproterozoic basement and mafic complexes are related to regional magnetic highs while Caledonian nappes are associated with lower magnetic anomalies. It also shows that crustal structures such as major fault zones can be extended offshore. Interpretation of the magnetic data suggests an elbow-shaped offshore prolongation of the Caledonides linking structures striking N 50° in northern Norway with the N–S structures on Svalbard. The basic interpretation has been tested by forward modelling along selected seismic transects. Seismic interpretation is integrated with density and magnetic modelling to investigate the crustal and deep-crustal configuration of the southwestern Barents Sea. The distribution of density, magnetic susceptibility and *Q*-ratio values allows us to distinguish different basement units.

Compiling onshore information with the inter-profile correlations of the 2D models has allowed us to compile a map of basement units. The distribution of basement lithologies lead to a new regional understanding of the crustal architecture of the Barents Shelf. The shape and strike of the offshore prolongation of the Caledonian structures suggest that terranes affected by the Timanian orogeny propagate across the Barents Shelf farther to the northwest than have been interpreted previously.

1. Introduction

The Barents Sea Shelf is located in northernmost Europe and extends from the North Atlantic and the Svalbard Archipelago in the west to Novaya Zemlya in the east, over a distance of 1000 km (Fig. 1). In the west, the Barents Sea is bounded by its Cenozoic passive margins that were formed during the final stages of North Atlantic break-up in the Early Eocene (Doré, 1991; Lundin and Doré, 2002).

Exploration of the Barents Sea is of great interest for both academic and economic purposes due to the hydrocarbon potential in the area. In such a context, a detailed knowledge of the basement is fundamental as its geometry and composition provide important constraints for basin analysis and heat flow studies.

A dense grid of industrial seismic reflection data exists in the area and the western Barents Sea has been the subject of many previous investigations and interpretations (Gabrielsen, 1984; Gudlaugsson et al., 1987; Gabrielsen et al., 1990; Faleide et al., 1993; Gudlaugsson and Faleide, 1994; Johansen et al., 1994; Gabrielsen et al., 1997; Breivik et al., 1998; Gudlaugsson et al., 1998; Ritzmann et al., 2007). On the Barents Shelf, sedimentary thicknesses locally reach to more than 14 km; therefore, conventional seismic reflection data do not allow reliable mapping below the Permian succession and the complex structure of the deep basement still remains poorly constrained. Little information about the regional structure of the crust is available from published models based mainly on Ocean Bottom Seismometer (OBS) data (Fig. 2). Seismic refraction data (Breivik et al., 2002; Mjelde et al., 2002; Breivik et al., 2003, 2005) had already been presented as an alternative method for constraining the sub-sedimentary crustal structure.

The present study aims to investigate the nature and complex history structure and lithology of the Barents Shelf using potential field data. Our specific study area for basement characterisation is the southwestern (SW) Barents Sea (69 °N–75 °N and 13 °E–30 °E). Situated offshore from northern Norway where Caledonian thrust sheets are well-exposed (Sturt et al., 1975; Ramsay et al., 1985; Siedlecka and Roberts, 1996), this area encompasses major structural highs, platforms and basins (Fig. 2); (Gabrielsen et al., 1990; Gudlaugsson et al., 1998).

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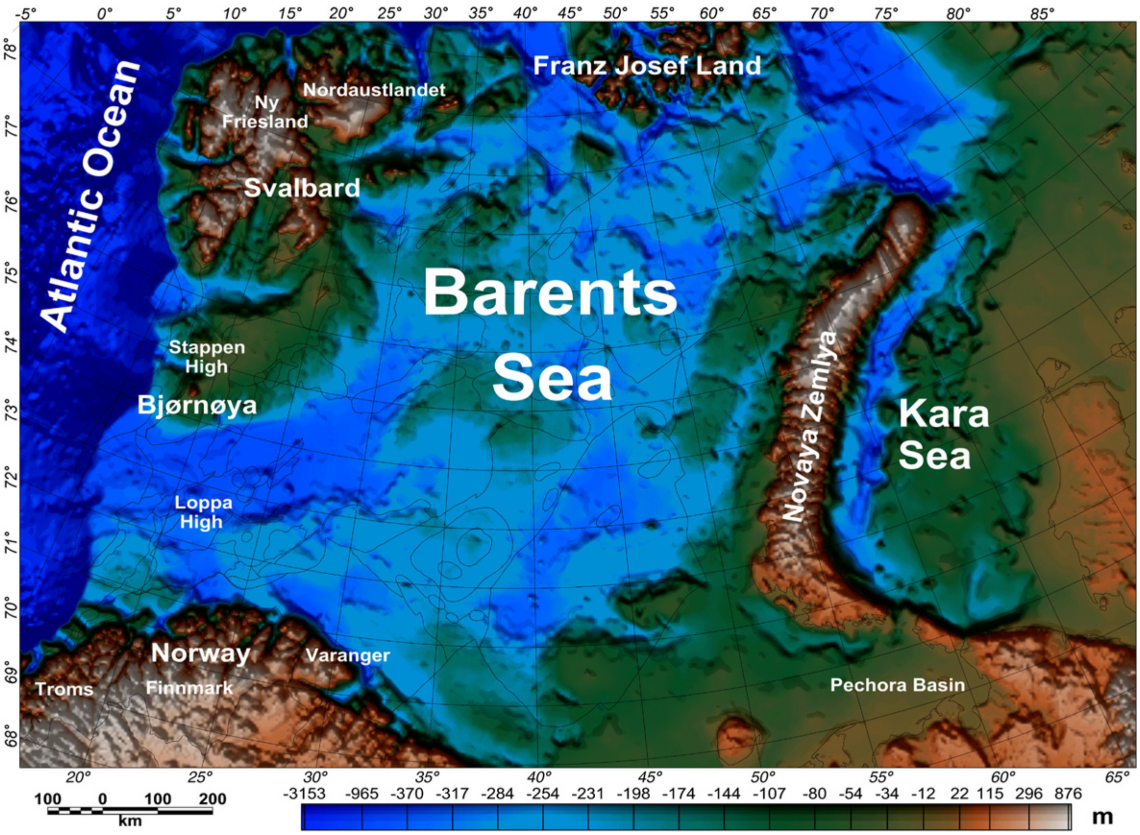

Fig. 1. Location map. Barents Sea Shelf and surrounding land masses: bathymetry–topography map. The study area for basement characterisation is the southwestern (SW) Barents Sea (69°N–75°N and 13°E–30°E). The black lines show the tectonic units as defined by the NPD (Norwegian Petroleum Directorate).

Offshore, most of the sedimentary rocks in the basins range in age from Late Palaeozoic to Quaternary. The investigations offshore started at the most prominent basement high of the area, the Loppa High (Fig. 2), which is surrounded by individual faults or fault complexes that were activated during the formation of the positive basement feature observed at present day (Gabrielsen, 1984; Gabrielsen et al., 1990).

Following a brief presentation of the geological setting, we correlate the geological information both available onshore and offshore with the regional potential field data. Maps are interpreted using different filtering techniques, onshore–offshore relationships and potential field modelling. Reliable crustal models across the SW Barents Sea are constructed by integrating structural information derived from seismic data and petrophysical constraints. A map showing principal basement units and a regional interpretation focusing on the prolongation of Caledonian structures offshore and the origin of sedimentary basins are presented.

2. Geological setting

The tectonic evolution of the Barents Sea area was strongly influenced by the Palaeoproterozoic (Svecofennian) orogeny, which established the stable Russian–European platform adjacent to the northern Archaean part of the Fennoscandian Shield (Alsgaard, 1993; Torsvik et al., 1996; Gee and Tebenkov, 2004; Roberts and Olovyanishnikov, 2004; Gee et al., 2006).

The north- to northeastward extension of the Norwegian Caledonides into the Barents Sea — generally referred to as the Barentsian Caledonides (e.g., Siedlecka 1975) is flanked to the east by the late Neoproterozoic Timanide fold belt (Fig. 3), recognised as far north as on Novaya Zemlya. Accreted and superimposed, Neoproterozoic (Timanian) orogenic trends are usually oriented NW–SE (e.g., Timan Range, Timan–Varanger Belt), and Timanian basement is present in the western and central Pechora Basin (Ivanova, 2001; Gee et al., 2006). On Varanger Peninsula in Norway, the Trollfjorden–Komagelva Fault Zone (Fig. 3) separates the Baltican platform domain terranes from the Timanian basinal terranes and can be followed south-eastwards into the Timan Range (Olovyanishnikov et al., 2000; Roberts and Siedlecka, 2002; Roberts and Olovyanishnikov, 2004).

From Late Cambrian time and over a period of 80 Myr, the gradual closure of the Iapetus Ocean (Roberts and Gale, 1978; Torsvik et al., 1996; Roberts, 2003; Gee, 2005; Gee et al., 2006) involved subduction zones, associated magmatic activity in island arcs and several tectonic events along the margins of both Laurentia and Baltica. The major collision between Baltica and Laurentia (forming the Larussia plate) began in the Silurian and extended until the Early Devonian, and is known as the Scandian orogeny.

Several studies on Spitsbergen have showed that the Caledonian basement terranes and structures (Harland and Gayer, 1972) correlate with similar terranes, faults and thrusts mapped on the East Greenland margin (Scott and Turton, 2001; Gee and Tebenkov, 2004). The affinity of terranes on Svalbard and in East Greenland to the Laurentian plate (Torsvik and Cocks, 2005) is well known. Nevertheless, the relative positions of these two terranes are still a matter of debate.

From Silurian to Early Carboniferous time, the Innuitian or Ellesmerian Orogeny (Fig. 3) affected Laurentia (Filatova and Khain, 2007; Piepjohn et al., 2007). Thereafter, the deformation regime changed from compression and lateral shortening to regional extension (Gee, 2005).

The Late Palaeozoic and Mesozoic tectonic history of the western Barents Sea was mostly dominated by several rifting episodes. Agreement exists about two main extensional periods, respectively in Early-Mid Devonian to Early-Mid Carboniferous and Permian to Early Triassic times (Lippard and Prestvik, 1997; Gabrielsen et al., 1990).