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Crustal structure and evolution of the Arctic Caledonides: Results from controlled-source seismology

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The continuation of the Caledonides into the Barents Sea has long been a subject of discussion, and two major orientations of the Caledonian deformation fronts have been suggested: NNW-SSE striking and NE-SW striking. A regional NW-SE oriented ocean bottom seismic profile across the western Barents Sea was acquired in 2014. In this paper we map the crust and upper mantle structure along this profile in order to discriminate between different interpretations of Caledonian structural trends and orientation of rift basins in the western Barents Sea. Modeling of P-wave travel times has been done using a ray-tracing method, and combined with gravity modeling. The results show high P-wave velocities (4 km/s) close to the seafloor, as well as localized sub-horizontal high velocity zones (6.0 km/s and 6.9 km/s) at shallow depths which are interpreted as magmatic sills. Refractions from the top of the crystalline basement together with reflections from the Moho give basement velocities from 6.0 km/s at the top to 6.7 km/s at the base of the crust. P-wave travel time modeling of the OBS profile indicate an eastwards increase in velocities from 6.4 km/s to 6.7 km/s at the base of the crystalline crust, and the western part of the profile is characterized by a higher seismic reflectivity than the eastern part. This change in seismic character is consistent with observations from vintage reflection seismic data and is interpreted as a Caledonian suture extending through the Barents Sea, separating Barentsia and Baltica. Local deepening of Moho (from 27 km to 33 km depth) creates "root structures" that can be linked to the Caledonian compressional deformation or a suture zone imprinted in the lower crust. Our model supports a separate NE-SW Caledonian trend extending into the central Barents Sea, branching off from the northerly trending Svalbard Caledonides, implying the existence of Barentsia as an independent microcontinent between Laurentia and Baltica.

1. Introduction

The Barents Sea is located in the northwestern corner of the Eurasian continent (Fig. 1) where the assembly of the crystalline basement is related to the mid-Palaeozoic Caledonian orogeny (e.g. Roberts and Gee, 1985). Early post-Caledonian extension created Devonian basins on Svalbard, but it is unknown how this phase affected the offshore areas. Late Palaeozoic rifting in the Barents Sea formed basins that accumulated large amounts of evaporite deposits, whereas Mesozoic rifting events formed major Cretaceous basins followed by Cenozoic breakup and opening of the Northeast Atlantic (Roberts and Gee, 1985; Gabrielsen et al., 1990; Faleide et al., 2008; Gee et al., 2008; Smelror et al., 2009). It has long been recognized that Caledonian and older basement structures have influenced subsequent basin development and structural configuration in the Barents Sea (Harland and Gayer, 1972; Gabrielsen, 1984; Doré, 1991; Ritzmann and Faleide, 2007, Fig. 2). Due to petroleum exploration in the southwestern Barents Sea the structures of the main Mesozoic grabens, highs and platforms are fairly well known (e.g. Gabrielsen et al., 1990; Faleide et al., 1993; Breivik et al., 1998; Smelror et al., 2009; Henriksen et al., 2011a). The deep structure of the Late Palaeozoic basins and their relationship to the Caledonian orogeny still remains unclear in most of the western Barents Sea due to sparse distribution of wide-angle seismic data and poor resolution of multi-channel seismic (MCS) reflection data below the Permian sequence (Breivik et al., 2005). Ziegler (1988) proposed that the Scandinavian Caledonides extend northwestward linking up with the N—S trending Caledonides of Svalbard. Later interpretations involve two branches of the Caledonides, one through the eastern Barents Sea, and one through Spitsbergen (Gudlaugsson et al., 1998; Breivik et al., 2005; Henriksen et al., 2011a). Others consider only the eastern branch through the Barents Sea to be the suture (Doré, 1991; Harland et al., 1997; Gee et al., 2006, Fig. 2).

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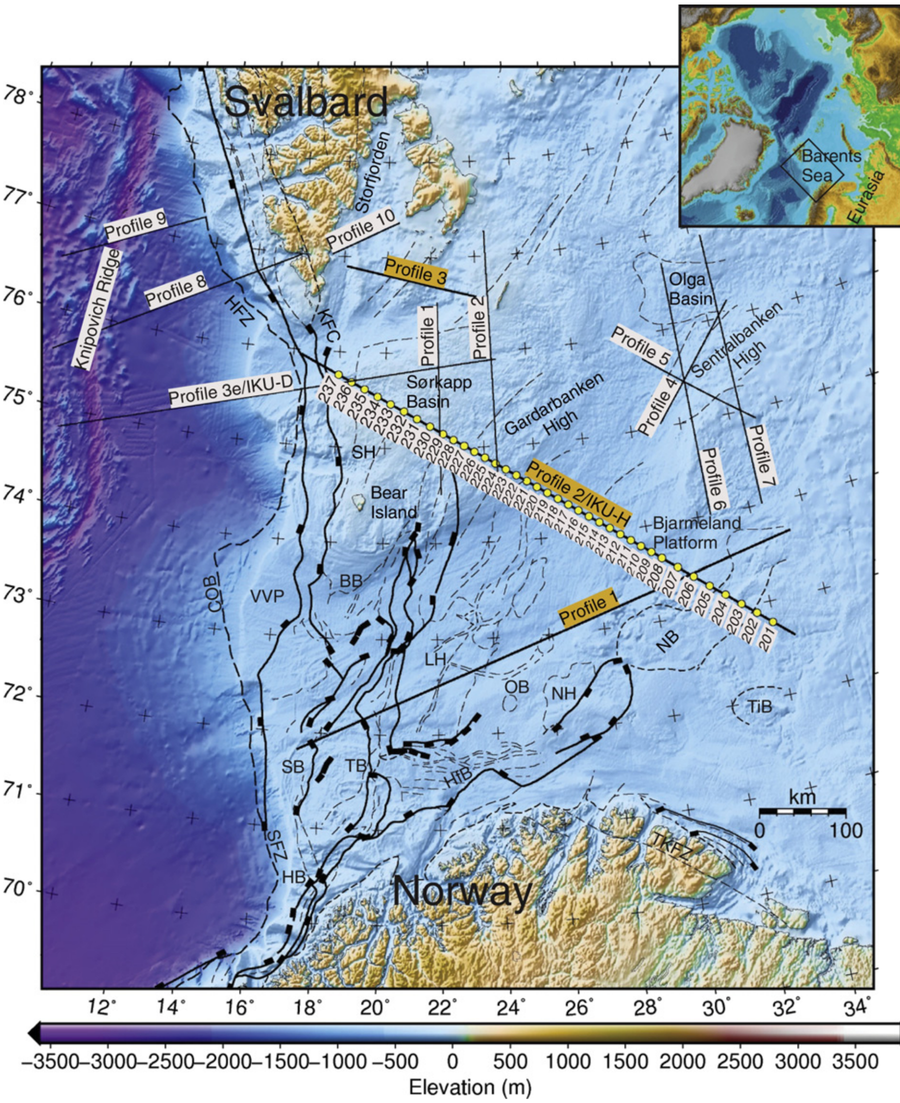

Fig. 1. Location the modeled Profile 2 with OBS locations marked by yellow dots. Profiles 1 and 3 from the 2014 survey are also shown. Bathymetry is taken from Jakobsson et al. (2012) fault positions from Faleide et al. (1993), outline of basin and highs from Gabrielsen et al. (1990). COB: continent-ocean boundary from Breivik et al. (1999) BB: Bjørnøya Basin, HB: Harstad Basin, HfB: Hammerfest Basin, HFZ: Hornsund Fault Zone, KFC: Knølegga Fault Complex, LH: Loppa High, NB: Nordkapp Basin, NH: Norsel High, OB: Ottar Basin, SB: Sørvestsnaget Basin, SH: Stappen High, TB: Tromsø Basin, TiB: Tiddlybanken Basin, TKFZ: Trollfjorden-Komagelva Fault Zone, VVP: Vestbakken Volcanic Province.

Further, it has been proposed that the Late Palaeozoic rifting in the southwestern Barents Sea developed in a north-easterly direction, following the inherited Caledonian structural grain, with a fan shaped distribution of rift basins and intra-basinal highs with orientations ranging from north-easterly in the main rift zone to northerly at the present continental margin in the west (e.g. Gudlaugsson et al., 1998; Breivik et al., 2005; Ritzmann and Faleide, 2007). However, based on new high quality aeromagnetic data covering the southwestern Barents Sea, Gernigon and Brönner (2012) and Gernigon et al. (2014) suggest that the sub-Permian basins and underlying basement grain have a dominantly NNW-SSE orientation and that Caledonian extensional collapse and subsequent rift evolution follow this trend. Contrary to previous interpretations the magnetic data do not recognize a NE-SW inherited Caledonian structural trend through the Barents Sea.

In areas where the deeper parts of the crust are difficult to image by conventional multi-channel seismic reflection data, wide-angle seismic experiments provide valuable information (e.g. Breivik et al., 2002). In 2014, three ocean bottom seismometer (OBS) profiles were acquired in the western Barents Sea (Minakov et al., 2014, Figs. 1, 2), crossing the proposed trends of Caledonian structures and Late Palaeozoic rifts. The P-wave velocity- and gravity model along OBS Profile 2 are presented in this paper. The profile is 650 km long and has a NW-SE orientation, crossing the western Barents Sea from the Stappen High area north of Bjørnøya to the Nordkapp Basin. The primary objective of this paper is to investigate how pre-existing structures inherited from the Caledonian orogeny and subsequent Devonian extensional collapse in the western Barents Sea influenced subsequent Palaeozoic rift evolution.

2. Geological setting

Four major orogenic events have influenced the geology of the Barents Sea area: the Timanian (Ediacaran), Caledonian (Mid Silurian–Early Devonian) (Fig. 2), Uralian (Early Carboniferous–Late Permian/Triassic) and Eurekan orogens (Early Cenozoic). During the Timanian orogeny terranes accreted against the present-day northeastern margin of Baltica. The Timanian structural trend generally has a NW-SE orientation and extends into the South Barents Basin (Olovyanishnikov et al., 1997; Roberts and Siedlecka, 2002), but how far north and west these trends extend is uncertain. NW trending Timanian structures are