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Caledonide development offshore–onshore Svalbard based on ocean bottom seismometer, conventional seismic, and potential field data

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Abstract

The western Barents Sea and the Svalbard archipelago share a common history of Caledonian basement formation and subsequent sedimentary deposition. Rock formations from the period are accessible to field study on Svalbard, but studies of the near offshore areas rely on seismic data and shallowdrilling. Offshore mapping is reliable down to the Permian sequence, but multichannel reflection seismic data do not give a coherent picture of older stratigraphy. A survey of 10 Ocean Bottom Seismometer profiles was collected around Svalbard in 1998. Results show a highly variable thickness of pre-Permian sedimentary strata, and a heterogeneous crystalline crust tied to candidates for continental sutures or major thrust zones. The data shown in this paper establish that the observed gravity in some parts of the platform can be directly related to velocity variations in the crystalline crust, but not necessarily to basement or Moho depth. The results from three new models are incorporated with a previously published profile, to produce depth-to-basement and -Moho maps south of Svalbard. There is a 14 km deep basement located approximately below the gently structured Upper Paleozoic Sørkapp Basin, bordered by a 7 km deep basement high to the west, and 7–9 km depths to the north. Continental Moho-depth range from 28 to 35 km, the thickest crust is found near the island of Hopen, and in a NNW trending narrow crustal root located between ~19°E and 20°E, the latter is interpreted as a relic of westward dipping Caledonian continental collision or major thrusting. There is also a basement high on this trend. Across this zone, there is an eastward increase in the V_P, V_P/V_S ratio, and density, indicating a change towards a more mafic average crustal composition. The northward basement/Moho trend projects onto the Billefjorden Fault Zone (BFZ) on Spitsbergen. The eastern side of the BFZ correlates closely with coincident linear positive gravity and magnetic anomalies on western Ny Friesland, apparently originating from an antiform with high-grade metamorphic Caledonian terrane. A double linear magnetic anomaly appears on the BFZ trend south of

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Spitsbergen, sub-parallel to and located 10–50 km west of the crustal root. Based on this correlation, it is proposed that the suture or major thrust zone seen south of Svalbard correlates to the BFZ. The preservation of the relationship between the crustal suture, the crustal root, and upper mantle reflectivity, challenges the large-offset, post-collision sinistral transcurrent movement on the BFZ and other trends proposed in the literature. In particular, neither the wide-angle seismic data, nor conventional deep seismic reflection data south of Svalbard show clear signs of major lateral offsets, as seen in similar data around the British Isles.

Keywords: Ocean bottom seismometers; Gravity anomalies; Crustal structure; Caledonian orogeny; Barents Sea; Svalbard

1. Introduction

In recent years the epicontinental ocean of the northern Barents Sea and the continental margin around Svalbard have been examined through wide angle seismic programs (Sellevoll et al., 1991; Neprochnov et al., 2000; Breivik et al., 2002, 2003; Ritzmann et al., 2002; Ritzmann and Jokat, 2003; Ritzmann et al., 2004). Earlier geophysical surveys aimed at the lower crustal structure include an Expanding Spread Profile (ESP) survey (Myhre and Eldholm, 1988; Jackson et al., 1990; Sanner, 1995), and deep seismic reflection profile surveys (IKU-84/85 and SVA-87) (Gudlaugsson et al., 1987; Gudlaugsson and Faleide, 1994; Faleide et al., 1993b; Eiken, 1994).

Unlike the southwestern Barents Sea, the platform area in the north did not experience major late Mesozoic tectonism. Conventional multi-channel seismic (MCS) surveys have not provided reliable mapping below the Permian sequence here. These MCS surveys all show variable, but occasionally large thicknesses of sedimentary strata below the Permian in the north. Seismic velocities are high (5–6 km s^{-1}) in these strata, and the velocity/density contrast to the crystalline basement is low. This is a difficulty in surveying the area, as there is no simple correlation between basement depth and the observed gravity field, in contrast to the southwestern Barents Sea (Riis et al., 1986; Breivik et al., 1995, 1998). Earlier work strongly indicated that the observed gravity is greatly influenced by bulk density variations in the crystalline crust near Svalbard, which also dominate over crustal thickness variations (Breivik et al., 2002, 2003). This paper establishes the correlation between gravity and seismic velocity in the crystalline crust more directly than the previous works. This dependence can be used to estimate the distribution of high-density crustal bodies away from the modeled profiles.

The sedimentary rock velocities are usually above 4 km s^{-1} just below the seafloor in the area. Extensive Plio-Pleistocene erosion has exposed well-consolidated strata, mostly Triassic, with patches of Cretaceous present (Eidvin et al., 1993; Sættem et al., 1994; Dimakis et al., 1998; Grogan et al., 1999).

The advent of satellite based potential field data at high latitudes in recent years provides new opportunities to interpret 1- and 2-dimensional velocity models into 3-dimensional geological structures. For gravity, the ERS-1 satellite mission has proven invaluable in the area (Laxon and McAdoo, 1994; Andersen and Knudsen, 1998). These data are only marine, and for this paper we have obtained access to a data set where the satellite data is enhanced with ship track and land station measurements from the Norwegian Geological Survey (Skilbrei et al., 2000), enabling correlation from offshore to onshore structures. Also magnetic marine/air track data compilations have been released in recent years, available from different sources in different resolutions and coverages (Verhoef et al., 1996; Olesen et al., 1997). Here we use a commercial aero-magnetic survey for Svalbard (courtesy, TGS-Nopec) (Olesen et al., 1997).

It is the constraints given by seismic data that make the potential field data interpretable. The Ocean Bottom Seismometer (OBS) survey obtained in 1998 southeast to southwest of Svalbard revealed a heterogeneous crystalline crust that obtained its present configuration during the Caledonian orogeny, throughout Late Ordovician to earliest