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Mantle transition zone beneath central-eastern Greenland: Possible evidence for a deep tectosphere from receiver functions

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ABSTRACT

We investigate the mantle of central-eastern Greenland by using recordings with data from 24 local broad-band seismograph stations. We apply P wave receiver function technique and evaluate the difference in the arrival times of seismic phases that are formed by P to SV mode conversion at the 410-km and 660-km seismic discontinuities. These boundaries mark the top and bottom of the mantle transition zone (MTZ). The difference in the arrival time of the phases from the 410-km and 660-km discontinuities is sensitive to the thickness of the MTZ and relatively insensitive to volumetric velocity anomalies above the 410-km discontinuity. Near the east coast of Greenland in the region of the Skaergaard basalt intrusions we find two regions where the differential time is reduced by more than 2 s. The 410-km discontinuity in these regions is depressed by more than 20 km. The depression may be explained by a temperature elevation of ~150 °C. We hypothesize that the basaltic intrusions and the temperature anomalies at a depth of ~400 km are, at least partly, effects of the passage of Greenland over the Iceland hotspot at about 55 Ma. This explanation is consistent with the concept of tectosphere and implies that the upper mantle to a depth of ~400 km translates coherently with the Greenland plate.

1. Introduction

Greenland has a geologic history of almost 4 Gyr. It is a Precambrian shield, with an Archean block in the south and Proterozoic mobile belts in the north. Since about 1.6 Ga Greenland was part of Laurentia and major geologic development took place mainly along its margins (Henriksen et al., 2009). In the late Ordovician (around 450 Ma) the closure of the Iapetus Ocean between Laurentia and Baltica led to the collision between the two continents and the Caledonian Orogeny. The opening of the Central Atlantic in the Cretaceous (around 130 Ma) reached southern Greenland at around 80 Ma. Initially, sea-floor spreading began at the west side of Greenland but at around 40 Ma it shifted to the eastern side (Torsvik et al., 2002). This shift is close in time to the main magmatic phase of the North Atlantic Igneous Province at ca. 60.5 and 54.5 Ma (Jolley and Bell, 2002). At about the same time, according to the plate reconstruction of Lawver and Müller (1994) east Greenland passed over the Iceland hotspot. A recent reconstruction (Torsvik et al., 2015) suggests that the Iceland hotspot was close to Greenland's east coast between ca. 70 and 40 Ma. This means that the Tertiary basaltic outcrops at the east coast (Fig. 1) with an age of around 55 Myr (Henriksen et al., 2009) may be at least partly related to the Iceland hotspot.

The crust and upper mantle beneath Greenland has been the focus of recent geophysical studies. The crustal structure of Greenland has been studied in a series of seismic experiments in the ice-free coastal regions. For the region under the ice sheet there are sparse estimates of crustal thickness ranging typically from 40 km to 50 km (Dahl-Jensen et al., 2003; Artemieva and Thybo, 2008, 2013). These estimates are obtained mostly by receiver function techniques at less than 10 locations and only one refraction seismic profile (Shulgin and Thybo, 2015). In the coastal regions the crust is relatively thin (20–30 km). The shear velocity structure of the upper mantle was investigated by Rayleigh wave tomography (Darbyshire et al., 2004). The results show high upper-mantle velocities in central regions and somewhat lower velocities in the east. The seismological lithosphere has an average thickness of ~180 km. A thick mantle lithosphere beneath central Greenland is also shown by Lebedev et al., 2017. Estimates of geothermal flux (Rogozhina et al., 2016) are indicative of a long east-west oriented geothermal anomaly which may be related to the passage of Greenland over the Iceland hotspot. The hotspots may have affected not only the crust and the upper mantle but also the mantle transition zone (MTZ). However, the mantle at depth of 400–700 km is still rarely sampled by

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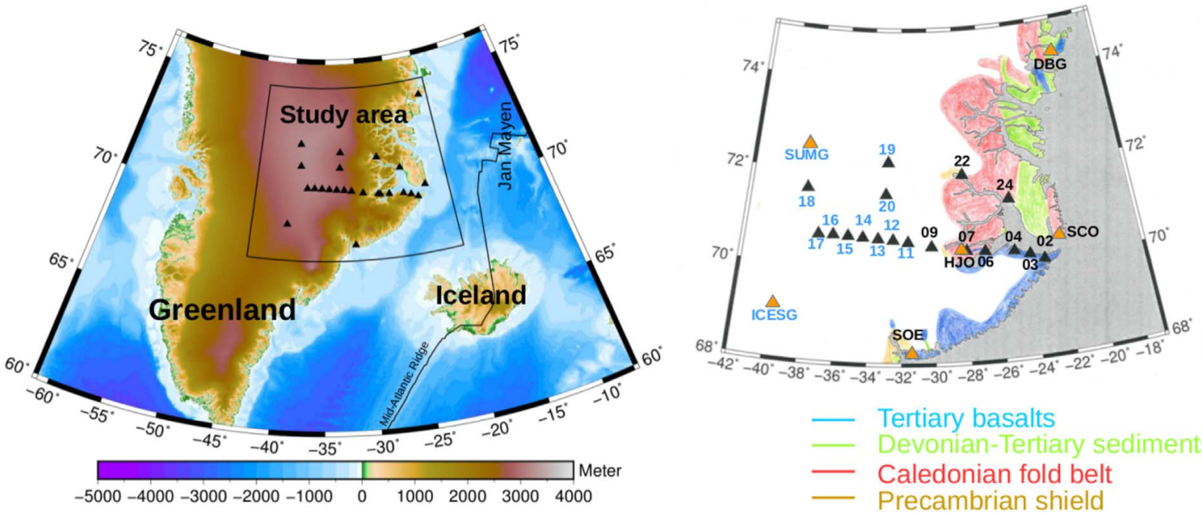

Fig. 1. Map of the North Atlantic region (topography from Amante and Eakins (2012), left) and of the study area (right). The white area on the right shows the extent of the inland ice, surface geology is from Henriksen (2008). Seismograph stations are shown by triangles. Black triangles mark the stations of the temporary deployment from 2009 to 2012. Orange triangles are the stations from GLISN/GLATIS networks. The stations with blue labels were installed on ice. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

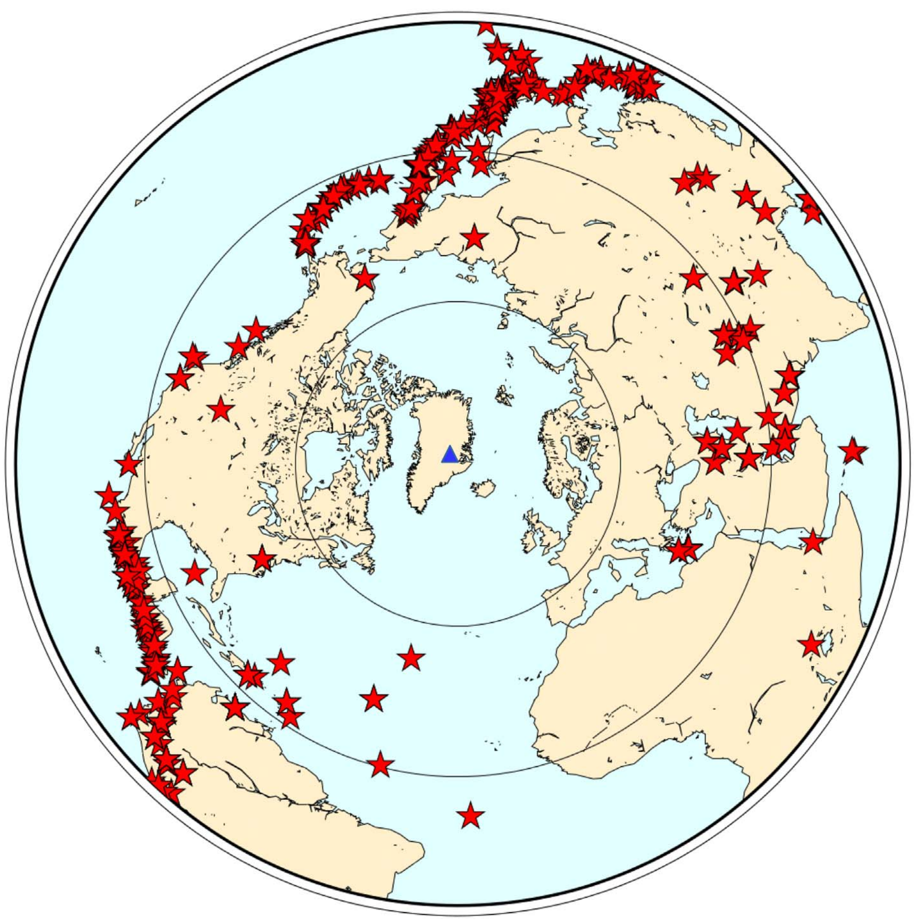

Fig. 2. Epicenters of seismic events that were used in receiver function calculations. The concentric circles mark 30°, 60°, and 90° epicentral distance to the centre of the array (marked with a blue triangle). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

available models (e.g., Rickers et al., 2013) and in the present study we address this issue.

2. Data and methods

We primarily used data from 18 STS-2 broadband seismometers which were installed in central-eastern Greenland in the region between Scoresby Sund and Summit from June 2009 to May 2012. Eight of these stations were installed on bedrock, and the remaining 10 were installed on the ice. These stations were complemented by stations from other networks (Dahl-Jensen et al., 2003): DBG, ICESG, SCO, SOE, SUMG, HJO (Fig. 1).