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Wide-Angle Seismic Data Across Northern Svalbard Continental Margin

A. Minakov[1], T. Funck[2], J. Meza-Cala[1], C. Gaina[1] and J.I. Faleide[1]

[1]Centre for Planetary Habitability, Department of Geosciences, University of Oslo, Norway; [2]Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark;

Abstract

The northern Svalbard continental margin formed due to early Cenozoic continental breakup in the Eurasia Basin. Gravity modeling and seismic reflection data have previously indicated a zone of hyper-extended crust and possibly exhumed mantle landward ocean chron 24 (53 Ma). This study aims to test this hypothesis by combining existing data with new ocean bottom seismometers northeast of Svalbard in 2022. The first-arrival seismic travel time tomography was performed using non-linear Bayesian inversion incorporating existing MCS data. The mean velocity model was analyzed using cluster analysis and gravity modeling. The results indicate a 1-2 km thin crust within the continent-ocean transition (COT) which makes likely the serpentinization of the uppermost mantle at COT (Fig. 1). The velocity model predicts normal oceanic crust at the location of magnetic chron 24.

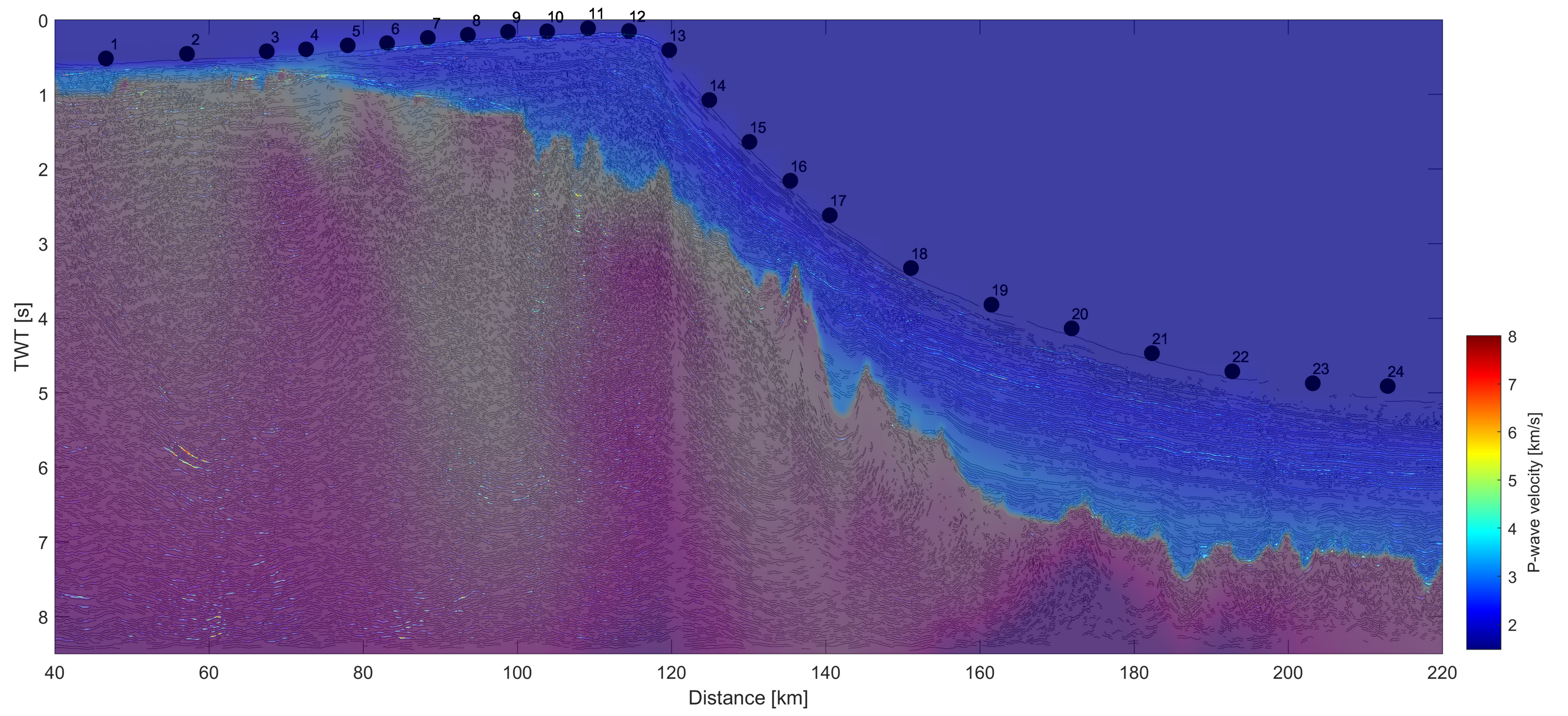

Figure 1:
Combined Multichannel reflection Line NPD-1204-402 and wide-angle seismic profile across the northern Svalbard continental margin. Location of ocean bottom seismometers (OBS) indicated.

1 Introduction and Motivation

The exhumation of sub-continental upper mantle at the continent-ocean transition in the Arctic Eurasian Basin has been previously inferred based on gravity modelling and seismic reflection data [Lutz et al., 2018, Minakov et al., 2012]. Lutz et al. [2018] postulated that corridors of the exhumed mantle have been embedded within the oceanic crust since its inception in the Early Eocene.

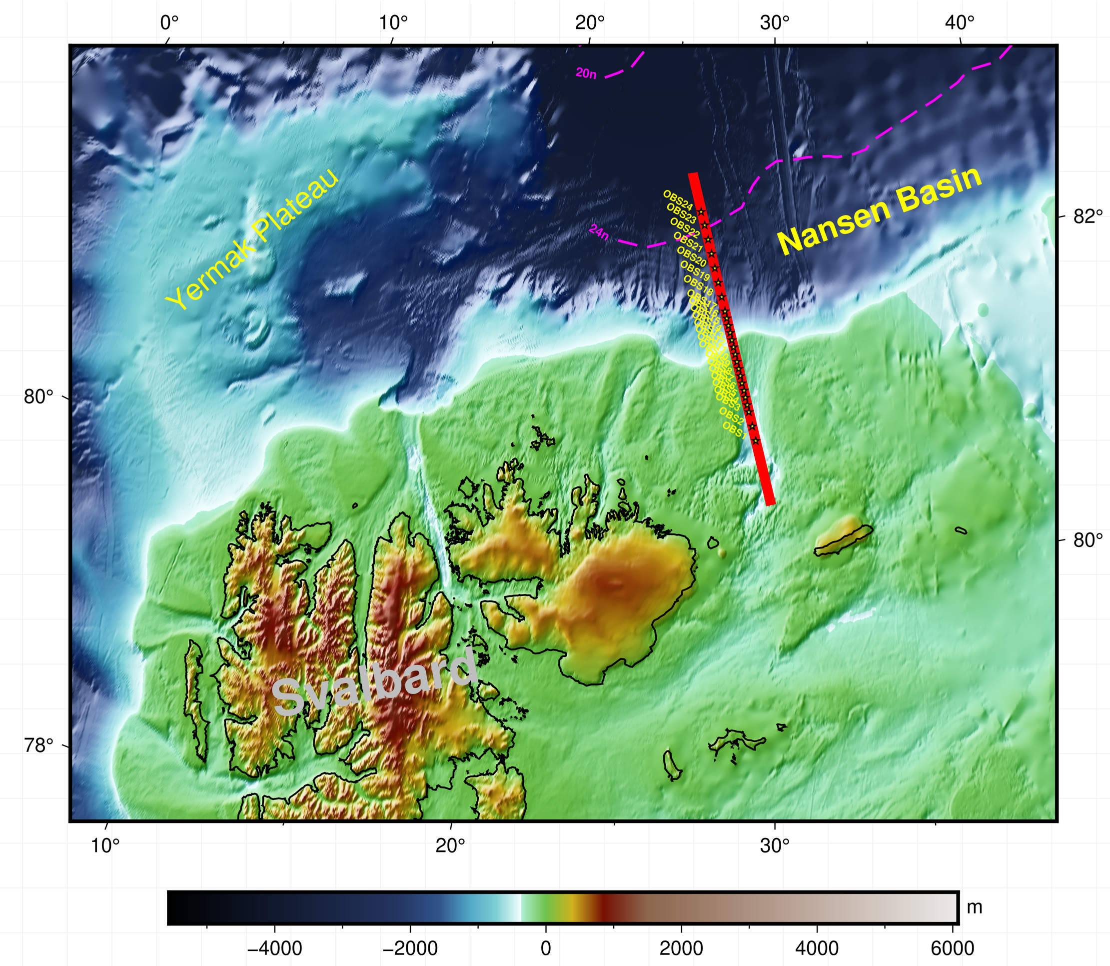

Figure 2: Location of the GoNorth-2022 wide-angle seismic data in the Arctic Eurasia Basin. Magnetic isochrons are shown by dashed lines.

In this study, we test this hypothesis and present results of travel time tomography based on an ocean bottom seismometer (OBS) survey carried out across the COT northeast of Svalbard (Fig. 2). The data acquisition was facilitated by the use of a remotely operated vehicle (ROV) which made possible the recovery of the instruments in the ice-covered area.

2 Data and Methods

The seismic refraction/wide-angle reflection data were obtained along a 200-km-long profile using 24 ocean bottom seismometers (OBS) operated from Kronprins Haakon icebreaker. The instrument array consisted of 5 Trilobit OBS of the University of Bergen (UIB) and 19 Sercel microOBS by DanSeis/GEUS (Fig. 3). The OBS deployed at the sites under the sea ice and UIB nodes were deployed/recovered using the ROV operated via the moonpool.

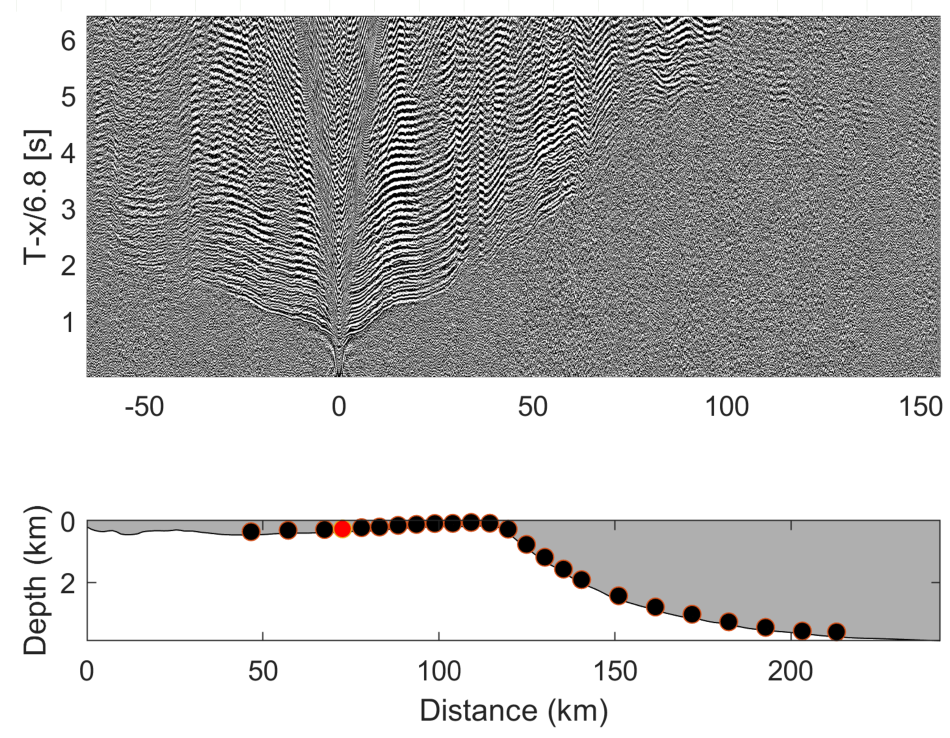

Figure 3: Data Example. Vertical component record from the UiB Trilobit instrument (OBS04). Red circle shows the OBS location.

The traveltime calculation is performed by solving the eikonal equation using the fast marching method [Sethian and Popovici, 1999]. The first-arrival traveltime tomography was based on a non-linear least squares minimization using the exponential covariance model and prior information (Fig. 4).

3 Results

The seismic P-wave velocity model along the coincident reflection-refraction profile (Fig. 4) reveals significant variation interpreted through the cluster analysis as lithological features (Fig. 5) and provides insights into tectonic evolution of the northern Svalbard rifted margin. The seafloor and the top acoustic basement were identified on a coincident multichannel reflection profile acquired by NPD/Dolphin Geophysical in 2012. The mantle exhumation is marked by a P-wave velocity >7.5 km/s between 160 and 200 km distance. Beyond this distance, the crustal velocity follows the oceanic crust profile. The continental crust is heterogeneous containing a P-wave velocity of 6.0-6.4 km/s as background values containing localized high-velocity (magmatic intrusions) and low-velocity (sedimentary basins) anomalies.

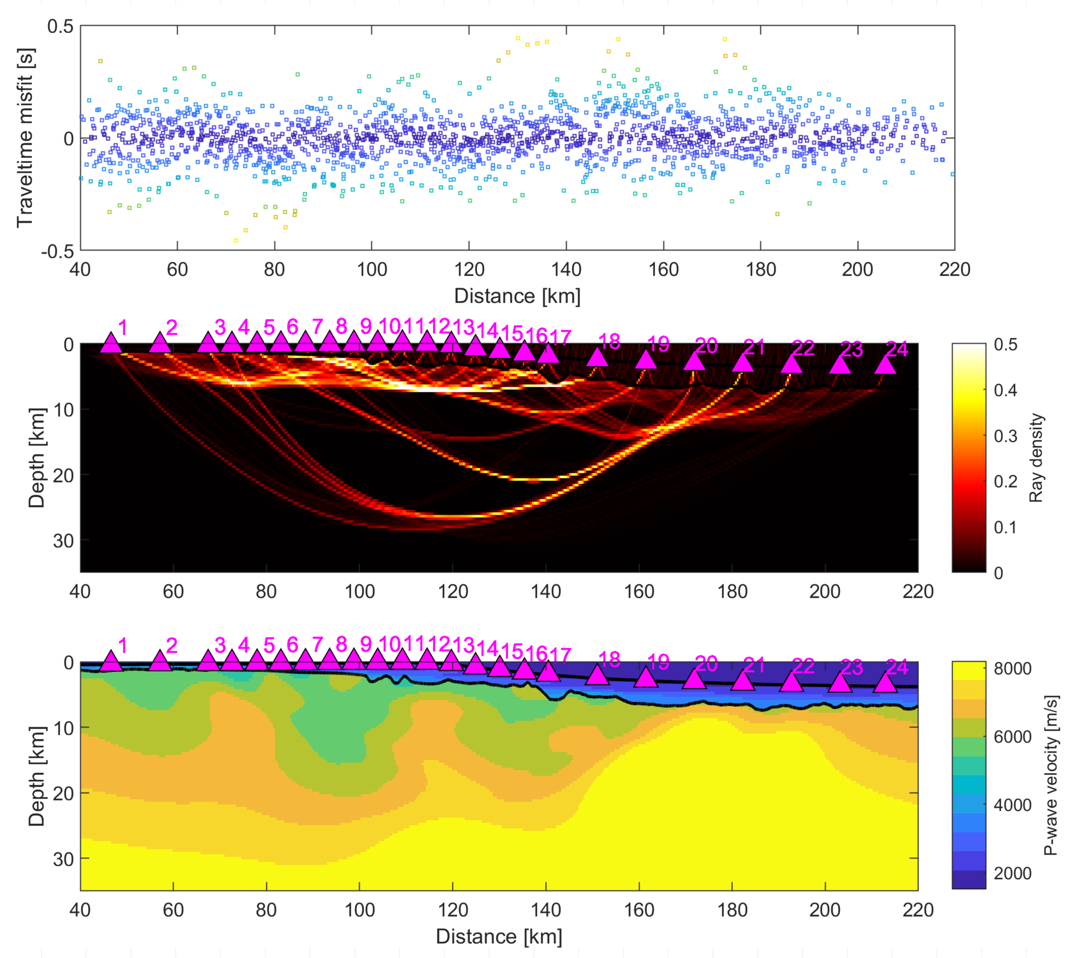

Figure 4: Traveltime tomography results. Traveltime misfit for the final model (a), ray density (b), mean velocity model (c).

3.1 Cluster analysis

The P-wave velocity model from traveltime tomography of OBS data was classified using the k-means method with an Euclidean metric in the space of seismic velocity, distance, and depth. Six classes were identified and corresponding lithologies were interpreted (Fig. 5).

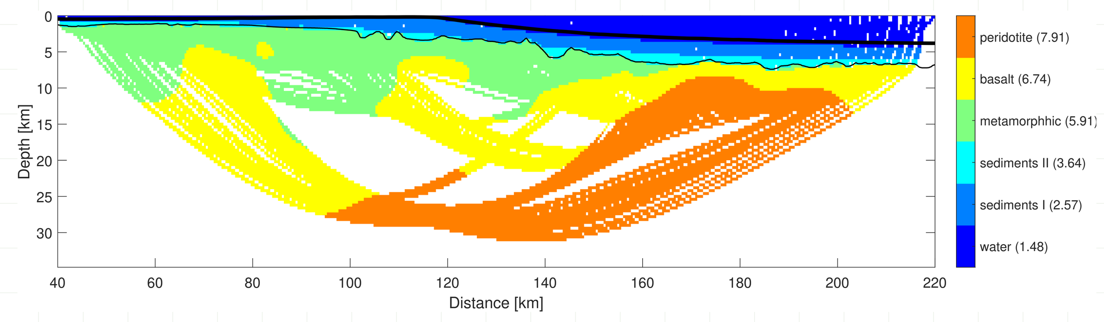

Figure 5: Classification of velocity model using cluster analysis. The model areas with no ray coverage are masked. The interpreted lithology and median P-wave velocity (km/s) are indicated.

3.2 Model resolution

The model resolution tests were performed using checkerboard templates and the real acquisition geometry (Fig. 6).

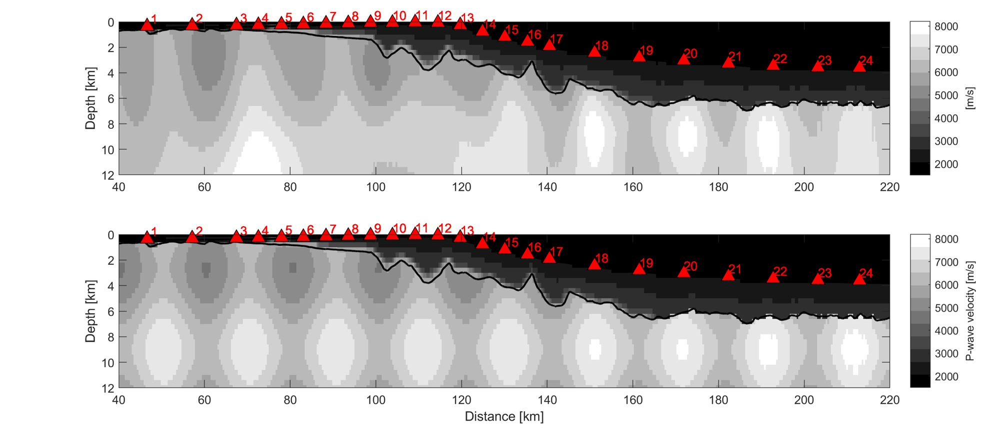

Figure 6: Checkerboard test. Bottom panel: The input test model with superimposed Gaussian perturbations with the size of 10x5 km and maximum amplitude of 10%; Top panel: Recovered test velocity model after 10 non-linear iterations.

3.3 Gravity modeling

The gravity anomaly was computed using the density model derived from the lithology classification and a grid search method (Fig. 7). The optimal density values were determined by minimizing the misfit between the model predictions and the observed gravity data.

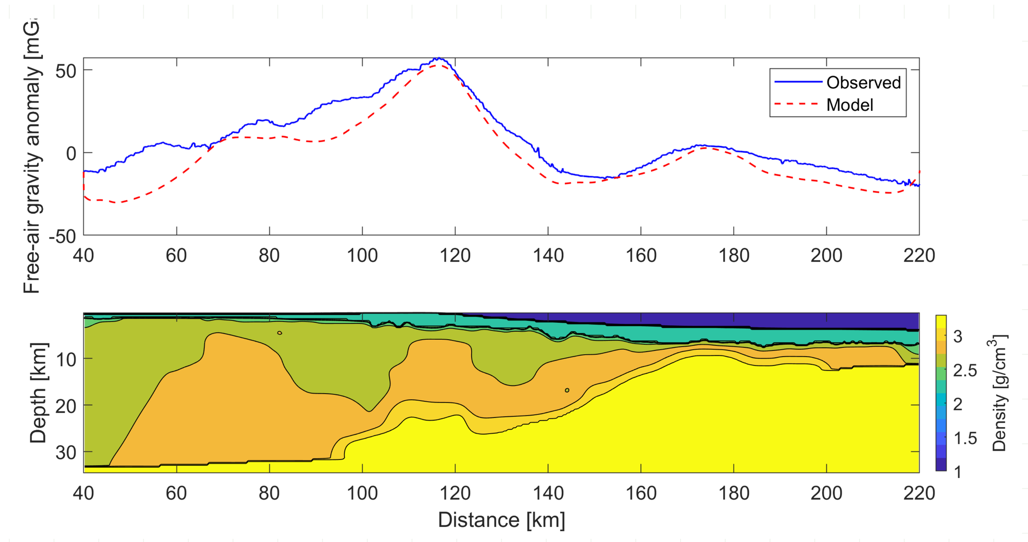

Figure 7: Density model along the GoNorth-2022 profile based on 2D gravity modeling. The observed gravity data were acquired during the expedition using onboard marine gravity meter.

4 Conclusions

- The analysis of GoNorth-2022 OBS data using seismic traveltime tomography provides a P-wave velocity model of the continent-ocean transition (COT) at the northeast Svalbard continental margin;
- The model predicts COT underlain by a very thin crust of 1-2 km that makes likely the serpentinization of the uppermost mantle in this region;
- The upper crust on the northern Svalbard continental shelf is laterally heterogeneous caused by magmatic intrusions and deep basins possibly containing metamorphosed sediments.

Acknowledgement

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