Crustal thickness in the Circum Arctic

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ABSTRACT

Crustal thickness data are used in calculating the corrections necessary for developing seismological and global geophysical models. Such data also offer some criterion for distinguishing the types of crust in zones of transition from continents to oceans. Extensive seismic investigations performed in the Arctic in recent years have considerably improved the accuracy of previous compilations and have enabled the development of a more detailed digital model of the Earth's crust. All available deep seismic geotransects acquired north of 60° N during the period 1960-2010 were used. This dataset includes more than 200 seismic profiles totaling approximately 110 000 line km. The new map is an important contribution to geophysical and geotectonic interpretations of the Arctic region and has global implications.

INTRODUCTION

Information on the Earth's crustal thickness plays an important role in studying the deep (down to 80-100km) structure of the Earth. It is necessary for calculating the corrections in seismological and global geophysical modeling, as well as for structural and geodynamic interpretations. In zones of transition from continents to oceans, the change of crustal thickness is often a defining criterion for determining the position of the continent-ocean boundary.

Seismic methods play a leading role in studying the thickness of the crust, where the base of the crust is identified by the depth of the Mohorovičić (M or Moho) discontinuity. The most common method is deep seismic sounding (DSS) in which Moho depth is determined from refracted and post-critically reflected wave data, often called wide-angle seismic (Mooney, 2007). Sometimes the base of the crust can be recognized in seismic sections obtained from sub-critical reflections using the multi-channel seismic (MCS) methods (Suleimanov et al., 2007), and sometimes by the receiver function methods (Zolotov et al., 1998). In the absence of seismic data, crustal thickness estimations can be made using the correlations between the Moho depth, topography and Bouguer anomalies (Demenitskaya, 1967; Kunin et al., 1987).

Under the international project "Atlas of geological maps of the Circumpolar Arctic at 1:5 000 000 scale" (BULLETIN 54 CGMW, 2006), Russia coordinates the compilation of the Tectonic map of the Arctic which includes the Earth's crustal thickness map as one of its components. Earlier compilations for individual parts of the area north of 60° N included a depth to Moho map from seismic data (Ritzmann et al., 2006; Grad et al., 2007; Erinchek et al., 2007) and crustal thickness maps derived from gravity anomalies (Verba et al., 2000; Braun et al., 2007; Alvey et al., 2008). However, due to the sparsity of seismic profiles in the Arctic and a lack of representative data on correlations between crustal thickness and gravity anomalies, these maps were not integrated and, indeed, show marked inconsistency. The only compilation of Moho depths for the entire Arctic region was the CRUST2.0 map based on the 2° x 2° global model (Laske et al., 2000) but it appeared too coarsely sampled for the purposes of tectonic interpretations (Fig. 1). Inconsistencies of Moho depths in overlapping areas of regional maps created by different authors group are within the range ±0–4 km in onshore and offshore areas supported by deep seismic investigations. Inconsistencies in offshore areas where Moho depths were derived mainly from gravity data are ±4–12 km. North American and West Greenland part is represented by the single CRUST 2.0 map, so its accuracy is not estimated. Extensive recent seismic investigations in the Arctic (Matveev et al., 2007; Poselov et al., 2007; Kaminsky, 2009; etc.) have greatly improved the accuracy of previous mapped products and have

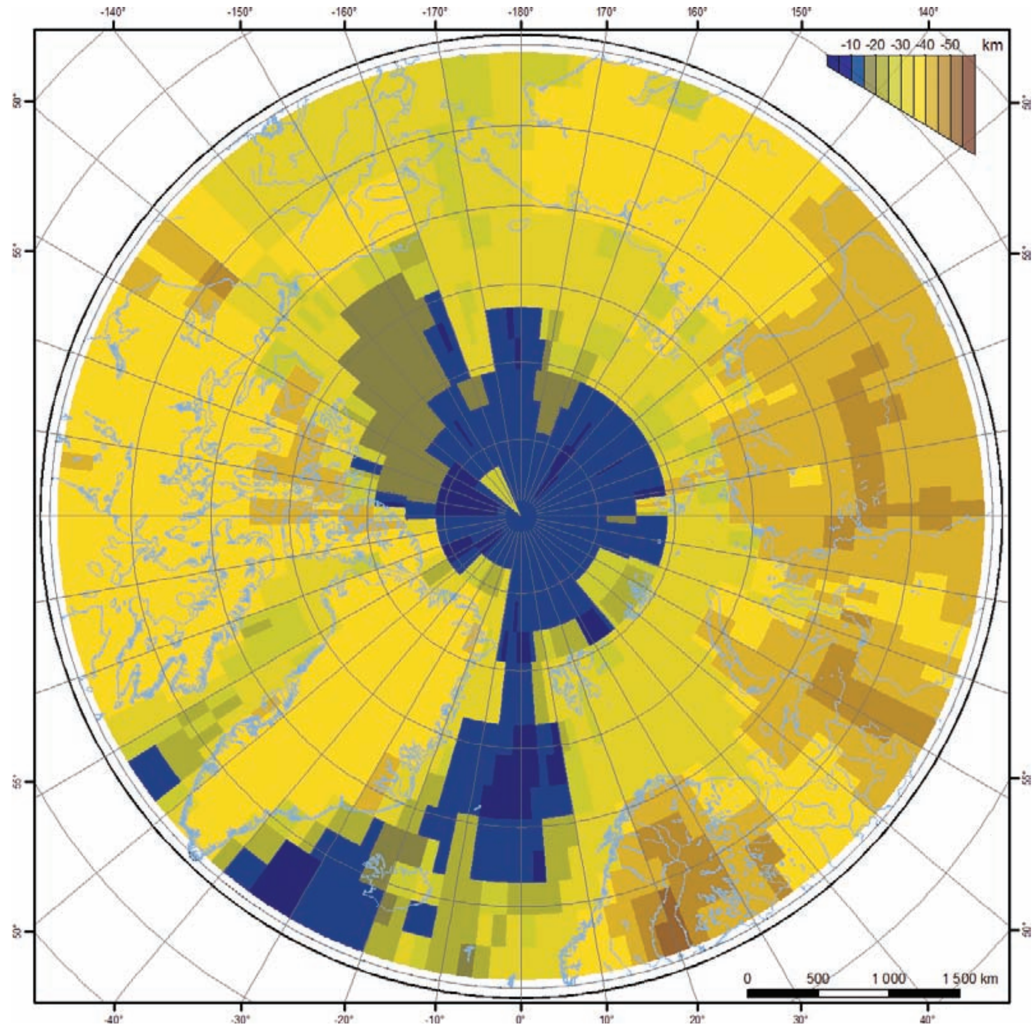

Fig. 1. Crustal thickness in the Circum Arctic based on the global crustal model CRUST 2.0 (Laske et al, 2000)

made possible a new digital model of the Earth's crustal thickness for the Circumpolar Arctic.

SEISMIC DATA

All available crustal seismic sections north of 60° N produced by earlier investigators between 1960 and 2010 were utilized in the compilation of the new map. This database includes more than 200 seismic sections totaling approximately 110 000 km in length (Fig. 2). About 75% of sections are based on wide-angle seismic data, the rest are based on MCS reflection and receiver function data.

As can be seen in Fig. 2, the coverage of the Arctic region by deep seismic methods is very irregular. The density of profiles in North Eurasia and in the Barents Sea is approximately 5 km per 1 000 km^2, whereas in North America and in the Canada Basin deep seismic profiles are virtually absent. Most seismic lines (c. 73 000 km) are located on land while about 32 000 km are located offshore.

A detailed list of publications (see Bibliography), describing approximately 180 crustal sections, plus more than 20 previously unpublished seismic sections kindly provided by RosGeolFond and individual research teams have been incorporated in this compilation.

CORRELATION BETWEEN MOHO DEPTH, TOPOGRAPHY AND BOUGUER ANOMALIES

A significant part of the Circum Arctic is not characterized by DSS observations and required utilization of additional information, in particular from gravity data. Due to peculiarities of deep seismic studies, information on Moho depth is commonly much more generalized than surface

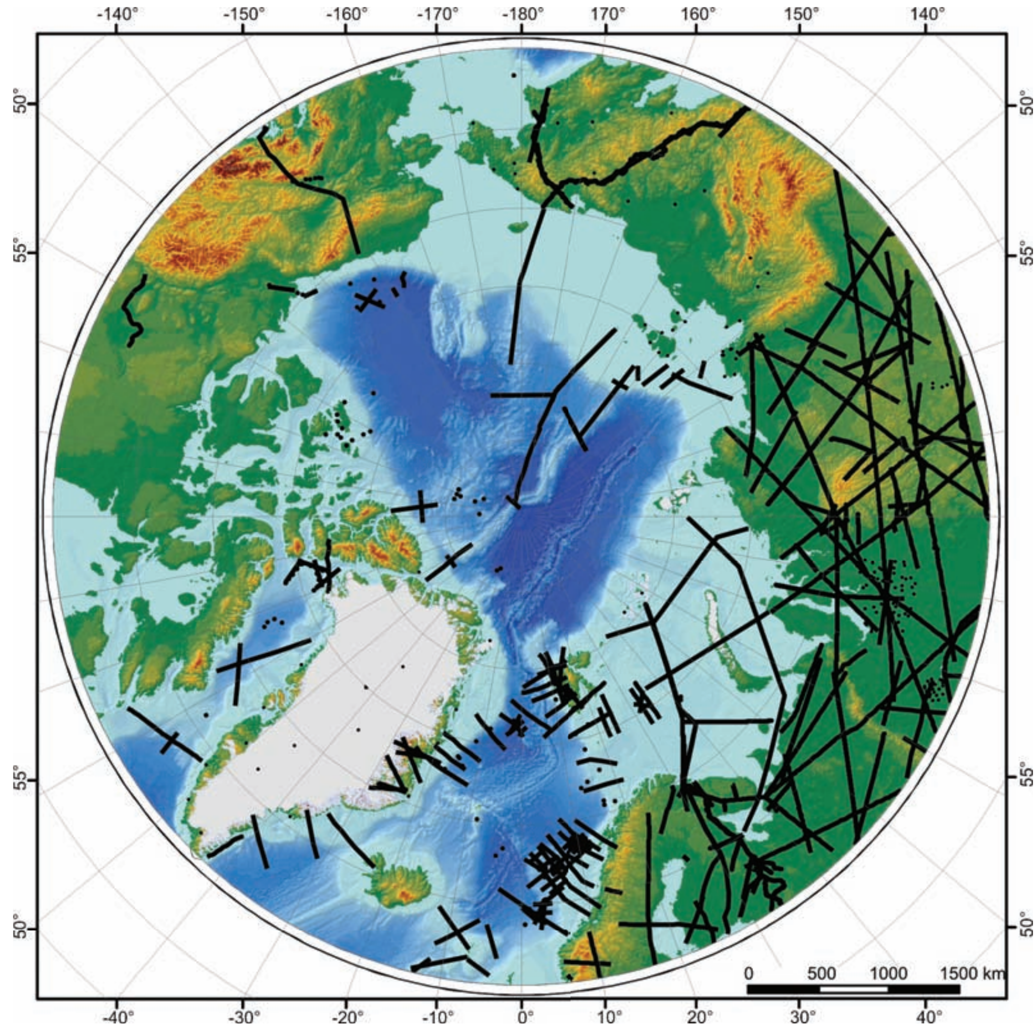

Fig. 2. Location of deep seismic profiles and points of determination of Moho depths from seismic data

topography and gravity data. Therefore, to achieve a more homogeneous view of crustal structure, we analyzed the correlation between the Moho depth, topography, and gravity anomalies smoothed by different averaging radii. To increase the representativeness of the correlation, the seismic data from the Circum Arctic (where the variations in model parameters, especially on land, are relatively small) were supplemented by seismic, topographic and gravity data from the whole of Eurasia, including highly mountainous fold belts.

The best correlation with Moho depth was found for topographic and Bouguer anomaly values calculated with an intermediate layer density of 2.67 g/cm^3 and smoothed by a 100 km window. Figure 3 shows scatter plot correlations of the model parameters: Moho depth (Z_M in km), topographic elevations averaged over a 100 km radius (h_{100} in m), and Bouguer anomalies, averaged over a 100 km radius (G_{100} in mGal).

It can be observed that the slopes of the regressions for land and marine data differ, notably in the Z_M–G_{100} plane (Fig. 3b), while remaining almost constant in the Z_M–h_{100} plane (Fig. 3c). This may be caused by a different relationship between the Bouguer reductions selected for onshore and offshore topography (Fig. 3d). Consequently, two bivariate regressions were selected to estimate values of Moho depth from known values of topographic elevation and Bouguer anomaly: the first one for land ($h_{100} > 0$), and the other for marine areas ($h_{100} < 0$) (Table). Both regressions have similar values of correlation coefficients equal to 0.83-0.84, that result in a root-mean-square error of Z_M estimates of 5 km.

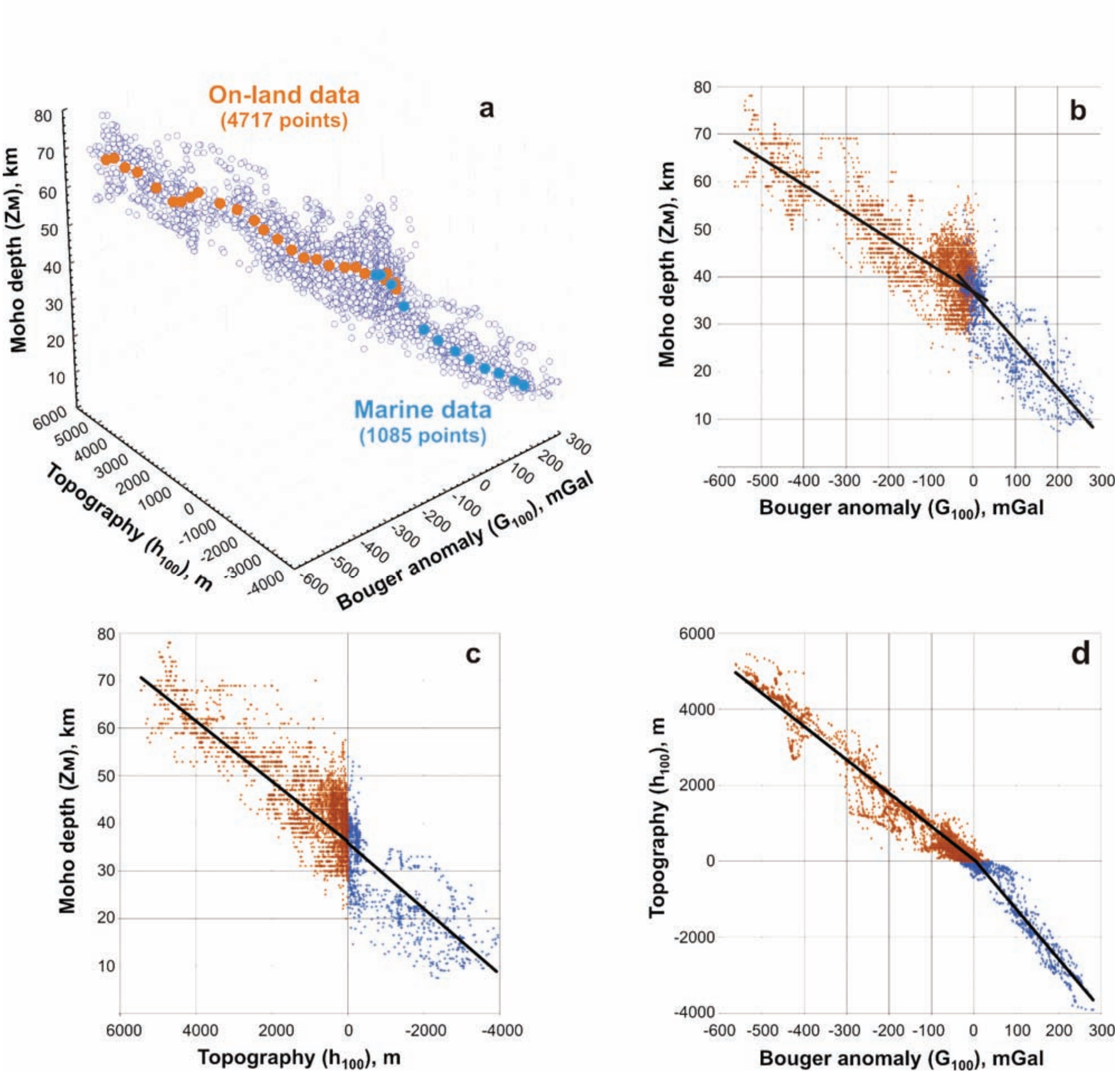

Fig. 3. Scatter plots and correlations between Moho depth, Bouguer anomalies and topography: a – regression domain for ZM, G_{100} and h_{100}, where ZM is depth to Moho (km), G_{100} is Bouguer anomaly (mGal) averaged over a 100 km radius, h100 is topographic elevation (m) averaged over a 100 km radius; b, c, d – projections of the regression domain on corresponding planes

Table. Empirical expression for estimating Moho depth from the smoothed Bouguer anomaly and topography. The first expression is for land areas while the second is for marine areas.

Equation	Range of values variation, dimensions		
	ZM	G_{100}	h_{100}
ZM = 36.3 – 0.038G_{100} + 0.003h_{100}	20.0 ÷ 80.0 km	-560 ÷ +35 mGal	0 ÷ 5400 m
ZM = 36.3 – 0.137G_{100} + 0.003h_{100}	7.5 ÷ 48.0 km	-30 ÷ +280 mGal	-4200 ÷ 0 m

COMPILATION PROCEDURE AND ERROR APPRAISAL

The Moho depth values were taken from seismic sections at 25 km interval and plotted on the data location map. Altogether this map included approximately 1000 ZM values in the Arctic Ocean and its marginal seas, and about 2600 ZM values in the continental part of the Circum Arctic.

In spaces between profiles and in vast areas devoid of seismic data, the Moho depth values were derived from digital maps of gravity anomalies (Gaina et al., 2009) and of onshore topography and offshore bathymetry (IBCAO ver 2.23). After averaging the Bouguer anomaly values and topographic elevations over a 100 km radius in accordance with the formulas shown in Table, ZM values were estimated separately for offshore and onshore areas using a 10 km x 10 km grid. The two grids were merged into a single model with subsequent Moho depth mis-tie correction along the coastline. Based on the adjusted data, a new digital dataset was calculated and integrated with earlier digital maps of Moho depths (Ritzmann et al., 2006; Grad et al., 2007; Erinchek et al., 2007) The resultant map is represented as a ZM digital model with cell size of 10 km x 10 km for the entire studied region.

An appraisal of interpolation error during recalculation of the ZM values into a uniform grid was made by comparing interpolated and initial values for 3600 locations where the depth values were also found from seismic data. The root-mean-square deviation between interpolated and initial values amounted to 1.7 km against 5 km contour interval in the final Moho depth map. Figure 4a shows the difference between gravity-derived and seismic-derived values for onshore areas, and Figure 4b – for offshore areas.

After subtracting ocean depth values and correcting for observation altitude on land, the map of Moho depth values was transformed into the map of the Earth’s crustal thickness for the Circum Arctic (Fig. 5).

The main significance of the crustal thickness map in the Arctic region lies in its potential for interpretation of the tectonic structure of the Central Arctic bathymetric highs which include the Lomonosov Ridge and the Mendeleev-Alpha system separated by the Podvodnikov-Makarov Basin and the Chukchi Borderland. The map’s value in this respect rests on the fact that its compilation is, for the first time, based on extensive findings from multinational deep seismic studies conducted in this area and its juxtaposition with the adjacent Eurasian and North American continental margins (“Transarctica-1989-92”, “Arctica-2000”, “Arctica-2005”, “Arctica-2007”, “Arta-2008 on the Alpha Ridge”, “Lorita-2006 on the Lomonosov Ridge”) (Jackson et al., 2010; Lebedeva-Ivanova et al., 2006; Poselov et al., 2007).

CONCLUSION

A new digital model of the Earth’s crustal thickness in the Circum Arctic significantly differs from the earlier CRUST2.0 global model (Laske et al., 2000) in capturing a much greater level of detail (compare Fig. 1 and Fig. 5). In the compilation we succeeded in incorporating a large amount of recent seismic data and interpretations, as well as in considerably less data smoothing compared to the global model and made all possible effort to avoid global data smoothing.

Crustal thickness in the Circum Arctic varies in a wide range from 5-10 km in the Norwegian-Greenland and Eurasia oceanic basins to 55-60 km in Scandinavia and the Urals. Horizontal size and configuration of the crustal thickness anomalies are comparable with those of regional geological structures. In our opinion, this new map is suitable both for introducing crustal-based corrections during seismic and global geophysical modeling, and for constructing geotectonic interpretations in the Arctic.

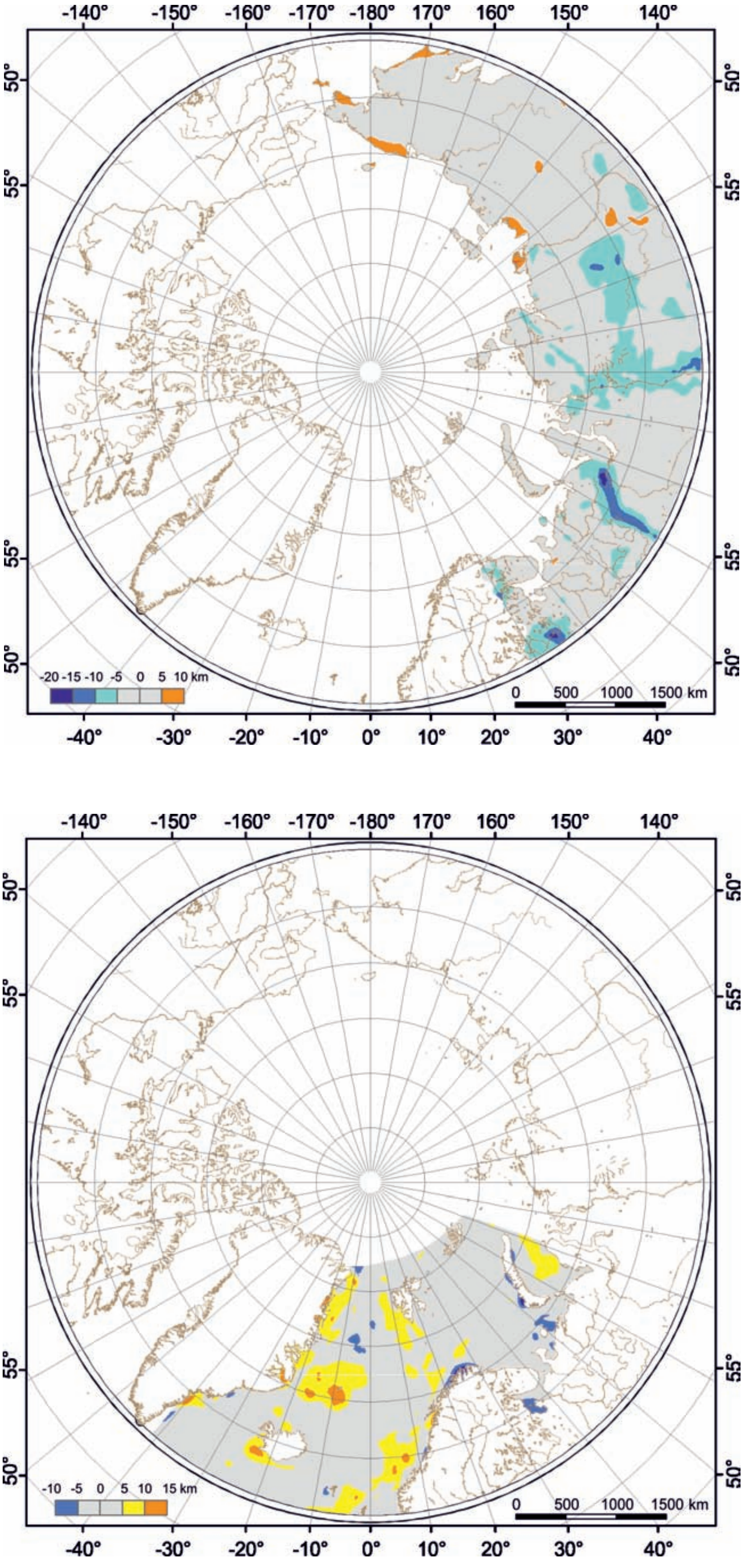

Fig. 4. Difference between the Moho depth map constructed on the basis of seismic data and the map constructed on the basis of bi-parameter correlation dependencies of Moho depth from Bouguer anomalies and topography: a – onshore areas, b – offshore areas

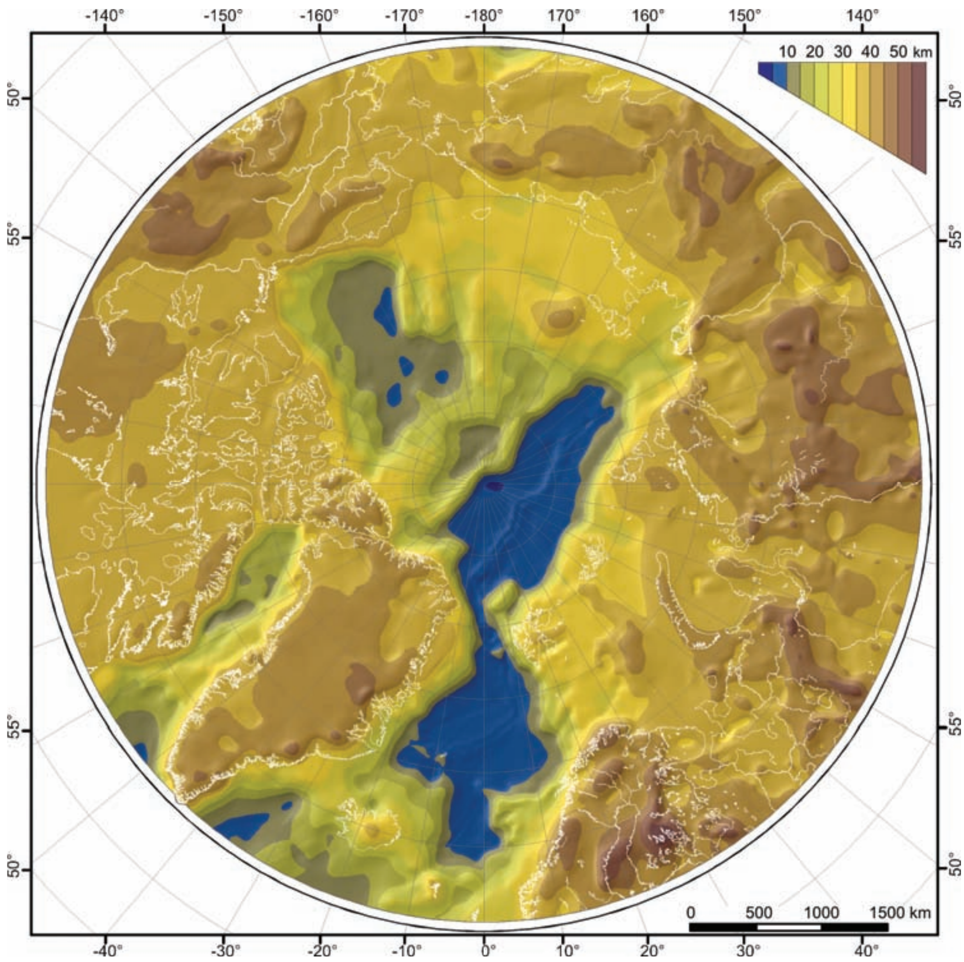

Fig. 5. Crustal thickness in the Circum Arctic

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