

THE OUTER EDGE OF THE CONTINENTAL MARGIN OF ARGENTINA, AUSTRALIA AND RUSSIA BY THE GRAVIMETRIC TOMOGRAPHY DATA

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Abstract: An outer edge of the continental mass is established by the foot of the continental slope in accordance with the UN Convention on the Law of the Sea (UNCLOS, article 76). It can be "visible" with the help of echo-sounding and seismic surveys. It is obvious that the real continental margin extends under upper layers of the abyssal ocean floor more seaward than the visible foot. The gravimetric tomography method [1] developed by us allows scientists to reconstruct the Earth's internal geological structure with the satellite altimeter and geoid data to determine the real outer edge of the continental mass and the breadth of the territorial sea along the coastal countries.

This method is based on using the observed gravitational potential of the Earth. Spherical harmonics of the EGM96 global geopotential model (geoid) are used as the input data for calculation of anomalous harmonic density.

Such an approach was used to determine the real boundary lines of the Argentine continental margin. It is shown that the natural geological outer edge of the Argentine continental mass is situated more seaward up to 300 km from the foot point at a depth of approximately 25 km. The Australian continental margin along 124°E is situated more seaward up to 140 km from the foot point at a depth of 12 km.

Similar research for the Arctic Region of Russia shows a significant shift of the Siberian continental mass to North. A connection between continental mass and Lomonosov and Mendeleev oceanic Ridges is disclosed at the depth of 80-250 km.

1. Introduction and target setting

Geoid topography is caused by the gravitational nature of the inhomogeneous geological structure of the Earth. The more dense mass generates an elevation on the surface of the sea and the less dense generates a depression. Such influence of the Earth's internal structure to the geoid topography can be easily detected by the altimeter data, which correlate with the sea bottom topography. Therefore, the documents of the Commission on the Limits of the Continental Shelf (CLCS) under the United Nation recommends to use this simultaneously with the conventional marine geophysical surveys to determine the continental margin boundary. Our method increases the amount of information of geoid data not only in the seabed topography research, but also for deep Earth masses (layers) determination. In Moritz's work [2], there is a solution which allows to determine the harmonic dense anomalies through the spherical harmonics of the gravity potential. Experienced geophysicist [3, 4] have mentioned their suggestions in regards to a connection between geoid's harmonics (degrees) and deep Earth's density disturbing

masses. Our method enables to create 3D models of the Earth's deep structure. The spherical coefficients of the EGM96 global geopotential geoid model were used.

Vertical and lateral sections calculated show a distribution of masses in all range of depths up to 5300 km, geometry and sizes of density inhomogeneities, their displacement in depth under the impact of geodynamic processes, and correlation of subsurface bodies with the known topographic features.

Geoid is the geodesic reference system, and the structure models calculated from the geoid data have a high degree of accuracy in terms of positioning. For this reason alone, we implemented the capacity of the gravimetric tomography method to the problem of determining the outer edge of the continental margin of coastal states. A term "foot" ("the point of maximum change of gradient at the base of the continental slope") in the sense of the outer edge of the continental margin and the natural prolongation of a coastal state land territory (UNCLOS, article 76) was accepted during earlier development, when the discoveries of the geological composition of the seabed were limited to a large extent by the methods of echo sounding and geomorphology.

An additional using of gravimetric and magnetic data and seismic profiling does not ensure a single meaning of the "foot" point location in a different of regions. A more exact understanding of the "continental shelf edge" as compared to "foot" is necessary to link to the real edge of continental masses located further offshore. The distribution of these masses under the oceanic abyssal floor in the current time may be determined by using new altimetry data or using the geoid model, as well as by the presented method of gravimetric tomography. The large available volume of altimetric data and the newly created geoid model EGM 2008 based on this data will allow to obtain the exact and objective evaluation of the extension and delimitation of the continental masses of coastal states. The spatial resolution of this model is 5-10 km, that is more detailed than the usual intervals between the costly shipboard oceanic researches over large field.

Examples of the use of the gravimetric tomography data in various regions for establishing of the outer limits of the coastal States's continental shelf in the context of the UNCLOS is shown in the subsequent sections.

2. Establishment of the outer limit lines of the Argentine continental margin

An application of our method is shown using the example of the Argentine shelf region in connection with the Argentine Project in determining the boundary of the Argentine continental margin.

The geophysical polygon and profiles of the geoid topography and the relief of the earth surface are shown in Figure 1.

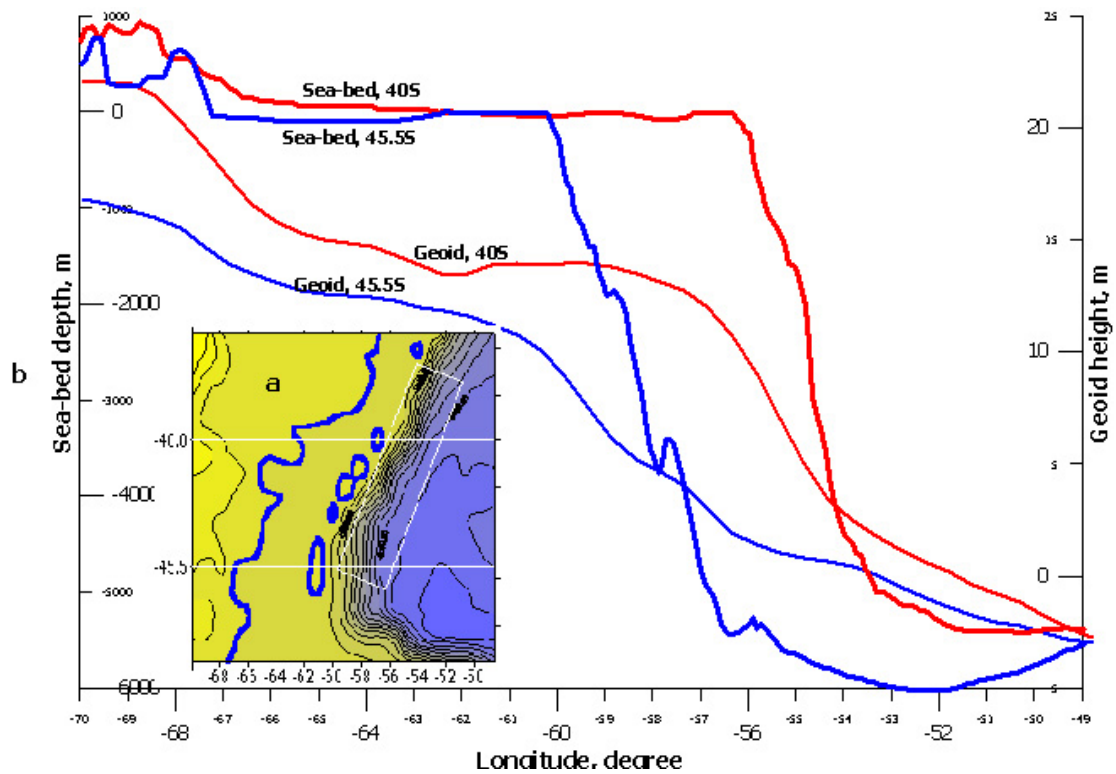


Figure 1. The geophysical polygon and profiles of the geoid topography and the relief of the earth surface (visible terrestrial and the sea-bed) at latitudes 40°S (red) and 45.5°S (blue).

a – topography of Argentina and the adjacent ocean floor,

b – topographical profiles (axis on the left), profiles of the geoid (axis on the right)

Figure 2 shows the vertical cross-section of density inhomogeneities with the harmonic density anomalies in g/cm^3 which is located along latitude of 45.5°S through the shelf, slope and abyssal floor of the Atlantic Ocean.

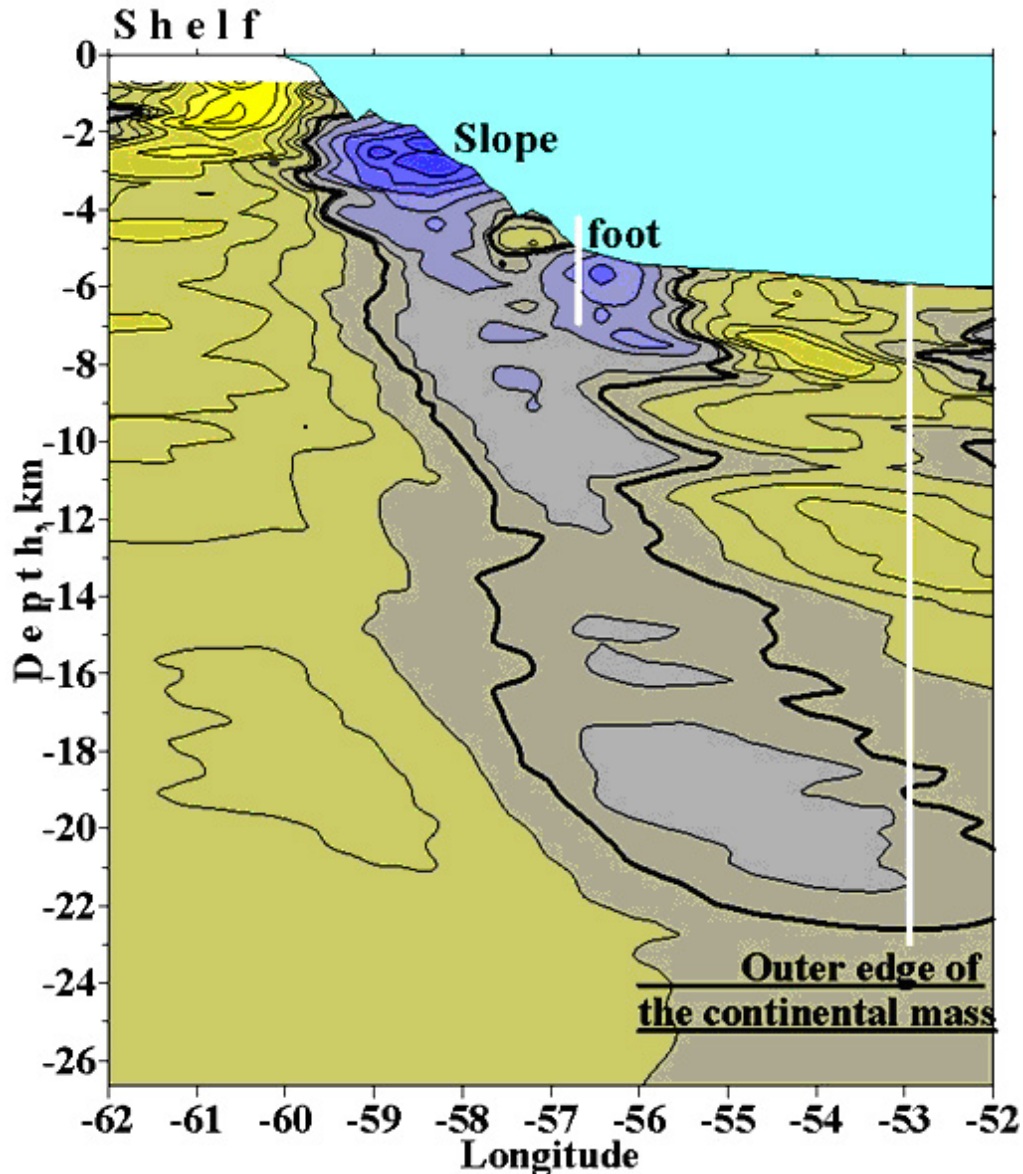


Figure 2. Vertical cross-section of density inhomogeneities along latitude of 45.5°S. Depths are from the sea surface. Contour interval is 0.005 g/cm³. Solid contour line is -0.005g/cm³. Blue color indicates regions of less dense structures and yellow color indicates more dense structures

Several deep cross-sections were calculated to determine the real boundary of the continental mass in different regions of the Argentinean shelf. Thus, the natural geological outer edge of the Argentine continental margin can be referred to the corresponding polyline on the map in Fig. 3. This line is situated more seaward from the foot line on distance from 50 km up to 300 km.

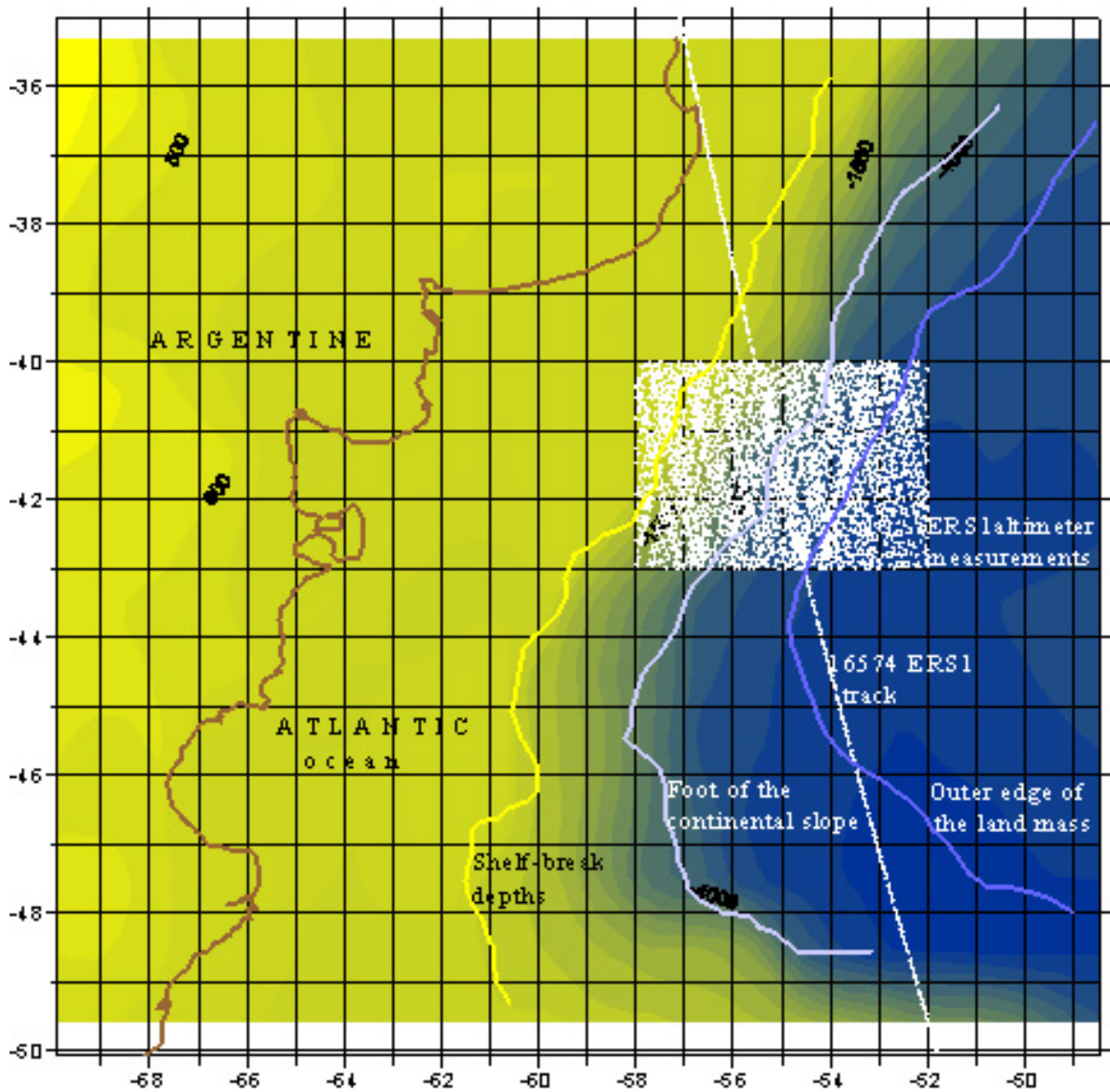


Figure 3. Location of the limit lines by the EGM96 geoid topography data. Background is the sea bottom topography by ETOPO5

Now, a high dense grid of the satellite altimeter measurements is achieved in the World Ocean due to the ERS1 and GEOSAT geodetic missions. One of sites of the region covered by the ERS1 measurements is shown on Fig. 3. They are a part of the ERS1 geodetic mission. Only 126 orbits are tracked within this small site. The whole extension of the ground tracks is more than 39000 km. An average distance between measurements is 5 km. ERS1, ERS2, ENVISAT and GEOSAT available data will increase density a few times. It is obvious these data are more detailed than any shipboard survey.

3. Geological structural features of Australia's continental margin

The continental margins of Australia collide with active oceanic lithosphere thrusts along the whole perimeter from the offshore at the west, south and east (Fig. 4). The Australian rather narrow shelf and steep slopes are generated by this reason apparently.

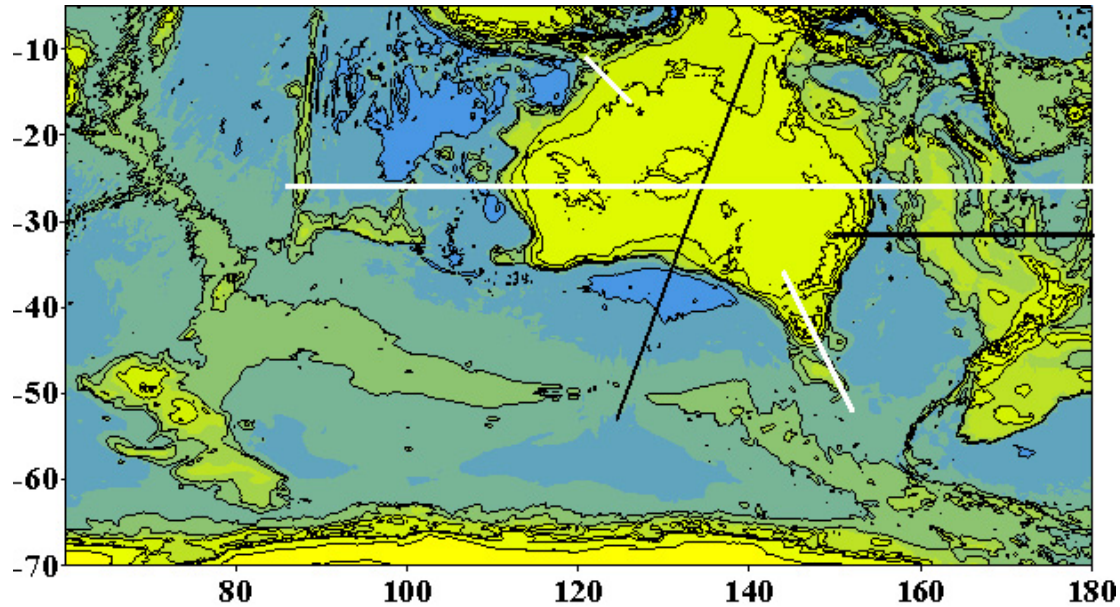


Figure 4. Vertical cross-sections through the continental margins of Australia. Background is the seabed and earth topography by ETOPO5

The structure of density anomalies along the 26°S cross-section is a clear indication of such situation, especially in the eastern part of the section with sharply declining structures coming from the Pacific Ocean towards the continent (Fig. 5). The thickness of the continental lithosphere can be noted down to the depths of 40-70 km. At the deep depths the border between the low-density mantle of the Indian Ocean and the higher-density mantle of the Pacific Ocean can be clearly seen with the solid line (0.0 g/cm^3).

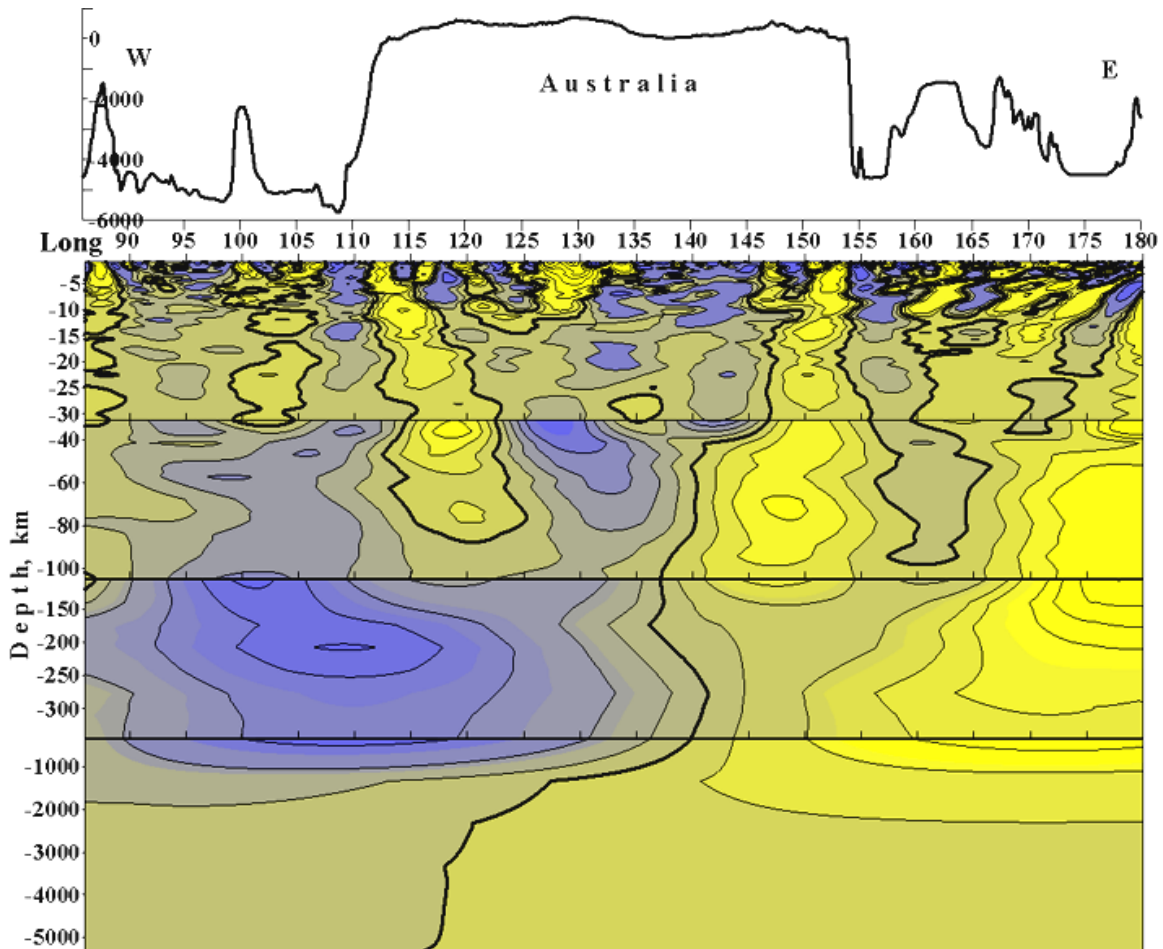


Figure 5. The vertical density section along latitude of 26°S from the seabed up to a depth of 5300 km. The vertical exaggerations are different for distinct layers (divided by horizontal lines), aimed to show important features within their boundaries. Therefore, the color scales are maintained within distinct layers only. The whole range of density anomalies values is between -0.078 g/cm^3 and 0.093 g/cm^3 . The thick isoline marks the value of 0.0 g/cm^3 . The spatial resolution is 30 km along the section as the EGM96 geoid data allows

There is another steep slope along the 124°E cross-section. The continental margin is located here more seaward up to 140km from the foot point. This is evident at the depth of 12 km.

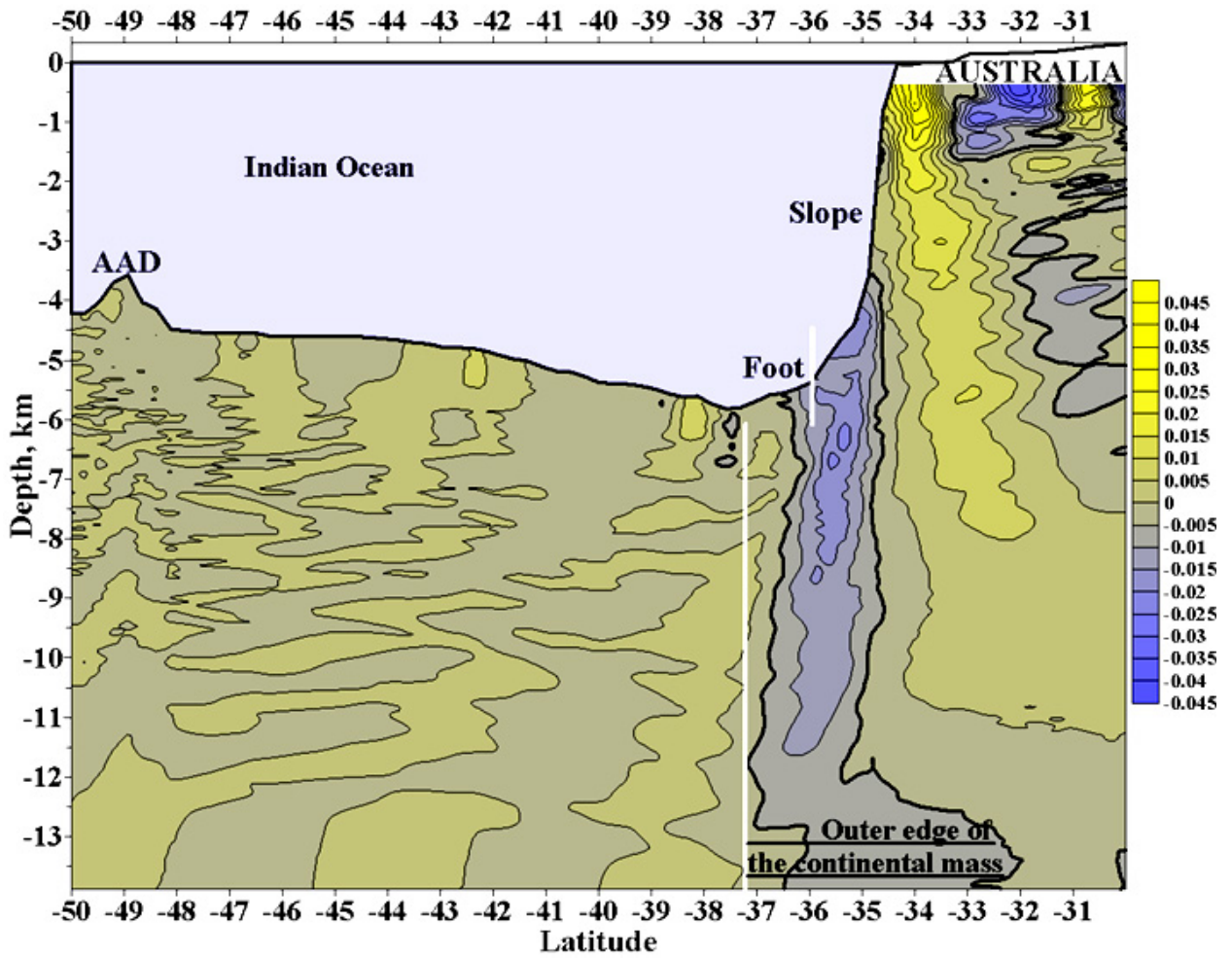


Figure 6. Vertical cross-sections of dense heterogeneities along the meridian of 124°E. AAD – Australian-Antarctic Discordance. Depths are shown from the sea surface up to 15km

The vertical cross-section from Australia through Tasmania to the Submarine Rise (Fig. 7A) was created and analysed.

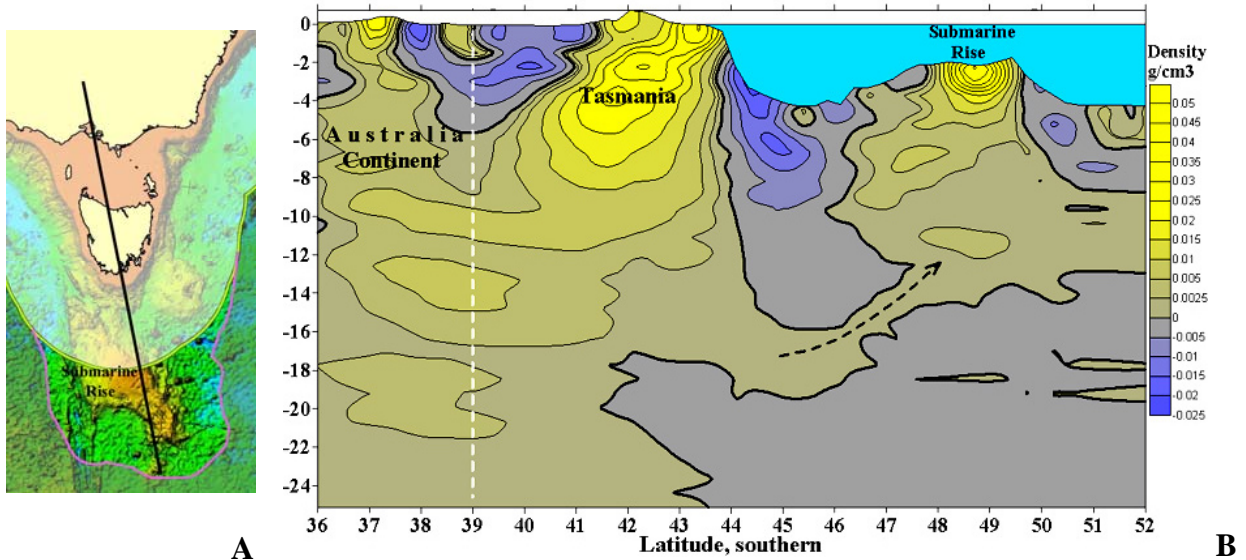


Figure 7. A – Location of the Continent-Tasmania Island- Submarine Rise section.
 B – Density inhomogeneities along the sections. Depths are shown from the sea surface. Dotted arrow denotes the channel between continental masses and Submarine Rise's bodies

The figure 7B shows a clear connection between the continental structures and the island at the depth of 10 km. The cross-section crosses the Submarine Rise which is also connected with continental masses at the depths of 16-17km (shown by the dotted black arrow). Furthermore, the distribution of the continental shelf beyond the 200 mile zone in the region of the Tasmania Island is presented in the Australian materials for the United Nations Commission on the Limits of the Continental Shelf in 2004. This is supported by our model which creates a connection between continental masses with this Submarine Rise.

4. Prolongation of the Eurasian structures into the Arctic basin

We applied to this region as an example to analyse the quality of the gravimetric tomography data from the point of view of the problem dealing with the distribution of continental masses into the Arctic ocean, as well as with the discussion regarding the belonging of the Lomonsov Ridge as a continental fragment to the continental shelf beyond the 200 mile zone. The purpose of the research was to identify visible connection (contact) of the continental masses with the Lomonosov Ridge. The calculations of density anomalies have been produced for several vertical cross-sections and lateral slices at various depths. The Fig. 8 shows meridional cross-section in the direction 90°W-Pole-90°E bounded by the limit 50°N. Only the boundaries of major masses are shown by contours -0.005 g/cm³ for clearer vision. Just like the previous figures, the blue color shows less dense masses and yellow shows more dense masses. The location of the cross-section is shown in Fig. 9.

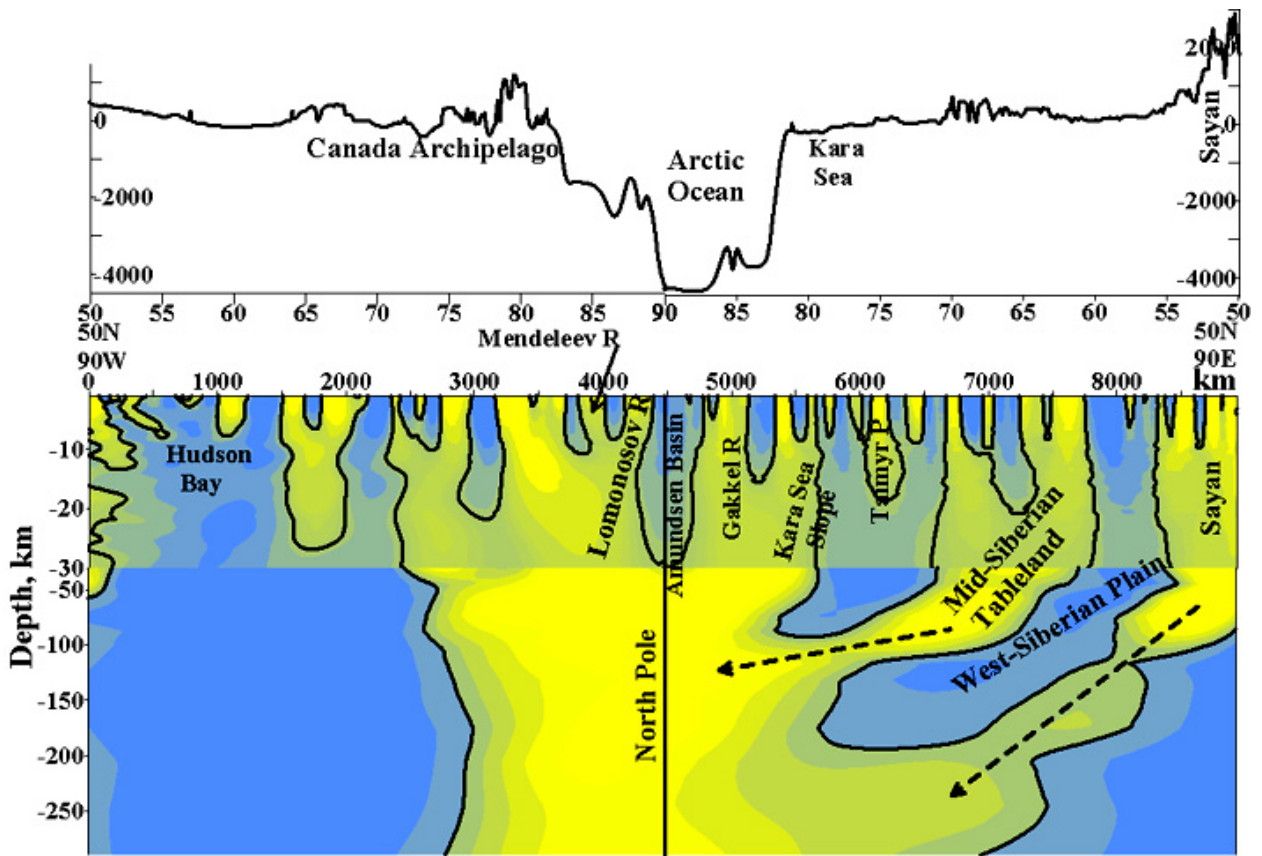


Figure 8. Structure of the Earth along meridians of 90°W-North Pole-90°E. Depths are shown from the earth's surface and the sea-bed (topographic profile on top). Arrows show the channels of links between continental structures and the polar zone

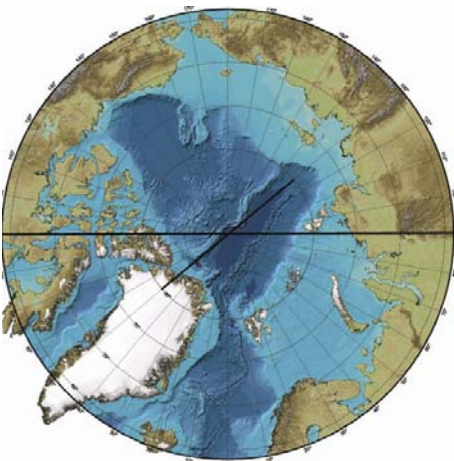


Figure 9. Location of two sections for Figures 8 and 10

There is a polar zone of higher density which is extended up to larger depths. The root parts of the well-known ridges, including the Lomonosov Ridge, join at this zone. Asian continental structures along the cross section also approach to this higher density zone and extend with a decline (Mid-Siberian Tableland, West-Siberian Plain and Sayan Ridge). The connecting channels are present at the depths of 100 to 250 km. Such significant shifts of root parts are caused evidently under the influence of mountain structures of the Himalaya and the Tibetau Plateau. The border with thinning zone (marked by blue color on figure 8), which hinders the extending of the North American continental masses to the polar region, is well shown. The closest continental structure to the Lomonosov Ridge is the Greenland Island. Figure 10 shows the cross-section along the 50°W-130°E meridians, which come across Greenland and the western part of the Lomonosov Ridge. The connecting channels are also noted here, but they appear broken and less definite than the 90°W-90°E cross-section.

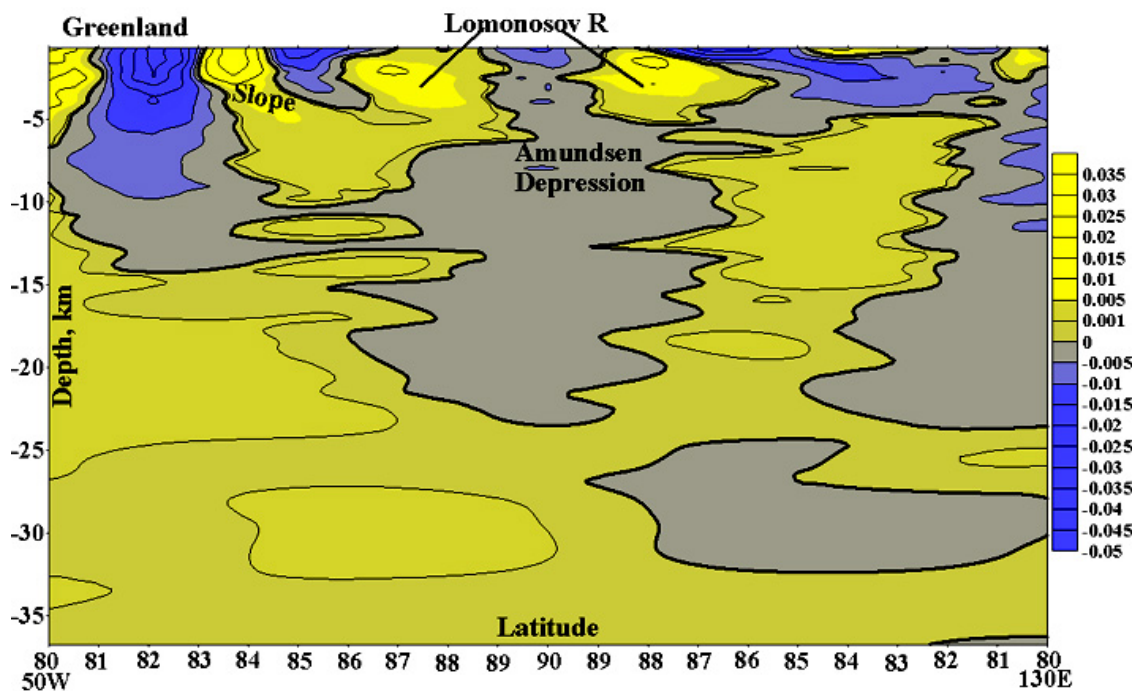


Figure 10. Cross-section along of 50°W-Pole-130°E within the latitude of 80°N. Depths are shown from the earth's surface and the sea-bed. The fragments of the Lomonosov Ridge appear separate due to the ridge's curve and shift from the line of cross-section

5. Gravimetric tomography technique

The Algorithm for Calculation of Anomalous Harmonic Densities

Our gravimetric tomography technique is based on realisation of the theoretical approach by Prof. H. Moritz [2] that the Earth's equipotential surfaces coincide with surfaces of the constant density and on usage of his algorithm of determination of the harmonic dense anomalies through the spherical harmonics of the gravity potential.

The solution of the inverse gravity problem is given by H. Moritz under some conditions. In particular, the distribution of density is a continuous function which can be

approximated uniformly by means of a system of polynomials. Then density, like the potential, can be expanded in series of spherical harmonics by polynomials. Another boundary condition is that a general solution, which corresponds to the zero-potential densities, is determined. That is the distribution of densities of the zero-potential is a set of positive and negative densities which do not change the external gravity potential as their total mass should be equal to zero. Anomalous harmonic densities are obtained by excluding the general solution from the harmonic densities.

Practically, we obtain distribution of anomalous harmonic dense inhomogeneities using one of the global spherical harmonic expansions of the external anomalous disturbing potential (conventional geoid model). The following final algorithm from [2] was used:

$$\rho_h = \sum_{n=2}^z \sum_{m=0}^n \frac{M(2n+1)(2n+3)}{4\pi R^{n+3}} \times r^n (c_{nm} \cos m\lambda + s_{nm} \sin m\lambda) P_{nm}(\cos\theta),$$

where ρ_h – anomalous harmonic density;

M – mass of the Earth;

R – radius of the Earth (in a point, to which the value of a geopotential is referred);

r – radius-vector of an internal point, in which a density disturbing the geopotential is determined,

$P_{nm}(\cos\theta)$ - Legendre polynomial of n th degree and m th order;

θ - central angle or spherical distance between R and r ;

c_{nm} and s_{nm} – coefficients of the surface geopotential spherical harmonics.

Transformation of the external spherical harmonics to the internal spherical harmonics is implemented by this algorithm.

Estimation of the depth of disturbing layer by the number of harmonics

The obtained above density anomalies are obviously situated in different depths. Therefore, the following question remains: which layers of the Earth are responsible for disturbance of one geopotential anomaly or another?

In our method an assessment of the disturbing layer's depth is computed by a known harmonic function in the geoid theory [2] for the case when the external potential of the internal masses confined by a sphere is determined

$$\frac{1}{r} = \sum_{n=0}^{\infty} \frac{\rho^n}{R^{n+1}} P_n(\cos\psi)$$

where r is the distance from the sphere surface down to the disturbing mass, ρ is the distance from the center of the sphere up to the disturbing mass, R is the radius of the sphere, $P_n(\cos\psi)$ is the Legendre polynomial of n th degree, ψ is the angle between R and ρ .

The calculation was carried out by using $n_{\min}=2$. Furthermore, the multiplier $(2n+1)1/2$ was taken into account in the right side of the expression, which is used for computing

the geoid for the normalisation of spherical functions. In the particular case where $\psi=0$, $P_n(\cos\psi)=1$ for all of n , and $r=R-\rho$. Thus, an appropriate n was selected by the assigned values of r , ρ and R .

Relationship between harmonic degrees n and depths l of disturbing layers is shown in the bilogarithmic diagram (Fig. 11). Main boundaries of the lithosphere are shown in accordance with the PREM density model of the Earth.

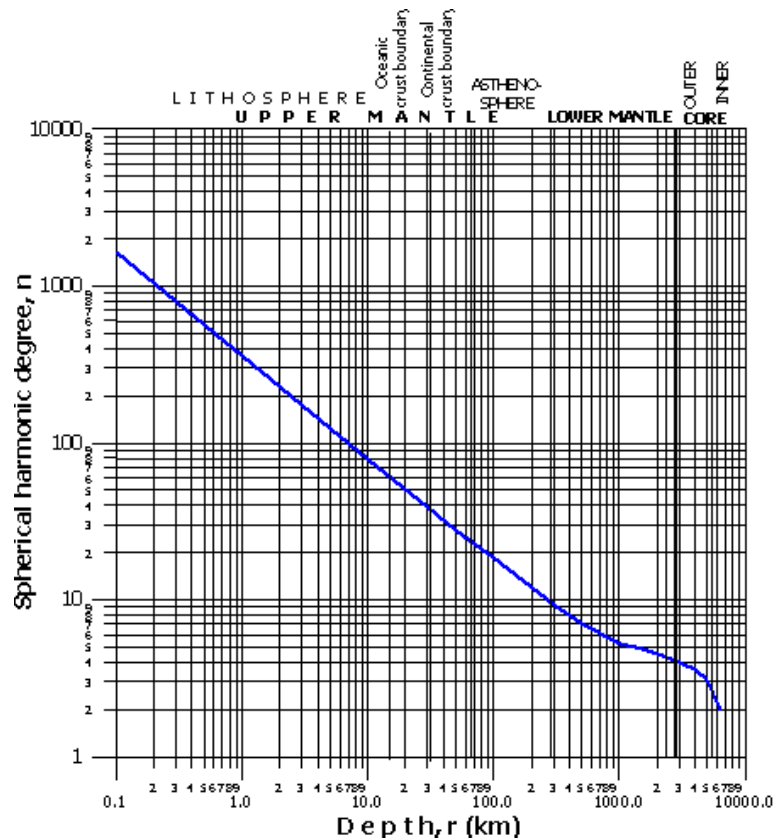


Figure 11. Relationship between harmonic degrees n and depths l disturbing layers of the Earth. Value n is a sum of harmonics in a range from degree 2 up to n . Depth l corresponds to upper cover of the disturbing layer; its thickness is considered from the center of the Earth

Conclusion

Marine geophysical sections for determination of the continental margin are carried out, as a rule, with an interval of 50-100 km.

The satellite altimetric data with an interval between tracks 2-3 km can be used before a marine survey is undertaken without the necessity of doing field work.

The method of gravimetric tomography is based on using data from the highly accurate geodetic geoid system. Its accuracy is comparable to the accuracy of the shore geodetic data and is even higher for the offshore shipboard data, which is possible because of the high density of satellite altimetry data. This method can play an important role in a solution for the problem of continental edges determination and could become a common

tool for all countries. All calculations can be carried out by a specialised international organisation. At the same time laborious and expensive marine geophysical methods (seismic, bathymetry, gravimetry and magnetometry) can be used only within the separate complex cases.

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