Modelling of Density Structure and Geodynamic Features of the Arctic Basin with the Geoid and Altimetric Data

R.Kh. Greku

Institute of Geological Sciences of NASU, 01054 Kiev-54, O. Gonchar str., 55b, Ukraine,
Phone: 38 044 2907188, Fax: 38 044 2169334, E-mail: satmar@svitonline.com

Abstract – This paper presents the Earth's interior data of the Arctic and surrounding regions obtained through the gravimetric tomography method developed by us and dedicated for reconstruction and displaying the structural geological inhomogeneities in different layers. Characteristics of the global geoid height model's spherical harmonics are the input data for the method. They are used both for determination of the layers' depths disturbing geopotential and for computing of harmonic dense anomalies. 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 also. A significant difference between geodynamic processes in geospheres of the core, mantle and crust is emphasized.

Keywords: geoid, deep structure, harmonic, density, geodynamics.

1. INTRODUCTION

Most of tectonic topics are restrained by insufficiency of the deep Earth's interior data. This problem relates especially for the difficult-accessible polar regions. An informative source of such data is the seismic tomography technology (Bijwaard, 1998) with the earthquakes and explosions signals. We developed and applied the another "gravimetric tomography" technique to reconstruct the interior structure.

Moreover, we used well known extracting procedure of certain harmonics determination of a residual (differential) geoid for lateral mapping of structures in different layers which disturb the geopotential.

Approximate depths of disturbing layers have been evaluated by experienced geophysicists. So, it was noted in the work (Gainanov. 1981) that the density inhomogeneities at the center of the Earth are responsible for harmonics of about $2 \leq n \leq 5$, the lower mantle is responsible for the range of $2 \leq n \leq 20$, and the upper mantle for the range of $2 \leq n \leq 100$. It is supposed in another reference work (Allan, 1975), that harmonics of up to 8 degrees are probably caused by the impact of masses located at the depth of more than 1000 km, and from 8 to 22 at the depth of 50-300 km.

These assessments of a logical conformity between number of a harmonic and depth of a disturbing layer motivated us to determine a numeric dependence in this relationship.

2. GRAVIMETRIC TOMOGRAPHY TECHNIQUE

2.1 The Algorithm for Calculation of Anomalous Harmomic Densities

Our gravimetric tomography technique is based on realization of the theoretical approach by Prof. H. Moritz (Moritz, 1990) 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. Other 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 (Moritz, 1990) 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.

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

The obtained above density anomalies are obviously situated in different depths. Therefore a following question remains: which layers of the Earth are responsible for disturbance of the 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

(Moritz, 1990) for the case when the external potential of the internal masses confined by a sphere is determined

$$\frac{1}{l} = \sum_{n=0}^{\infty} \frac{r^n}{R^{n+1}} P_n(\cos\theta),$$

where l - distance between point, to which the value of a geopotential is referred and point, to which the density disturbing the geopotential is referred.

Calculation was carried out with $n_{min}=2$. At the right part of the expression the normalizing coefficient of spherical functions $(2n+1)^{1/2}$ was used (Shimbirev, 1975). If $\theta = 0$ then $P_n(\cos\theta) = 1$ for any n, and l = R-r. Under these conditions and for given values of l, r and R the corresponding values of n were calculated.

Relationship between harmonic degrees n and depths l of disturbing layers is shown in the bilogarithmic diagram (Fig. 1). Main boundaries of the lithosphere are shown in accordance with the Bullard's density model of the Earth (Bullard, 1954).

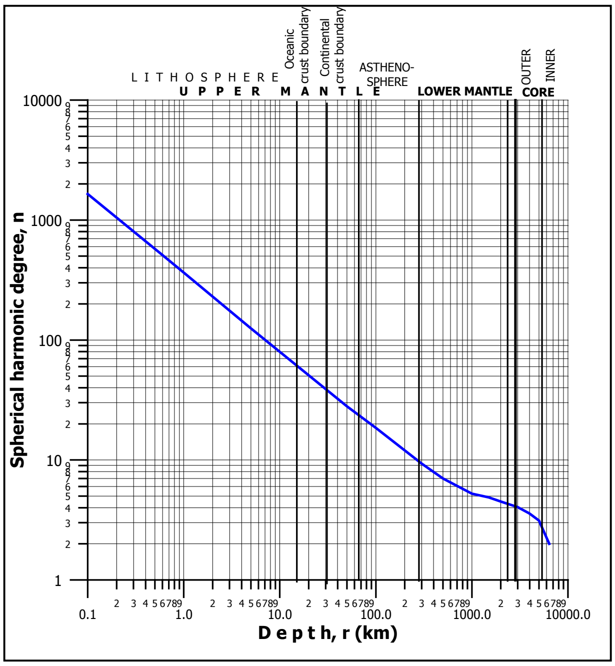

Figure 1. Relationship between harmonic degrees *n* and depths *l* disturbing layers of the Earth. Value n is a sum of harmonics in a range from degree 2 up to n. Depth *l* corresponds to upper cover of the disturbing layer; its thickness is considered from the center of the Earth.

3. DISCUSSION ON THE ARCTIC BASIN STRUCTURE

Our software developed within the gravimetric tomography method allows to compute values of heights of both - the full geoid (all harmonics of a model used) and differential geoid, values of the anomalous harmomic densities in units of g/cm3 and values of upper cover depths of disturbing layers of the Earth. Spherical coefficients of the EGM96 global geopotential geoid model was used. An interval between calculated points is 15 km.

The polar stereographic map (50N-90N) of the Arctic Basin in Fig. 2 shows a distribution of density inhomogeneities through heights of the differential geoid. This residual topography are calculated by a range of spherical harmonics 50-360 degrees which are disturbed by layers of 20 km thickness from the geological surface of the land and sea-bottom. Many of these undulations have a good accordance with known topography of the relief.

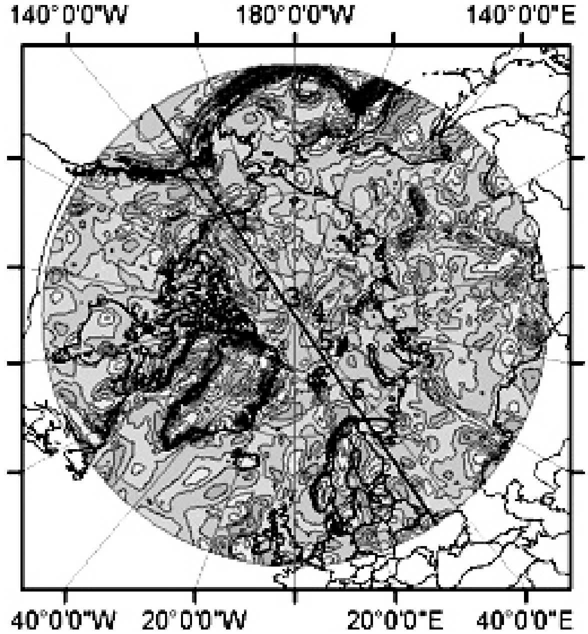

Figure 2. Map of the Arctic Basin differential geoid (latitudes 50N-90N) shows a distribution of density inhomogeneities in layers of 20 km thickness. Contour interval is 0.5 m. Straight line is geotraverse along longitudes 146W-34E: 1- Canadian Basin, 2 – Alpha Ridge, 3 – Makarov Basin, 4 – Arctic Mid Ocean Ridge, 5 – Nansen Basin, 6 – elevation in the Barents Sea. More bright tone is more dense structure.

The three-dimensional images of a deep structure from surface to the core for any cross section have been built. The vertical structure up to depth 100 km along the geotraverse is shown in

Fig.3. Numbers in the image correspond to structures in Fig. 2.

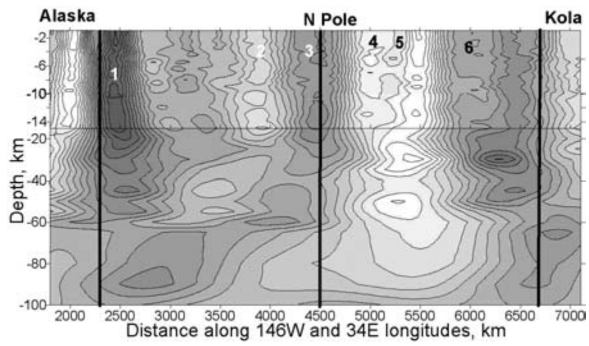

Figure 3. Vertical cross-section of the deep structure along the geotraverse in Fig. 2. Numbers of the bodies correspond to Fig. 2. Boundary of the asthenosphere is on depth 60 km. Height exaggeration is different for layer up to 15 km and for layer 15-100 km.

Characteristic subduction trenches are discovered in front of the Alaska at the Canada Basin and Kola Peninsula. Boundaries of the ocean crust at depths 4-6 km and the continental crust at depths 55-58 km in the North America (Beafort Sea) and Scandinavia regions and 80 km under Ural mountains, asthenosphere 55-65 km. It is noted that the Arctic Mid Ocean Ridge, Mid Atlantic Ridge and island ridge in the sector between the Greenland Sea and Franz-Joseph Land although are separated by the Nansen Basin by topography data, they have one a root system at depths 60-80 km. The Aleutian Arc subduction zone along meridian 180° is presented by a wide (2000 km) plate diving to the Mendeleev Ridge with inclination of 2.3° up to depth 25 km.

Structure and dynamics of lower horizons (asthenosphere, mantle and topography of the outer core) are distinguished considerably.

4. CONCLUSION

Results of the structural modeling using the gravimetric tomography method shows an appropriateness of such information to promote understanding of problems of the neotectonics, geodynamics, location of adjoining and deformation zones of the Arctic Basin and surrounding regions interior.

Altimeter data is a base information for determination of the geoid in ocean. Using the local detail altimetric geoid can provide higher degree of the harmonic expansion than the global model. It will allow to increase a resolution by depth in the highest sedimentary layers.

6. REFERENCES

R.R. Allan, “Depth of sources of gravity anomalies,” “Nature. Phys. Sci.”, vol 236, #63, p.p.22-23, 1975.

H. Bijwaard, W. Spakman, E. R. Engdahl, “Closing the gap between regional and global travel time tomography,” J. Geophys. Res., 103, B12, p.p. 30,055-30,078, 1998.

E.C. Bullard, “The interior of the Earth. In the Earth as a Planet” (G.P. Kuiper, ed). Univ. of Chicago Press, p.p. 57-137, 1954.

A.G. Gainanov, “Geology and Geophysics of the Eastern Indian Ocean Floor (by the 54 and 58 cruises data of the RV Vityaz),” Moscow, Nauka, p. 256, 1981(in Russian).

H. Moritz, . “The Figure of the Earth. Theoretical Geodesy and the Earth's Interior,” Wichmann, Karlsruhe, 1990.

B,P. Shimbirev, “Theory of the Earth’s Figure,” Moscow, Nedra, p. 431, 1975 (in Russian).