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New Digital Compilation of Russian Aeromagnetic and Gravity Data over the North Eurasian Shelf

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THEME 2: Aerogeophysics of the Eurasian Shelves: Signatures and Interpretations

Summary: Coherent and precise potential field data bases are crucial for automated production of accurate magnetic anomaly and gravity maps as well as for quantitative modeling and geological interpretation. In the area of North Eurasian Shelf the original aeromagnetic profiles and free-air gravity observations collected by Russian organizations have been assembled and digitized. The digital information has been totally edited, reprocessed, merged and readjusted using interactive visualization, crossover analysis, navigational shifting, directional filtering etc. To produce new magnetic anomaly and free-air gravity anomaly maps of the North Eurasian Shelf the coherent data sets were gridded at an interval 5 x 5 km for the Western (Barents, Kara and Laptev) Seas and at an interval 10 x 10 km for the Eastern (East Siberian and Chukchi) Seas. These maps provide essential information for regional characterization of major tectonic elements and estimation of potential reserves of hydrocarbons in the region.

INTRODUCTION

It is widely known that the lithosphere beneath the sea and ice of the Arctic High Seas is probably one of the least known part of the Earth. North Eurasian Shelf has a few sedimentary basins expressed by several large depressions of various spatial orientations and different structure of the basement (GRAMBERG et al. 2001). The region of North Eurasian Shelf is known for potential reserves of hydrocarbons, but the western part only (Barents and partly Kara Seas) is covered by significant amount of industrial reflection seismic profiling sufficient to characterize the regional patterns of the basins. In the area of East Arctic Shelf (Laptev, East Siberian and Cukchi Seas) only few seismic profiles are available. Thus, accurate magnetic anomaly and gravity maps provide important and somewhere unique information for the synthesis of geological concepts and understanding of the tectonic evolution in the region of North Eurasian Shelf.

Geological and geophysical explorations in the area of the North Eurasian Shelf have been conducted for many decades. A bulk of original geophysical data of both fundamental and applied values have been collected in Russia (formerly USSR) mostly by VNIIOkeangeologia (formerly NIIGA-Research Institute for Arctic Geology), Polar Marine Geosurveying Expedition (PMGE) and Marine Arctic Geological Expedition (MAGE). Russian geophysical surveying in the Arctic during 1960s to 1980s was presented by shipborne and aircraft supported gravity observations and aeromagnetic data at various scales and resolutions. The potential field data in the area of the North Eurasian Shelf were compiled in early 80s as a set of hand contoured maps at scales varying from 1 : 2 500000 to 1:6000000 (GAPONENKO et al. 1981, VERBA et al. 1987, SHIMARAEV et al. 1991, all maps unpublished). Unfortunately due to formal limitations caused by data confidentiality this representations of gravity and magnetic anomalies were not demonstrated to the western geoscientific community for a long time.

Several digital potential field products and maps became available during past few years although the usage of those data sets for purposes of regional mapping and detailed interpretation remains problematic. The marine geophysical data on GEODAS CD-ROM (MARINE TRACKLINE GEOPHYSICS 1997) involve only small amount of irregular shipborne profiles in the western and central parts of the Barents Sea and in some places of the Chukchi Sea. The recent ERS-1 satellite gravity data (LAXON & MCADOO 1994) in the areas covered by ice are adequate only for purposes of quite regional geological interpretation. At shorter wavelengths, the ERS-1 gravity reveals oscillations that are most likely due to high-frequency noise caused by residual errors in the retracked heights. Another essential limitation in usage of satellite derived marine gravity field in the Arctic High Seas is caused by the existence of unmapped areas around the North Pole. The digital magnetic anomaly grid and map distributed by Geological Survey of Canada (VERHOEF et al. 1996) cover a large part of the Arctic Ocean and North Atlantic. For the North Eurasian shelf area this compilation is based exclusively on digitized hand-contoured maps originally prepared at a scale 1:5000000 (SHIMARAEV et al. 1991). In some areas the level of the reference field and the patterns of magnetic anomalies in the SHIMARAEV et al. (1991) map are quite problematic due to hand contouring and distortion of initial maps by reprinting process. Our experience shows that the magnetic anomaly patterns are changed significantly after reprocessing of initial aeromagnetic profiles data.

To improve the understanding of fundamental problems of geological structure, tectonic evolution and perspectives of hydrocarbon potential in the Arctic region the geoscientific community needs high quality digital potential field maps. New computer derived magnetic and free-air gravity anomaly maps compiled on the basis of digitized original information collected by Russian agencies are presented in this paper.

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INFORMATION ON DATA ACQUISITION

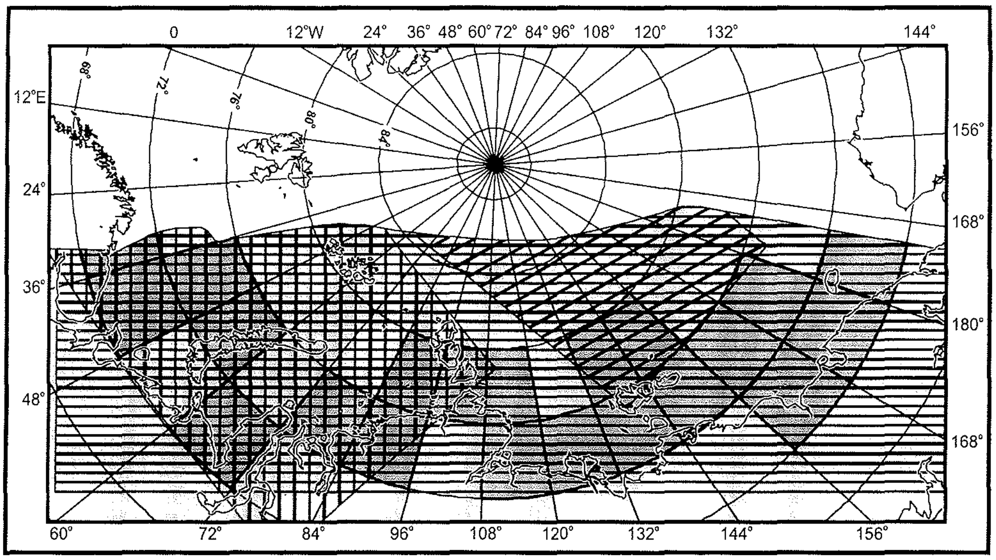
Aeromagnetic data

Magnetic anomaly data in the North Eurasian Shelf were acquired between 1962 and 1981 during aeromagnetic surveys carried out by NIIGA and PMGE with variable line spacing and orientation (GRAMBERG et al. 2001). Model AMM-13 fluxgate magnetometers, and later models PPM, AMP-7 and YMP-3 proton precession magnetometers, and model KAM-28 quantum (optically pumped) magnetometer were used. Base stations were established on islands, in the coastal areas and on ice to monitor the diurnal variations. Several modifications of POISK radiogeodetic system were used for navigation, yielding the airplane positions with standard deviation between 200-500 m. The average altitude of surveying was 300 m. The RMS errors of the magnetic field observations over the North Eurasian Shelf range between 10-14 nT in the Barents and Kara Seas and more than 25 nT in some areas of the Eastern Arctic Seas. Original information is stored at VNIIOkeangeologia library as analogous records and magnetic anomaly profiles charts compiled at various geographical projections and scales ranging between 1 : 2 000000 (20 km trackline spacing), 1 : 200000 (2 km trackline spacing), and even 1 : 50000 (0.5 km trackline spacing). The original magnetic anomaly profiles presented at miscellaneous vertical scales between 50-200 nT per cm depending of the magnitude of magnetic anomalies. The total length of magnetic anomaly profiles in the North Eurasian Shelf region included in the compilation is more then 600000 km. The IZMIRAN reference field maps based on analytical representation of geomagnetic field were mostly used to calculate magnetic anomalies displayed on original charts.

Gravity data

Gravity data in the area of North Eurasian Shelf were collected between 1963 and 1989 both by shipborne surveys and on-ice aircraft supported measurements. The on-ice observations were carried out in the eastern part of Kara (east of 78 °E), Laptev, East Siberian, and Chukchi Seas by NIIGA and PMGE. Data coverage in these areas varies from one point per 8 km (southward of 80 °N) to one point per 25 km (northward of 80 °N). Shipborne gravity surveys were carried out in the Barents and the western part of Kara Seas by MAGE and VNIIOkeangeologia with line spacing varying from 10-15 km (southward of 75 °N) to 15-30 km (northward of 75 °N), some individual gravity lines integrated with marine magnetic and seismic reflection profiling were collected in the Laptev and Chukchi Seas.

A set of Model GMN marine gravity meters and several modifications of Models GDK and GAK ground gravity meters were used for the surveying. From 1963 up to late 70s airborne on-ice and shipborne gravity surveys were navigated by both astronomic positioning, and POISK-C, POISK-ZVEZDA radiogeodetic systems, yielding positions with standard deviation between 200-300 m in average. Later TRANSIT and ZIKADA satellite navigation systems were used for marine



Free-air gravity anomaly map. Scale 1:6 000 000, 1988, authors: Gubernov A. P., Malygin G. V., Murashov I. A.

Gravity map of the USSR's Arctic shelf and adjacent areas. Scale 1:2 500 000, 1980, authors: Gaponenko G. I., Zatsepin E. N., Lastochkina N. N.

Free-air gravity map of the Barents-Kara shelf. Scale 1:2 500 000, 1987, authors: Verba M. L., Juravlev V. A., Bulgak N. N.

Free-air gravity map. Scale 1:2 500 000, 1995, authors: Kartelev A. A., Murashov I. A.

State free-air gravity anomaly map of the USSR. Serie of sheets at scale 1:1 000 000.

Fig. 1: Location of Russian gravity anomaly maps used in the compilation.

observations. The RMS errors of free-air gravity anomaly data in the North Eurasian Shelf mostly range between 1-3 mGals with maximum value of 5 mGals. The original gravity information is stored in various analogous forms such as catalogues of shipborne and aircraft supported on-ice gravity observations, sheets of free-air gravity anomaly map of the USSR at scale 1 : 1 000000, free-air gravity anomaly map of the USSR Arctic Shelf and adjacent areas at scale 1 : 2 500000 (GAPONENKO et al. 1980 unpublished) and free-air gravity contours map of the Barents-Kara Shelf at scale 1 : 2 500000 (VERBA et al. 1987 unpublished), the location of those maps is presented in Figure 1. The total amount of gravity observations in the North Eurasian shelf is about 150000 km of shipborne profiles and about 35000 points of on-ice measurements.

DATA PROCESSING

Data processing involved several major steps (Fig. 2):
- selection and systematization of initial potential field data presented in original maps;
- digitizing on large scale digitizer (charts of analog profiles for aeromagnetic data, the maps showing the contours and observation points for gravity data). Some gravity data originally stored in catalogue form were loaded to the data base just using word processor;
- data conversion to standard format and preliminary editing;
- data conversion to geographical coordinates;
- interactive visualization, displaying and plotting of each data set at scale and projection of initial data for final checking of errors and corrections;
- merging, leveling, cross-over analysis and adjustment (reference field correction, navigational correction, directional filtering) to minimize RMS errors,
- loading to the coherent data base for gridding and mapping.

Both AUTOCAD and originally written software (KORNEVA 1995) were used for digitizing of analogue data and conversion from decimal to geographical coordinates. For instance the original programs were developed to convert the digitized data which were initially hand-drawn using Kavraysky equidistant conic projection widely used in the Soviet Union. The package for potential field data processing developed by Geological Survey of Canada - Atlantic and Blue Vajra Computing (VERHOEF et al. 1995) for HP-UNIX workstation has been used for merging, leveling, cross-over analysis and adjustment of digital data. For some historical surveys in the eastern part of Russian Arctic Shelf the automated shifting of original profiles was applied to correct their navigation (the procedure is described in GLEBOVSKY et al. 2000). The profile data were merged and adjusted to produce the coherent data base. Then the observations were gridded using minimum curvature algorithm (SMITH & WESSEL 1990) that calculated anomaly values at regular intervals of 5 km by 5 km over the western part of North Eurasian shelf and Laptev Sea. In the areas of East Siberian and partly Chukchi Seas the distribution of aeromagnetic data allows only the grid intervals of 10 km by 10 km. In several areas (central part of Laptev Sea and eastern part of Barents Sea) the directional filtering was applied to correct the erroneous anomalies oriented along profiles. Then the coherent digital magnetic anomaly and gravity data bases and grids were used as a basis for mapmaking and interpretation.

COMPUTER DERIVED MAPS AND INTERPRETATION

Several computer derived potential field maps for the North Eurasian shelf both color and contour were produced using GSC-Atlantic software (VERHOEF et al. 1995). The shaded relief color magnetic anomaly and free-air gravity maps of the North Eurasian Shelf are presented in Figure 3.

Several major patterns are revealed in the compiled potential filed maps. The free-air gravity anomaly map shows several large negative anomalies corresponding to major sedimentary basins (South and North Barents, South Kara, Uedinenia,

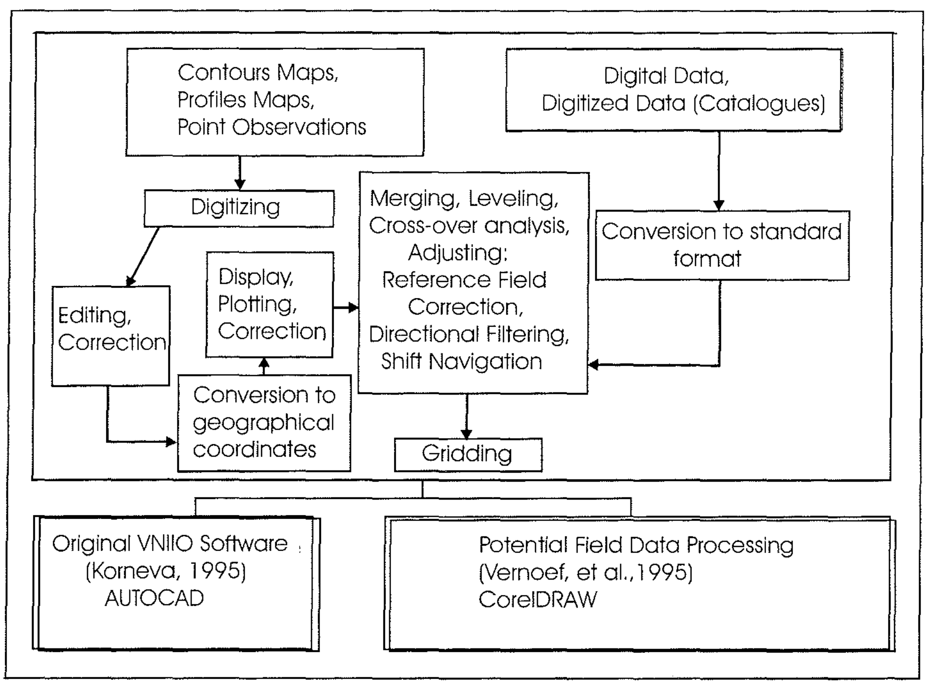


Fig. 2: Computer technology of potential field-data processing applied to the Russsian aeromagnetic and gravity data in the North Eurasian Shelf.

South Laptev, Novosibirsky, South and North Chukchi). Both magnetic and gravity anomalies grains generally follow to the North-East trend in the most part of the Barents-Kara Seas. In the Eastern Russian Arctic seas the orientation of anomalies becomes more irregular. In the south and central parts of the Laptev Sea several elongated negative gravity anomalies oriented from South-East to North-West are in well correspondence with the Laptev Rift System bounded by the New Siberian Islands from the East. Several crustal uplifts such as Central Barents High, Severnaya Zemlya block, De Long massive are revealed as intensive positive gravity anomalies.

The magnetic anomaly map shows less prominent features. In the southern part of the Barents-Kara Shelf the directions of magnetic anomalies clearly continue the patterns revealed in the North-West part of Russia landmass (VERHOEF et al. 1996), and then turn off following the trend of Novaya Zemlya. Both positive and negative magnetic anomalies varying in intensity (mostly low amplitude) are observed in the basins. The crustal uplifts mentioned above usually are revealed in compiled

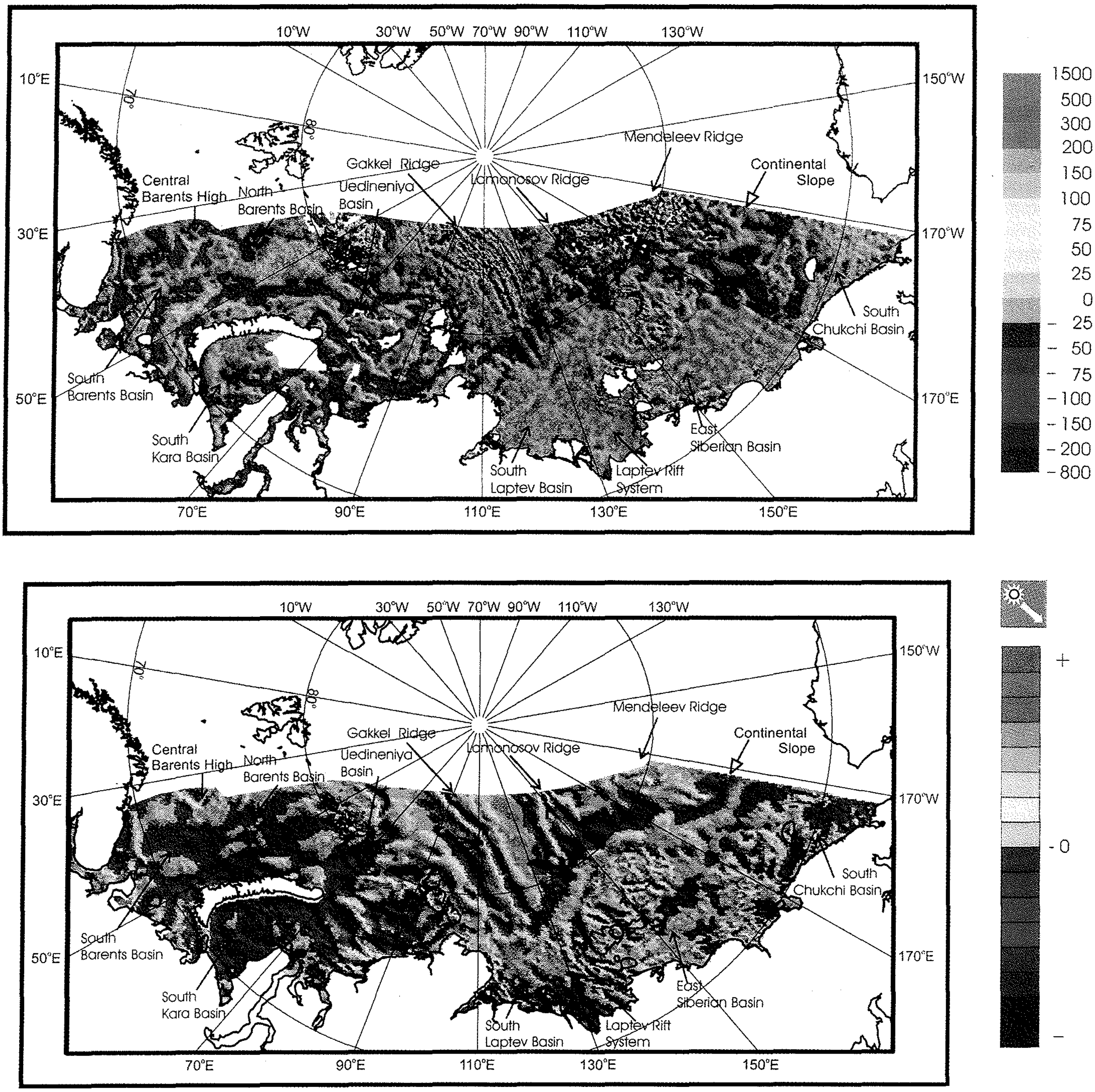


Fig. 3: Magnetic anomaly maps of the North Eurasian Shelf; top: shaded relief magnetic anomaly map; bottom: shaded relief free-air gravity anomaly map.

magnetic anomaly map as intensive highs. In the southern part of East Siberian Sea a distinct set of elongated magnetic anomalies corresponds to the South Anyui Suture zone. The long linear magnetic anomaly is mapped in the Laptev Sea from the Khatanga Bay to the end of Gakkel Ridge and further to the oceanic basin. Probably this is magnetic signature of transform fault proposed in plate tectonic reconstructions of the region (SAVOSTIN & KARASIK 1981).

In general, there is different regional correlation between positive and negative gravity and magnetic anomalies in the areas of basement depressions. These differences may be explained either by different magnetic and density properties of sediments or by influence of specific blocks of the crust. In some areas, for instance in the central part of South Kara basin, the positive gravity and magnetic anomalies over basement deeps may be caused by overcompensation of gravity field by sediments with high density and by existence of magnetic sources (igneous rocks) in the sedimentary cover. On the contrary, in the North Barents-Kara Shelf there are large basement depressions marked by negative gravity anomalies and low amplitude of anomalous magnetic field.

CONCLUSION

This paper presents for the first time the results of compilation of magnetic anomaly and gravity data collected by Russian organizations over the North Eurasian Shelf during the past three decades. The complete cycle of computerized reprocessing of original data allows two high quality gridded data sets (magnetic anomalies and free-air gravity anomalies) to be created. There are two evident applications for the grids. First, the digital data sets present the reliable basis for regional geological mapping and characterization of major tectonic units in the region. The potential field grids are applicable also for various procedures of quantitative interpretation such as calculations of derivatives, 3-D inversion, but this is out of scope of presented paper.

In combination with the interpretation of seismic profiles, the lateral features of gravity anomalies allow the contours of sedimentary basins to be mapped. The depression of basement filled by sediments are revealed as prominent regional lows in the free-air gravity anomaly map. The features of magnetic anomalies over sedimentary basins in the North Eurasian Shelf are more heterogeneous due to complexity in basement composition. The uplifts of consolidated crust are revealed as intensive highs both in magnetic anomaly and gravity maps. Therefore the presented potential field maps of the North Eurasian Shelf provide basic information for tectonic analysis and estimation of potential reserves of hydrocarbons in the region.

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