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SEDIMENTARY THICKNESS ESTIMATIONS FROM MAGNETIC DATA
IN THE NANSEN BASIN

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ABSTRACT
In spite of several geophysical expeditions during the past decade, the seismic documentation of sediments in the Nansen Basin is still sparse. At the same time, airborne surveys conducted by the US Naval Research Laboratory in 1974-75 and 1998-99 make up a grid of magnetic profiles spaced by 18 to 10 km in the western half of the basin. It is known that the depth to oceanic basement may be calculated from magnetic data by a multiple-source Werner Deconvolution method (MSW). Recent bathymetry compilations provide relatively good control of the seafloor. Sediment thickness represents the difference between depths of basement and seafloor.

Results of analysis regarding the possibility to use MSW calculations as a support to seismic lines in the mapping of sediment thickness in the study area are presented. The study area, at 80–86°N, 11–35°E, includes the Nansen Basin, Gakkel Ridge flank, Yermak Plateau and north Svalbard margin.

Principles of analysis and sorting of MSW solutions are discussed in detail. Uncertainty of the method is estimated. It is established that in general, both the magnetic basement surface and the sediment thickness values estimated from magnetic data fit well with seismic data from icebreakers Oden and Polarstern (2001). Possible reasons for differences between magnetic and acoustic basements revealed along seismic lines are discussed. The regional map of the sediment thickness in the study area shows that in general the thickness of sediments decreases from the Barents Sea shelf toward the Gakkel Ridge. Least thickness or absence of sediments is observed in the axial zone of the Ridge. The largest accumulation of sediments (4-5 km) is discovered on the continental shelf and slope, north and south of Yermak Plateau, and in the southern part of Litke Trough. The thickness of sedimentary cover on Yermak Plateau varies from 1 to 2 km.

INTRODUCTION
Information on the sediment thickness is important for both the regional study/modeling of geological processes related to development of sedimentary basins and the assessment of oil and gas reserves. Moreover, sediment thickness of the ocean floor has become a major concern to many coastal states in relation to the revision of outer limits of the continental shelf in accordance with Article 76 of the UN Convention on the Law of the Sea.

Existential maps of sediment thickness in the Arctic Ocean (e.g. Jackson and Oakey, 1988; Gramberg and Puscharovsky, 1989; Gramberg et al., 1999) are mainly based on widely spaced and irregular seismic lines. Thus wide areas of the maps are based on interpolation of seismic data. The most effective method of sediment thickness mapping is obviously based on the integrated analysis of seismic, gravity, magnetic and bathymetry information.

For both scientific and Article 76 purposes, Norwegian and Russian institutions (Norwegian Petroleum Directorate; Department of Geosciences, University of Oslo; VNIIOkeangeologia and Polar Marine Geological Research Expedition) entered into a collaborative project to study the feasibility of using potential field data integrated with seismic and bathymetry data to determine the ocean floor and sediment thickness in the Arctic Ocean. The area 83°50'-86°N, 13-34°E in the western part of the Nansen Basin (small box, Fig.1-B) was chosen as the test area. This part of the basin has the best coverage of seismic data in addition to high-quality digital aeromagnetic and aerogravity information. Later the area of investigation was extended to the south (large box, Fig.1-B). This paper summarizes results of the mapping of oceanic basement relief and estimated sedimentary thickness from aeromagnetic data integrated with bathymetry.

Mass depth to magnetic source estimations is the common technology to study the geomagnetic structure of oceanic crust. Euler Deconvolution (Nabighian, 1974) and Werner Deconvolution (Werner, 1953) are the most widely used methods of estimation. The first method is usually considered as a fast one for rapid estimation of depths to magnetic sources (upper edges) from gridded magnetic data. The second method is more laborious and needs magnetic anomaly profile data. At the same time it allows estimation of parameters of magnetic sources more precisely. That is why it was used in this project. Seismic data were used...
both to calibrate and check results of independent estimations from magnetic anomalies.

**DATA PROCESSING AND INTERPRETATION**

Several geophysical data sets from the Nansen Basin were used under the project (Fig. 1-A): seismic data collected in 2001 from the icebreakers *Oden* and *Polarstern* (Gjengedal, 2004; Jokat and Micksch, 2004), free air gravity and magnetic profiles collected by the Naval Research Laboratory (NRL). Bathymetry information was presented by the latest version of the IBCAO grid (Jakobsson et al., 2000), by paper copy of the Russian map “Bottom Relief of the Arctic Ocean” at scale 1:5,000,000 (1999), and by bathymetry

![Figure 1. Data coverage and area of study. A) shows position of seismic lines from *Oden*-2001 (1) and line 20010100 from *Polarstern*-2001 (2), aeromagnetic tracklines of NRL 1974-75 (3) and NRL 1998-99 (4). B) shows positions of the initial test area (small box) and the extended study area.](image-url)
The preliminary processing and analysis of the data sets included:

- Seismic interpretation and construction of depth sections.
- Levelling, adjustment and compilation of NRL 1998-99 aerogravity data sets (Brozena et al., 2003), satellite data (Laxon and McAdoo, 1998) and Norwegian marine gravity observations to construct an updated grid and map of gravity anomalies.
- Digitizing and gridding of isobaths from the Russian bathymetry map, comparison of the resulting grid and the IBCAO grids with shiptrack bathymetry (Thiede, 2002) and Russian profiles to upgrade existent information and/or to select the most reliable grid values among multiple sources.
- Levelling and adjustment of aeromagnetic data sets. Adjustment included navigational correction (shift) of old (NRL 1974-75) magnetic anomaly profiles with poor navigation using recent data sets (NRL 1998-99) with excellent navigation as reference information. The average magnitude of shift was about 1-2 km and the maximum value ran up to 5 km. The final coherent magnetic database was used both for mapping and for mass depth to magnetic source estimations.

Depths to oceanic basement were calculated by a multiple-source version of the PDEPTH program (Cordell et al., 1992) based on the Werner Deconvolution method (Hansen and Simmonds, 1993). It estimates depths to magnetic sources approximated by simple models: magnetic contact between two differently magnetized bodies or a magnetized thin dike. The contact model was chosen as the basic one after test calculations. Initially the magnetic anomaly profiles in the Nansen Basin were filtered by a six-point running average filter with 3 km window length to remove high frequency noise. Input parameters for the calculations, including number of points in the running window, radius of cluster (a group of solutions around the “real” solution, generated by the program), number of solutions in cluster etc., were defined on the basis of test estimations within the swath of the geotransect “De Long Islands-North Pole” (Lickhachev, 1999). This swath is covered by 5 km spaced aeromagnetic profiles. The basement relief here is known from seismic data (Sorokin et al., 1999). Parameters that gave the best fit between the real and estimated depths were chosen as optimal.

Mass depth to magnetic sources estimations were carried out and these formed the initial database for further analysis. Next, detailed analysis and sorting of all estimations were performed to define those estimations belonging to magnetic basement. The editing procedure included several steps:

- Single solutions were regarded least reliable and were removed from the initial database. Solutions in clusters were averaged (Fig. 2). Only averaged solutions (AS) were accepted for further analysis and...
• The most shallow AS that fell above the ocean floor known from bathymetry were removed from the database and recorded in a separate file. Analysis of these solutions shows that a part of them is connected with high frequency components of the magnetic field (noise), but another part (especially in the axial zone of the Gakkel Ridge) may be connected with real highs of the sea bottom relief smoothed in the bathymetry grid.

• AS from magnetic anomalies with unusual shapes (i.e. elongated along profile or known to differ significantly from the reference anomaly shape assumed in the Werner Deconvolution method) were removed from database.

• AS related to magnetic profiles that are not orthogonal to strike of magnetic anomalies (within limits 0-30°) were corrected (reduced by \( \cos \lambda \), where \( \lambda \) is the angle between directions of profile and the perpendicular to the magnetic anomaly axis). Solutions were removed from the database if \( \lambda \) exceeded 30°. The cutoff limit of \( \lambda \) was determined from model calculations.

• All remaining AS are presumably connected with oceanic basement were plotted and compared with seismic information in the test area (Fig. 1-B).

It is necessary to note that seismic information was used not only for comparison with the results of depth to magnetic basement estimations, but also for the calibration of results. Thus the process of mass calculations and editing was iterative. Accordingly, the input parameters for depth calculations chosen at first on the basis of Russian data (Sorokin et al., 1999) were gradually adjusted to the best fit of magnetic estimations with acoustic basement in the test area (Fig. 1-B). After the completion of this process the majority of these estimations agreed well with the seismic data collected from the icebreaker Oden (2001). The average error was within a few hundred meters. However, some estimations conform to magnetic sources at depths noticeably below acoustic basement. It was supposed that such deep sources could be situated within or close to faults. As a result it became necessary to map fracture zones and other structures in the study area.

The structural map was developed mainly on the basis of potential field and bathymetry maps constructed under the project. Seismic data and recent publications (Thiede et al., 2002; Brozena et al., 2003; Engen et al., 2003; Glebovsky et al., 2003) were used as additional information. Main fracture zones were interpreted from displacements of magnetic lineations, and from characteristic features of potential fields and their horizontal gradients compared with bathymetry data.

Deep AS corresponding to linear lows in the bottom relief and located near faults were removed from the database. Further analysis made it clear that these solutions may be identified also by statistical analysis along each profile. The deep AS is generally more than two standard deviations away from the average AS of the same magnetic profile.

Since the results of estimations in the test area were encouraging, the mass depth to magnetic sources...
estimations and further sorting were carried out in the wider region at 80–86°N, 11–35°E (Fig. 1). All finally selected AS presumably related to the top of basement (see Fig. 3) were transformed to grid with cell size 10×10 km using the Kriging method (Cressie, 1990). This method allows grids to be calculated from widely spaced and irregularly distributed point observations. Later, this grid was used to estimate both the sediment distribution in the study area and the uncertainty of the MSW method.

Analysis of the bathymetry information shows that there are essential differences between different data sets especially in the axial zone of the Gakkel Ridge. At the same time it revealed that the IBCAO grid seems to be the most reliable bathymetry model available at present. The final sediment thickness grid and map (Fig. 4) were constructed by subtracting the IBCAO grid (Jakobsson et al., 2000) from the above-mentioned grid of estimated depth to basement.

**UNCERTAINTY OF METHOD**

The uncertainty of the method was estimated by comparison of results of depth to magnetic basement calculations with depth sections based on seismic data collected in 2001 from the icebreaker *Oden* and the research vessel *Polarstern* (Jokat and Micksch, 2004). While data from *Oden* was used to calibrate depth estimations, data from *Polarstern* was only used to estimate uncertainty of the method. Results of the comparison are presented in Figure 5. Both final point depths to magnetic basement projected on seismic profiles within swaths of different width (0-3, 3-6 and 6-10 km) and the difference between seismic basement and magnetic basement extracted from final grid are shown.

The correlation factor (R) and the standard deviation (σ) between seismic and magnetic basement depths were calculated for statistical estimations of uncertainty of the method (Fig. 6). Both point estimations (A) and those extracted from the depth to magnetic basement grid within a 10 km swath (B) were analysed. An integrated analysis of the results presented in Figure 5 and Figure 6 allows for several conclusions:

- A high coefficient of correlation between magnetic and acoustic basement depths as well as a small standard deviation testify to relatively high accuracy of estimations from magnetic data. The average error is less than 20% of depth to basement and usually about 10%.
Errors of point estimations are presumably related to two main effects: non-uniqueness inherent in the method of depth to magnetic sources estimation, and natural differences between magnetic and acoustic basements.

In spite of the relatively high resolution of the method, the final grids constructed under the project determine only regional fluctuations of the basement surface and the distribution of sediments. This may be explained by the fact that the density of magnetic profiles in the study area is too low to map basement elevations and lows visible on seismic profiles. Aeromagnetic trackline spacing is about 10-18 km. The majority of basement lows and highs are not more than 10-15 km wide.

A total amount of 732 final point estimations remained in the data base after analysis and sorting within the 218,810 km² study area. Only 66 of these occurred within 10 km wide swaths around seismic profiles and were used to estimate the uncertainty of the method.

Presumably, the effects of non-uniqueness of the method might be reduced if the spacing between magnetic profiles is reduced to about 5 km.

SUMMARY AND CONCLUSIONS

1. Depth to magnetic source calculations by the MSW Deconvolution method may support seismic investigations for the estimation of the regional sediment distribution in the Arctic Ocean. The crucial prerequisites to get positive results are the following:

- High quality of observations and correct direction of magnetic anomaly profiles. Any artefacts of magnetic anomaly shape result in incorrect fitting of input parameters for MSW calculations and finally in depth estimation errors. Direction of profiles must not differ noticeably from the orthogonal to the strike of magnetic anomalies in order to avoid sizeable corrections.
- The tectonic and structural maps constructed on the basis of all available potential field and bathymetry data have to be considered as additional information in
the formalized procedure of depth to basement estimation sorting/selection.

2. It is established that, in spite of relatively high resolution of the MSW method, the final maps of the basement surface and sediment distribution maps represent only regional variations in these two features.

3. In spite of its regional character the final sediment thickness map (Fig. 4) looks more detailed than earlier published maps (Jackson and Oakey, 1988; Gramberg and Puscharovsky, 1989; Gramberg et al., 1999) and shows the principal features of sediments distribution in the study area. In accordance with the physiographic classification of Jakobsson et al., 2003, this area includes a few first-order provinces: Gakkel Ridge; Barents Abyssal Plain, Continental Rise and Slope, and Continental Shelf; Yermak Plateau and Continental Slope.

4. In general the thickness of sediments within the whole study area decreases from the Barents Continental Shelf toward the Gakkel Ridge. The least thickness of sediments (less than 0.5 km) is observed in the axial zone of the Gakkel Ridge. The rift valley has practically no sediments. Large accumulations of sediments (3-4 km) are identified within both the Barents Continental Slope and the Yermak Continental Slope north and south of the Plateau. Even larger accumulations of sediments (4-5 km) are found within two small areas confined to the Barents Shelf and Continental Rise and located in the very southwest part of the study area in the Litke Through (Bottom relief of the Arctic Ocean (map), 1999). The thickness of sedimentary cover both within central and eastern parts of the Barents Continental Rise and Abyssal Plain varies from 2 to 3 km and gradually decreases toward the Gakkel Ridge. The thickness of sediments within the Yermak Plateau varies from 1 to 2 km.

The sediment thickness map (Fig. 4) also indicates that the predominantly buried relief of the basement follows the two main tectonic trends of the area, i.e. an ENE-SWS trend (the trend of the Gakkel Ridge, Eastern Yermak Plateau and the Barents Continental Slope) and a NNW-SSE trend (parallel to the fracture zones of the Gakkel Ridge). Applying the MSW method over larger parts of the basin eastwards may confirm whether this is a systematic feature of the sediment thickness distribution of the Nansen Basin.

It is proposed to use the new sediment thickness grid and map under international project “Map of the Arctic Sediment Thickness” (MAST).

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Figure 6. Statistical estimations of the uncertainty of the method. Correlation between depth to acoustic basement from seismic data and two types of magnetic depth estimates are shown. In A, depth estimates are extracted from the database (Fig. 3) and projected onto seismic profiles from different distances. In B, the same points are extracted from the depth to basement grid and projected onto the lines. R and σ are the computed correlation factor and standard deviation (km), respectively.
information required for uncertainty estimation of the approach developed, and for constructive comments to our study. We sincerely thank Robert Scott and Dennis Thurston for improvements on the manuscript and Olav Eldholm for fruitful discussions and collaboration.

REFERENCES

Bottom relief of the Arctic Ocean; map at scale 1:5,000,000, 1999. Head Department of Navigation and Oceanography (HDNO) and All-Russian Research Institute for Geology and Mineral Resources of the World Ocean (VNIIOkeangeologia), St. Petersburg, Russia.


