Introduction

The pre-Jurassic formations of the Nyurol trough of the Tomsk region (West Siberia) are characterized by complex structures, that includes deep beddings, tilted block structures, steep dip angles faults and the absence of clear seismic reflection horizons. We observe that neighboring subvertical tilted blocks can be represented by rocks of various lithological composition characterized by different petrophysical properties. According to results of deep drilling, carbonate, clay-siliceous, effusive, metamorphosed Palaeozoic formations are developed in the study area, the age of which is determined from Cambrian to Carboniferous (Jero et al., 1968).

The characterization of those formations is difficult due to insufficient geological exploration. Firstly, there is uneven drilling density. Secondly, most of the wells penetrate pre-Jurassic rocks to a depth of about 100 m (upper sedimentary cover is about 3 km). To help in better characterizing the formations, measurements of the magnetic susceptibility and density on core samples were carried out, which allowed to evaluate the petro-density characteristics of the formations for potential fields’ interpretation.

This paper reveals that potential field methods integrated with seismic data and deep drilling help in interpreting geology with better accuracy. Linear gravity and magnetic anomalies indicate tectonic disturbances while isometric anomalies characterize blocks of rocks with different lithology. The study demonstrates that suggested approach to the potential field data with the integration based on other geophysical and geological information helps specify the geological structure of the West Siberian Palaeozoic basement.

Materials and Methods

Geological formations in this study are covered by gravimetric and magnetic survey on a scale of 1:50,000. It should be emphasized that root mean square error of gravity observation is 0.08 mGal and the density of the intermediate layer 2.30 g/cm³. At the beginning of the 20th century, generalization and reinterpretation of aeromagnetic survey materials, including ground-based high-precision magnetic surveys (accuracy about 2.5 nT), were carried out. We found out that, the quantity and quality of the initial materials is sufficient to perform the integrated study.

Primary fields are characterized by heterogeneous structure and the presence of a series of positive and negative large anomalies with NW and NE directions (Figure 1). Taking into account the available geological information, this field configuration is due to a complex combination of geological and structural elements. The rocks that form the base of the Nyurol trough and the adjacent inversion anticlinoriums, cut off in the SE part of the site by the zone of the graben rift oriented NE. The main tectonic disturbances have a predominant NW and NE orientation, consistent with the main geological structures of the pre-Jurassic basement.

Figure 1 Primary fields. Left – gravity (mGal), right – magnetic (nT). Wells are shown as black dots.
As mentioned above, Palaeozoic basement is covered by thick (about 3000 meters) sedimentary layers with their own potential fields’ anomalies. The authors carried out forward modeling on a analog model close to real deposits of the pre-Jurassic complex of the region (Volkova&Merkulov, 2019). Anomalies autolocalization effect from the sedimentary cover and basement rocks was the most pronounced in the gravitational field. The proposed solution was reduction of sedimentary layer potential field, which include the following steps:

- Geological model building with the seismic data (4 reflected horizons – 3 in sedimentary layer and 1 is the top Palaeozoic) and density section by wells. The optimal trend for density distribution is linear-quadratic ratio of the layer’s thickness and its depth.
- Gravity and magnetic fields calculation (forward modeling) by density and magnetic susceptibility (reestablished from density by core petrophysical relationships) for sedimentary cover.
- Sedimentary cover potential fields subtraction from primary fields.

We observed that anomalies in primary fields before processing are smoothed and ambiguously interpreted. The methods of anomalies emphasizing include different transformations of gravity and magnetic fields. These recalculations include the upper half-space, averaging, low-pass filtering (Gaussian filter), calculation of higher derivatives (gradients), component field analysis, statistical analysis, field classification, correlation sounding, conversion according to Andreev, etc (Blokh, 2009). As reference, we used papers where magnetic field data are used for refinement of the geological structure of magmatic complexes (Ziska et al., 2019) and the methods of gravity and magnetic data integration including jointed inversion (Zhdanov&Cuma, 2019).

Results and Discussion

As a result, integration of geophysical and geological data was done on a synthetic geological model with the aim of removing the sedimentary cover effect. Geophysical data integrated include seismic horizons and geological data using density sections of exploration wells. After that, synthetic gravity and magnetic fields were subtracted from the primary fields. Using this method, we insured that computed potential fields reflected the real characteristics of pre-Jurassic basement.

Next steps, we used a series of transformations applied to potential fields of pre-Jurassic rocks with the aim of emphasizing local anomalies emphasizing. Component and statistical field analysis were used for qualitative interpretation and field composition. Correlation analysis – for connections with geology finding and nature of anomalies detection, classification – special position of pre-Jurassic formations, recalculation to the upper half-space – local anomalies estimation and higher derivatives were used for lateral position, shapes and sizes recognition. Higher derivatives (gradients) gave very good results for the West Siberian pre-Jurassic rocks as shown on Figure 2. Observed strong gradient zones were interpreted as a block boundaries with different lithological composition and tectonics.

![Figure 2 Gravity Vzx in E (left) and magnetic in nT/km (right) field gradients.](image-url)
In the fields of residual magnetic and gravitational anomalies, spatially oriented structures are clearly distinguished in the form of different-order of positive and negative anomalies mainly oriented NW and NE. This is consistent with the field gradient zones and understanding of the regional geological structure. We observed also a good correlation between the magnetic anomalies and gravitational fields. Given the transformations performed, we think the main local anomalies of the gravitational and magnetic fields are due to the predominant influence of the complex pre-Jurassic formations. Tectonic disturbances are distinguished by a gradient field, in which a sharper contrast of the boundaries of anomalous objects is observed in different directions. The patterns of tectonic disturbances are extended gradient zones, steps, zones of anomalies traceability losses and their displacement.

As a result, we consolidated all those results into a new geological map, based on core lithology hard data, predictive distribution scheme of pre-Jurassic formations, combined with structural and tectonic features (Figure 3). It shows clearly that, pre-Jurassic basement rocks are characterized by increased density and a significant variety of magnetic properties. Magmatic formations of mafic and intermediate composition are characterized by sharply increased values of magnetic susceptibility and density. This may be the reason for the appearance of positive magnetic and gravitational anomalies combined under these formations. A decrease in magnetic properties and an increase in the density of carbonate rocks correlated with positive gravitational and negative magnetic fields anomalies over carbonate massifs. The presence of other lithotypes in magnetic and gravitational fields will generally depend on the structure of the geological section.

Figure 3 shows clearly that within the studied area, a significant amount of tectonic disturbances of mainly NW and NE strike was additionally revealed. They separate blocks of basement rocks with different density and magnetic properties. The zones of intersection of these tectonic disturbances, as a rule, are associated with regional hydrocarbon fields, localized in the carbonate rocks of the pre-Jurassic basement. In the central, northeastern and southeastern parts of the object, zones of development of magmatic formations of presumably mafic and intermediate composition are distinguished. Magmatic bodies are linearly elongated fissure intrusions, formed in concert with the main tectonic disturbances in the final consolidation period of the pre-Jurassic basement of the West Siberian Plate.
The result can be confirmed by high-resolution gravity and magnetic data at a large scale. However, interpretation results are still uncertain and need validation from additional hard data (for example, core analysis). We expect to validate those results by integrating new hard data coming from new wells drilled in this area in a near future. It is the fact that increasing the length of the wellbore can bring new crucial information.

Conclusions

The study clearly showed that potential field methods integrated with seismic data and deep drilling help make more accurate geological interpretation for pre-Jurassic basement rocks in West Siberia. Integrating appropriate transformations (after removing the sedimentary cover effect) helped also in the calibration of the gravity and magnetic fields. The most appropriate transformation was field gradient of second derivative and showed a great improvement in the geological field characterization. The boundaries of different lithology blocks and locations of tectonic faults were changed and updated. Magmatic formations most confidently detected on potential field data.

The main part of the studied area was covered by 2D seismic with processing focused on the sedimentary cover. So the next crucial step of the study will be the integration of the potential fields data with those reprocessed 2D seismic sections. After that geological structure of Palaeozoic rocks will be adjusted in both directions – lateral and vertical. Geophysical data integration will allow clarifying the geological structure, conditions for the localization of hydrocarbon deposits in the pre-Jurassic basement and develop a series of criteria for their successful search. New data and subsequent results will be used in the planning of exploration strategy on the heterogeneous pre-Jurassic rocks of the West Siberia.

References


