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GEODYNAMIC ASPECTS OF INVESTIGATIONS IN UNDERGROUND RESEARCH LABORATORY (NIZHNEKANSK MASSIF)*

According to the actual international practice, the first stage of building a deep geological repository is construction of an underground research laboratory (URL) in order to detail enclosing rock mass characteristics. In 2018 in the Krasnoyarsk Territory, in the Nizhnekansk Granite-Gneiss Massif, the URL construction is planned at a depth of 500–600 m below ground surface. After the research completion scheduled in 2024–2025, the final decision on the suitability of rock mass for the high-level radioactive waste isolation will be made.

This article discusses geodynamic aspects of underground research in the framework of data on modern movement in the earth crust in the north of the Nizhnekansk Massif according to satellite geodetic survey and high-precision relevelling. The studies executed in 2010–2016 provided new knowledge on the modern geodynamic behavior in the region which lies in the contact zone of the largest tectonic structures—Siberian Platform, West Siberian Plate and Sayan orogen. The instrumental observations prove the cyclic nature of the modern geodynamic movement governed by the interaction between the listed structures. In 2012–2013, the regional tectonic regime altered abruptly in the form of the sign change of compression and tension on the right and left banks of the Yenisei River, as well as the increase of the horizontal movement velocities.

The maximum horizontal movement velocities are recorded in the dynamic influence zone of the Muratov and Right Bank faults. Plotted by the observation data, the map of the earth surface dilation confirms the earlier drawn conclusion that the right bank regions experience uplift while the left bank region undergoes subsidence. These data correlate with the high-precision leveling carried out by Geolkom in 2012–2015. The observation results also imply the existence of a differential movement zone with the limits of the Yenisei site. The authors propose a package of investigations into modern tectonics in the region of URL.

Key words: *geodynamics, radioactive waste, underground research laboratory, Nizhnekansk Massif, space geodesy, modern earth crust movement, GPS/GLONASS*
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Introduction

As an initial stage of deep geological repository (DGR) in the Nizhnekansk Granite–Gneiss Massif, an underground research laboratory URL is scheduled for construction on the right bank of the Yenisei River in Russia in 2018. After completing investigations of rock mass at a depth of 500–500 m below surface up to 2024–2025, the final decision of applicability/inapplicability of the selected site for the disposal of high-level waste HLW will be made. The determinants will be the hydrogeological regime stability in the territory and the insulating properties of the geological environment for the entire period of HLW radiobiological hazard which is longer than 10 thousand years [1–3].

The geological, geophysical and hydrological research accomplished in this territory provides general understanding of “static” parameters of the geological environment. At the same time, the geodynamic aspects of safe isolating properties of rocks and the hydrogeological regime stability of groundwater for such a long period yet remain to be studied more comprehensively [4]. In recent years, new instrumental data are obtained on the modern horizontal and vertical movement in the earth crust in the north of the Nizhnekansk Massif using the methods of space geodesy and high-precision relevelling. These data enable newly assessment of kinematics of tectonic blocks, which governs stress fields in the rock mass, and allow planning and optimizing future geodynamic and geomechanical investigations in underground openings of URL.

In connection with this, the present study focuses on geodynamics of the territory with regard to dynamic rock pressure phenomena (earthquakes, microshocks, rock bursts) which can induce loss of isolating properties in adjacent rock mass, alteration of hydrological characteristics as well as damage of engineering barriers and radioactive waste packages [5]. The study of the project documentation being the basis for permits, licenses and approvals in construction of URL and DGR has revealed that the problem was scarcely discussed earlier. In the meanwhile, the underground mining experience, including uranium production shows that rocks can start failing dynamically at a depth of 200 m [6].

Geology and tectonics of the area under study

The Nizhnekansk Massif is located at the juncture of three tectonic structures—Siberian Platform, West Siberian Plate and Altai–Sayan orogen, which govern the regional stress state in the north of the Massif. Regarding the prediction of the long-term safety in the tectonic block meant for DGR, it is important to study fields of stresses and strains directly within the limits of the Yenisei site (**Fig. 1**).

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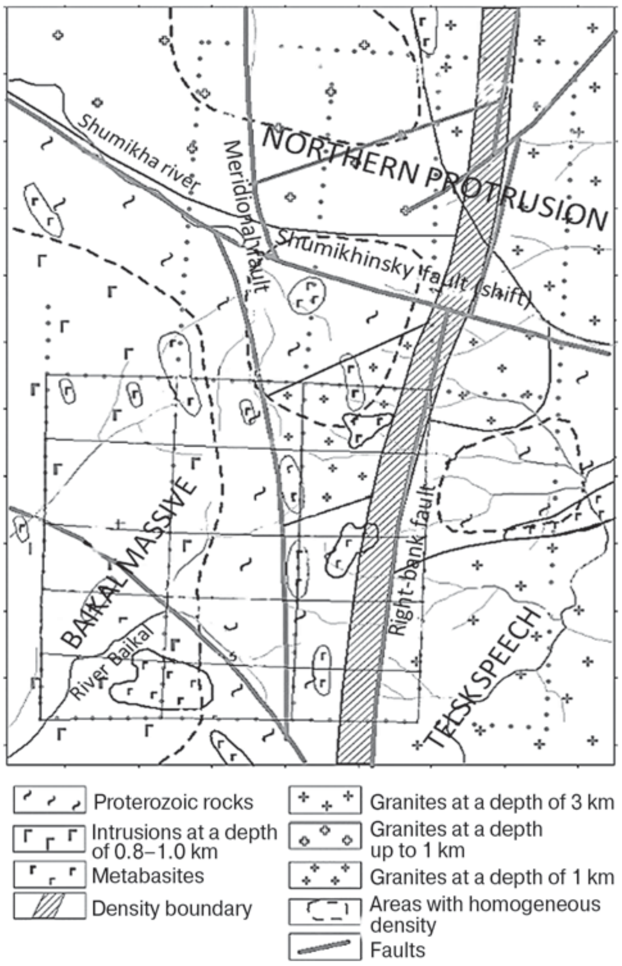

Fig. 1. Schematic tectonics in the area of the Yenisei site by the data of geological mapping and geophysical studies (2004)

The Yenisei site belongs to the magnitude 8 seismic hazard zone. It is well known that even local shallow M 4–5 earthquakes can generate extended fractures up to 10 km long. Weak earthquakes (in case when their hypocenters are in vicinity to an underground structure) can also initiate dynamic rock pressure phenomena in adjacent rock mass of mine shafts and tunnels in the form of scaling, spalling and rockbursting [6].

The east of the site is cut off by the old though currently activated Right Bank fault (see Fig. 1). The fault forms the northeastern shoulder of the Ataman ridge. The maximum amplitude of the Triassic–Jurassic fault within the Yenisei site is 400–580 m at the length of round 20 km. The amplitude of the post-Jurassic fault is on average 300 m. The fault revived during the Holocenic system and continues displacing at the present time, which is proved by the high-precision relevelling. The influence zone of the Right Bank fault is from 300 m to 3 km wide. In perpendicular to the fault, the Shumikhinsky fault cuts off the depressed neotectonic block from the central part of the Yenisei site.

In this manner, two faults divide the site into three different-altitude neotectonic blocks. Furthermore, the relief clearly reflects the other faults, e.g. 2–3 km westward of the Yenisei site boundary, there is the Muratov fault—the modern interface of the Siberian Platform and West Siberian Plate. Along this interface, the plate slowly goes down while the platform goes up. The amplitude of the vertical displacements reaches 3 mm/yr.

Instrumental measurements of the earth crust movements

In 2010 in the north of the Nizhnekansk Massif, a geodynamics testing ground was created for the instrumental measurements of the earth crust movements (ECM) using GPS/GLONASS in case of horizontal movement and by high-precision relevelling for the vertical displacements. **Fig. 2** presents the ECM monitoring scheme by the end of 2016, with the marked satellite observation points and high-precision relevelling line with the linkage to the Yenisei site boundary. The maximum velocities of horizontal ECM are recorded in the lines connecting the points lying in the dynamic influence zone of the Muratov, Right Bank and Bolshetelsky faults.

By the satellite data, the earth surface dilation was calculated, and the axes of the principal compressive and tensile stresses were plotted (**Fig. 3**). The analysis of the earth surface deformation in the period from 2012 to 2016 reveals 4 areas with anomalous background values:

– points 1204, 1205, 1206 in the zone of the Ataman fault at the contact of the Siberian Platform and West Siberian Plate;

– contrast compression and tension zones within the Yenisei site;

– points 1207, 1208, 1209 in the zone of the Right Bank fault.

These data correlate with the results of high-precision relevelling executed by Geolkom in 2012–2015 [2] in the region of levelling line No. 1.

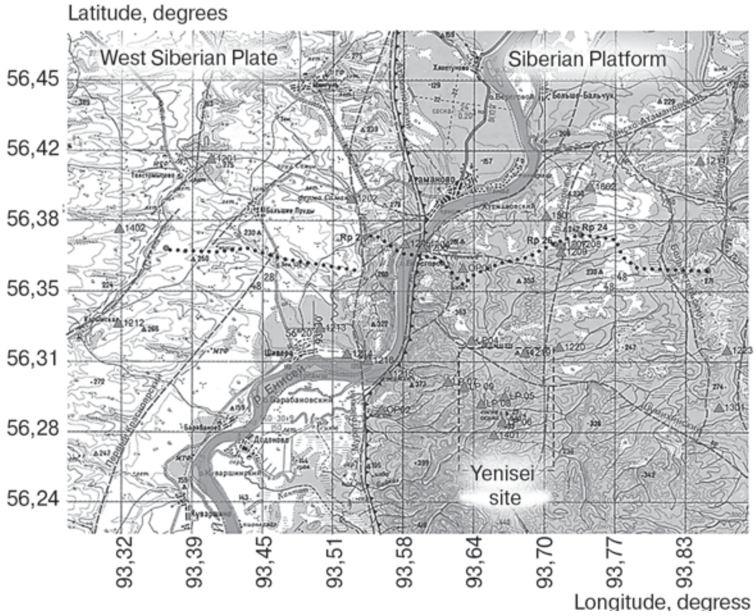

Fig. 2. Exploration area map. The dashed lines show the main faults. The dotted line makes the high-precision relevelling profile. The triangles are the GPS points

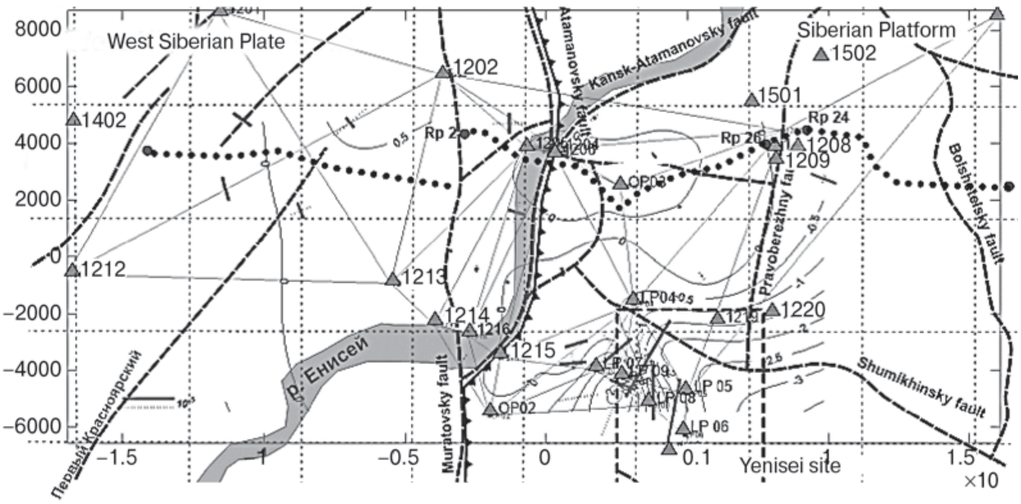

Fig. 3. Map of the earth surface dilation in the north of the Nizhnekansk Massif in 2012–2016 by GPS data

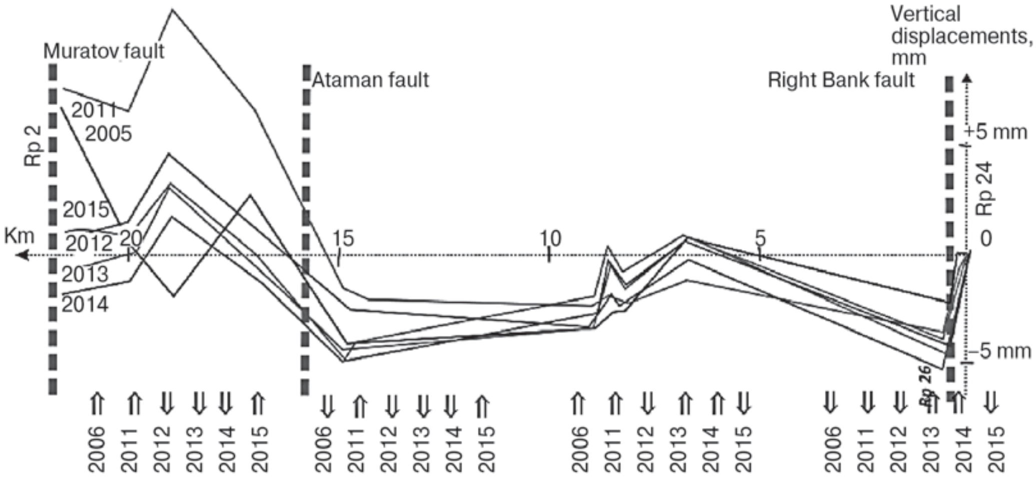

Fig. 4. Variation in elevations of bench marks by the data of Class 1 levelling along line No. 1 in 2002–2015

According to the plot of varied elevations of the levelling points in line No. 1 in **Fig. 4**, the depressed (east) wing of the Right Bank fault, which is morphologically normal fault and bounds a deep (to 500 m) erosion tectonic depression, undergoes an uplift. Over the period from 2002 to 2015, points Rp 26 and Rp 2 in line No. 1, as well as the segment in-between, experienced different-directed vertical movements relative to point Rp 24 located in the east wing of the Right Bank fault. In both cases, the periods of down movement prevailed over the alternation of different-length periods of uplift. The general trend in 2002–2015 is foundering of the west wing of the Right Bank fault relative to its east wing at the total amplitude of round 5 mm in 12 years, which is on average 0.4 mm/yr. Farther westward along line No. 1, in 2002–2006, a slight down movement is observed in the west wing (Rp 0197), bounded by the Right Bank fault in the east and by the Ataman fault on the west, relative to the east wing (Rp 26). Uplift takes place again in 2006–2011 and, then, subsidence is observed in 2011–2015 in the west wing. It should be emphasized that the vertical movement velocities of the bench marks are very slow, lower than errors of observations. At the same time, the trend of the whole process gives no rise to a doubt (see Fig. 4).

The directivity determined from the high-precision levelling coincides with the orientation and sign changeover times of horizontal deformations by the data of GPS/GLONASS, which dictates the same observations to be carried out on the Yenisei site.

Conclusion

In 2012–2016 on the Yenisei site, the deformation velocities have a positive sign (tension) in the west and a negative sign (compression) in the east. The zone of the sign change geometrically coincides with the Meridionalny fault and grasps the DGR area 2.0–2.5 km. The Baikal Massif (see Fig. 1) and Telsky Massif experienced uplift and subsidence, respectively, in 2012–2016 by GPS data. The orientation of the principal tectonic stress (northeast–southwest) agrees with the earlier results of the exploration and tectonics surveys.

Construction of large DGR 1.5–1.0 km in size at a depth of 500–600 m below ground surface will obligatory alter the current stress fields and groundwater flow directions in adjacent rock mass. In connection with this, it is required to analyze possible after-effects, including dynamic rock pressure phenomena. The mechanism of the accumulated deformation energy "release" in the form of destruction of tectonic blocks is analyzed in [7]; the instrumental observation data on history of stress fields in adjacent rock mass with a view to rock burst prediction are discussed in [8–10]. It is shown that location of mine openings and tectonic faults relative to each other is the key cause of rock bursts. A fault in close vicinity to a mine opening can be seismicity-generating (rock burst, weak earthquake at $K = 2–3$) and induce damage comparative with the large-scale blasting impact [10, 11].

Earlier the authors showed that stresses can concentrate in such areas [12–16]. It is assumable that local concentration zones of tectonic stress can exist at a depth of 500–600 in the zones which are detectable in deformation fields on the ground surface within the limits of the Yenisei site. Assuming possibility of seismically generated fractures across the DGR openings, the related seismic phenomenon will result in the loss of isolating properties in engineering barriers and in the tectonic block as a whole.

Therefore, regarding the ECM parameters determined in the URL arrangement zones as preliminary results, the authors believe it is required to implement integrated geological and geophysical survey in the area, including:

1. Geodynamics observations, including high-precision levelling and space geodesy within a radius of 15 km from DGR along bench mark lines intersecting all neighbor active faults;
2. Seismic observations within a radius of 10 km, including local seismic stations capable of recording seismic events of energy class 4;
3. Using newly drilled and existing holes for measurement of tectonic stresses in the URL locality;
4. Stress–strain analysis in rock mass surrounding DGR, including shafts;
5. Geomechanical observations in underground openings of URL.

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