IOP Conf. Series: Earth and Environmental Science **95** (2017) 032024 doi:10.1088/1755-1315/95/3/032024

Modern Geodynamics of South Yenisei Ridge to Result of the GPS/GLONASS Observations

Viktor Tatarinov[1,2], Vladimir Kaftan[1,3], TatianaTatarinova[1,2], Alexander Manevich[1]

[1] Geophysical Center of Russian Academy of Sciences, 117296, Moscow, Molodezhnaya 3, Russia
[2] Institute of Physics of the Earth of the RAS, Bolshaya Gruzinskaya, 10-1, Moscow 123242, Russia
[3]Agro-Technological Institute, Peoples' Friendship University of Russia (RUDN University), Moscow, Russia

victat@wdcb.ru

Abstract. Yenisei Ridge is located at the junction of major tectonic structures - Siberian Platform and West Siberian Plate. Its southern part is characterized by stable tectonic regime, the average speed of uplift according to geological data is 0.2-0.3 mm per year with the total amplitude of 400-500 m. However, the speed of modern movements of the Earth's crust is by more than an order of magnitude higher due to the temporary effect of large-scale geodynamic movements. The Yenisei river divides the area into two parts. The left bank is characterized by predominantly negative vertical movements and the right bank by positive ones. The major tectonic disturbances occur in the areas of the Muratovsky, Atamanovsky, Pravoberezhny and Bolshetelsky submeridional faults.
It was investigated the dynamics of changes in the lengths of ΔL baselines for separate epochs of observations. In 2010-2013 the absolute values of ΔL were significantly lower than for the periods 2013-2014 and 2014-2015. For the entire observation period the average value of the differences of the line lengths is 3.8 mm. This suggests that in general the area experienced strain during the period 2010-2015. Maps of the Earth's surface dilatation zones (deformation rate) showed that the maximum deformations were recorded in the area of Muratovsky and Atamanovsky faults located at the junction of Siberian Platform and West Siberian plate.

1. Introduction
The Yenisei Ridge is located at the junction of major tectonic structures - the Siberian Platform, the West Siberian Plate and the Altai-Sayan orogenic area. It is an active orogenic zone, i.e. the formation of the Yenisei Ridge is not finished yet. Therefore, prediction of geodynamic movement's velocity is highly relevant for the general fundamental problem of securing the insulation properties of the rocks to ensure the Yenisei Ridge is located at the junction of major tectonic structures - the Siberian Platform, the West Siberian Plate and the Altai-Sayan orogenic area. It is an active orogenic zone, i.e. the formation of the Yenisei Ridge is not finished yet. Therefore, prediction of geodynamic movement's velocity is highly relevant for the general fundamental problem of securing the insulation properties of the rocks to ensure environmental safety of the radioactive waste disposal.

In this regard, experts of GC RAS, JSC "Geolokom" and the ROSATOM Mining and Chemical Combine in Krasnoyarsk (GKHK) created a geodynamic testing ground for modern crustal movements monitoring based on GPS/GLONASS global navigation satellite systems. Over the last five years 30, stations of the geodynamic polygon carried out regular observations. The results of research are described below.

In this regard, experts of GC RAS, JSC "Geolokom" and the ROSATOM Mining and Chemical Combine in Krasnoyarsk (GKHK) created a geodynamic testing ground for modern crustal movements monitoring based on GPS/GLONASS global navigation satellite systems. Over the last five years, 30 stations of the geodynamic polygon carried out regular observations. The results of research are described below.

2. Geological and tectonic of the area

The Nizhnekansky rock massif is located in the southern part of the Yenisei Ridge, which is a projection of the crystalline basement of the Siberian platform. In the north it is bordered by the Riphean structures of the Trans Angara area, in the east it is blocked by the Vendian-Cambrian deposits of the Kansk-Taseevsk depression, in the south by the middle Paleozoic and Mesozoic sediments of the Rybinsk depression, and in the west, along the Baikal-Yenisei deep fault borders with the West Siberian Plate [1].

The massif is formed by an intrusive body, stretched from the southeast to the northwest for 60 km with a width of about 30 km. Its capacity ranges from 5-6 km to 8 km. The age of rock was determined by geologists from 450 to 850 million years. Large faults are of sub-latitudinal and sub-meridional orientation; the latter are considered younger. Despite the complexity of the geological structure and shape of the modern landscape, the area is characterized by the stable tectonic regime, the total amplitude of the territory's uplift in the recent period is estimated at 400-500 m, and the average rate of uplift is 0,2-0,3 mm/year. However, the instrumentally established crustal movement velocities are by orders of magnitude higher due to the scale of the time factor of modern movements.

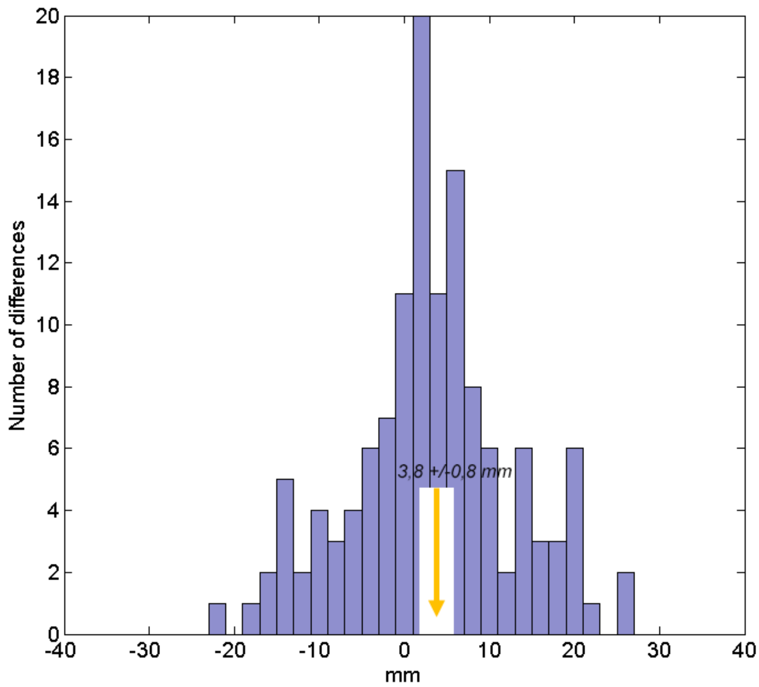

Figure 1. The distribution of length differences over the entire observation period from 2010 to 2015

The Yenisei river divides the area into two parts. The left bank is characterized by predominantly negative vertical movements and the right bank by positive ones [2, 3]. The major tectonic disturbances occur in the areas of the Muratovsky, Atamanovsky, Pravoberezhny and Bolshetelsky submeridional faults [4]. Therefore, to create a geodynamic testing ground the observation point's layout was arranged as a graph of the profile, crossing all the major tectonic faults from west to east.

3. Results of research

From 2010 to 2015 five cycles of observations were carried out, the dynamics of changes in the lengths of baselines was investigated (*ΔL*) and maps of crustal deformation velocities were created. For the total period of observations, the average value *ΔL* (Figure 1) was +3,8 ±0,8 mm. This suggests that the geodynamic regime of the whole area was characterized by tensile stress (extension).

Figures 2-4 show the changes in the lengths of baselines between observations points for the periods 2010-2013, 2013-2014, 2014-2015, respectively. Their analysis showed that each of the two epochs of observations has its own peculiar features: a) a change in absolute values *ΔL* and a change of their sign (compression-extension), depending on the epoch of observations. Figure 2 shows that from 2010 to 2013 the lines shortened on the right bank, i.e., the compression of the upper crust took place, and on the left bank, on the contrary, the length of almost all lines has increased, i.e. the geological medium experienced extension. In 2013 (Figure 3) the picture has changed to the opposite: lines on the right bank mainly extended, and compressed on the left bank. At that, the absolute values *ΔL* increased dramatically — by 30-50%.Then, in 2015 (Figure 4), the left bank has almost completely returned to its original geodynamic regime that existed before 2013, and on the right bank, this return process has just begun.

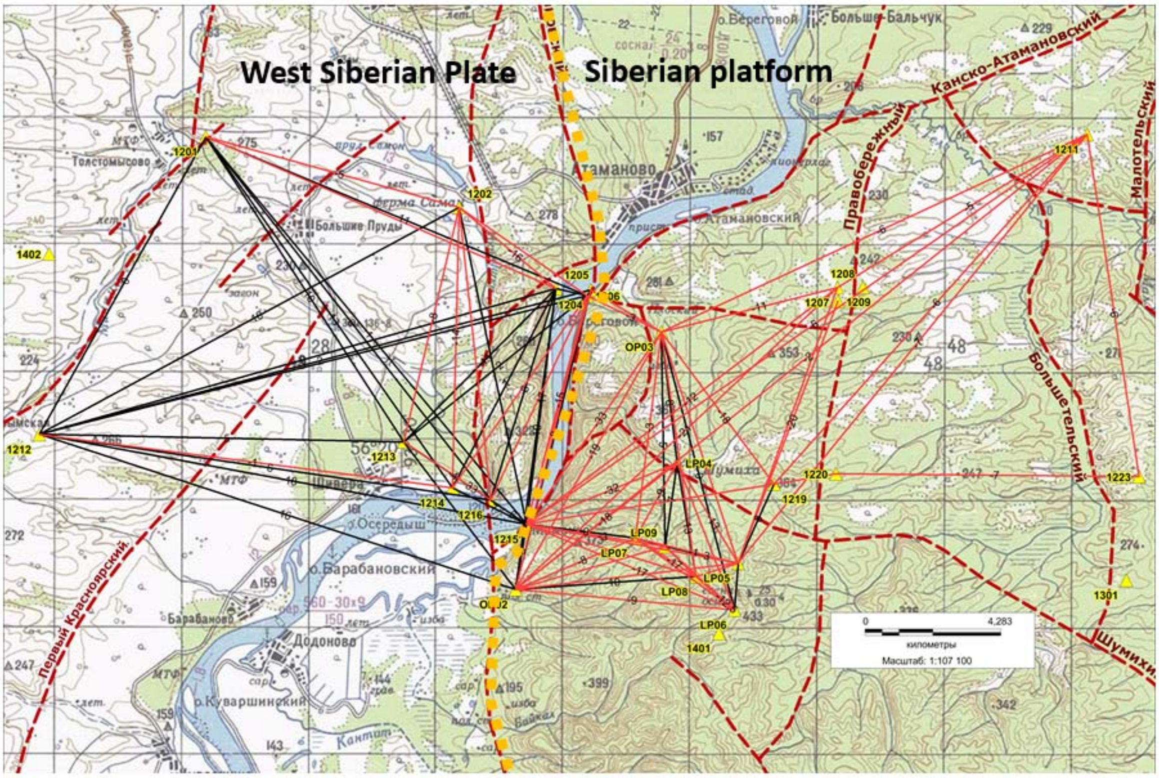

Figure 2. Changing the length of the baselines for 2010-2013, black color - length is not changed or increased (extention), red - length decreased (compression)

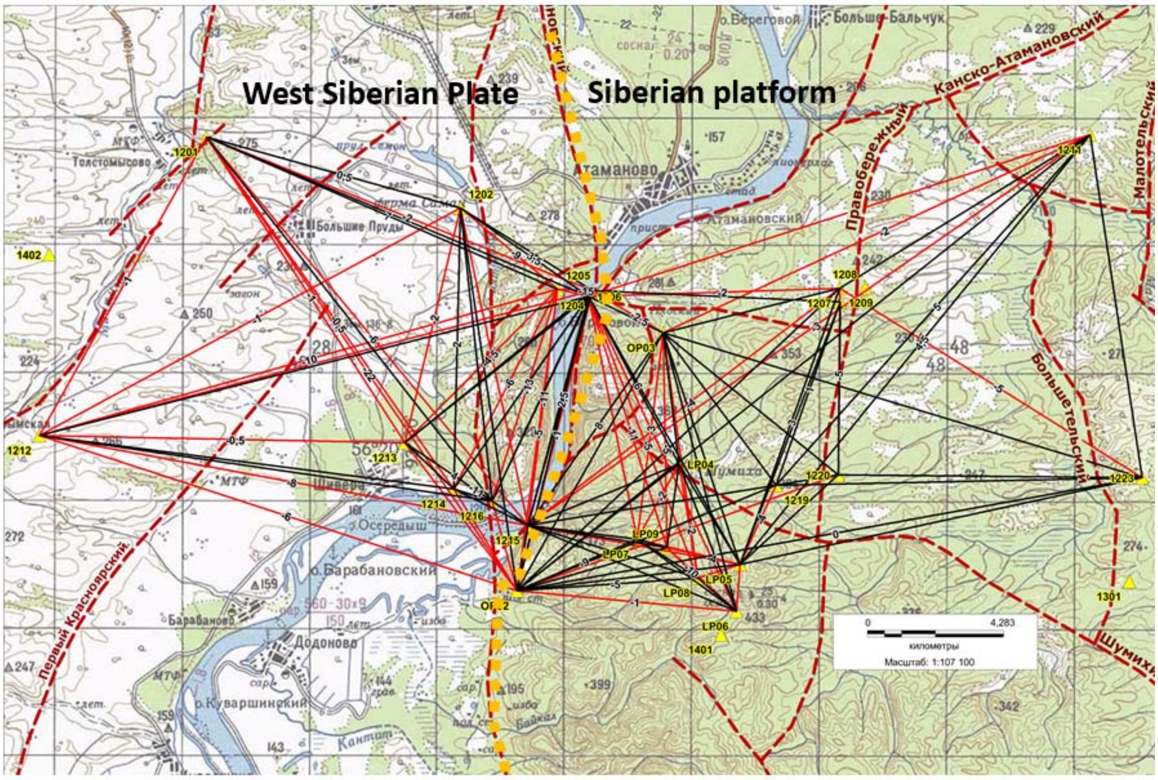

Figure 3. Changing the length of the baselines for 2013-2014, black color - length is not changed or increased (extension), red - length decreased (compression)

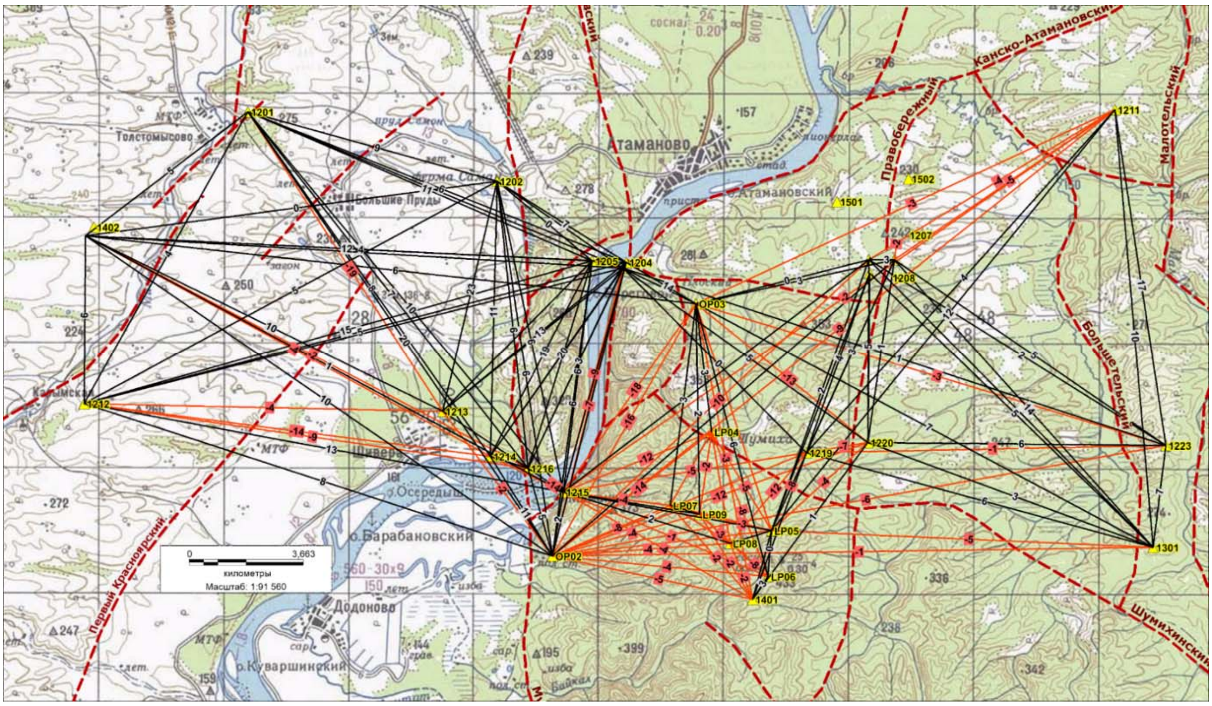

Figure 4. Changing the length of the baselines for 2014-2015, black color - length is not changed or increased (extension), red - length decreased (compression)

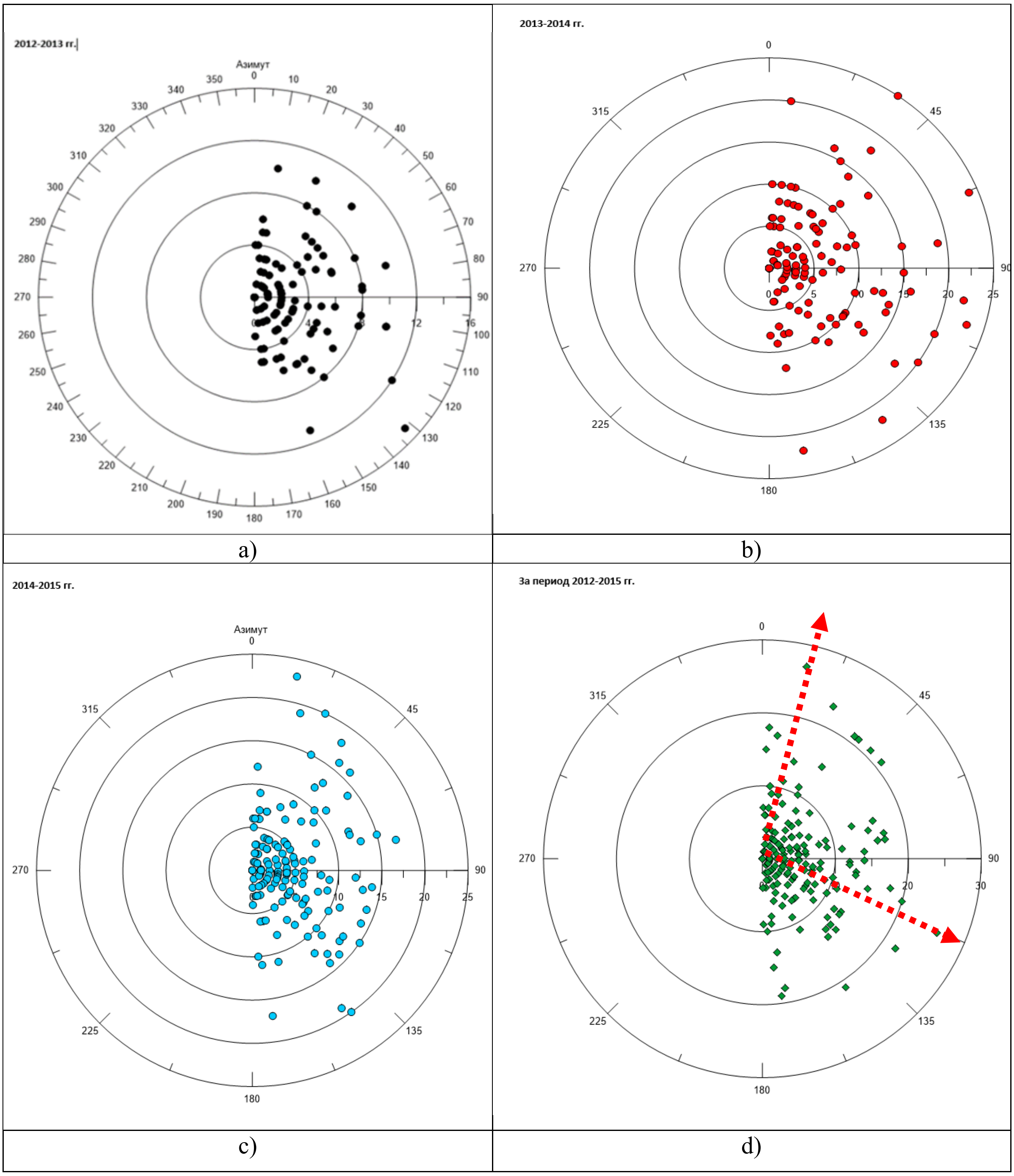

Figure 5. Diagrams of changing the length of lines in dependence on azimuth for the following periods of time: a) 2012-2013, b) 2013-2014, c) 2014-2015, d) 2012-2015

The reason for this effect, apparently, is the fundamental property of the behaviour of the Earth's crust [5] which is the cyclical development of geodynamic movements in time, when relatively long periods of accumulation of elastic energy, accompanied by relatively small movements, were followed by periods of intensification of movements, often of the opposite sign. Geodynamic movements of this nature can be found in other areas. For example, in the Urals, which is tectonically similar to the area of research, the results of measurements of voltages at 25 underground mines at depths of 100 to 800 meters revealed tectonic stress pulsing with a period of 12-18 months.

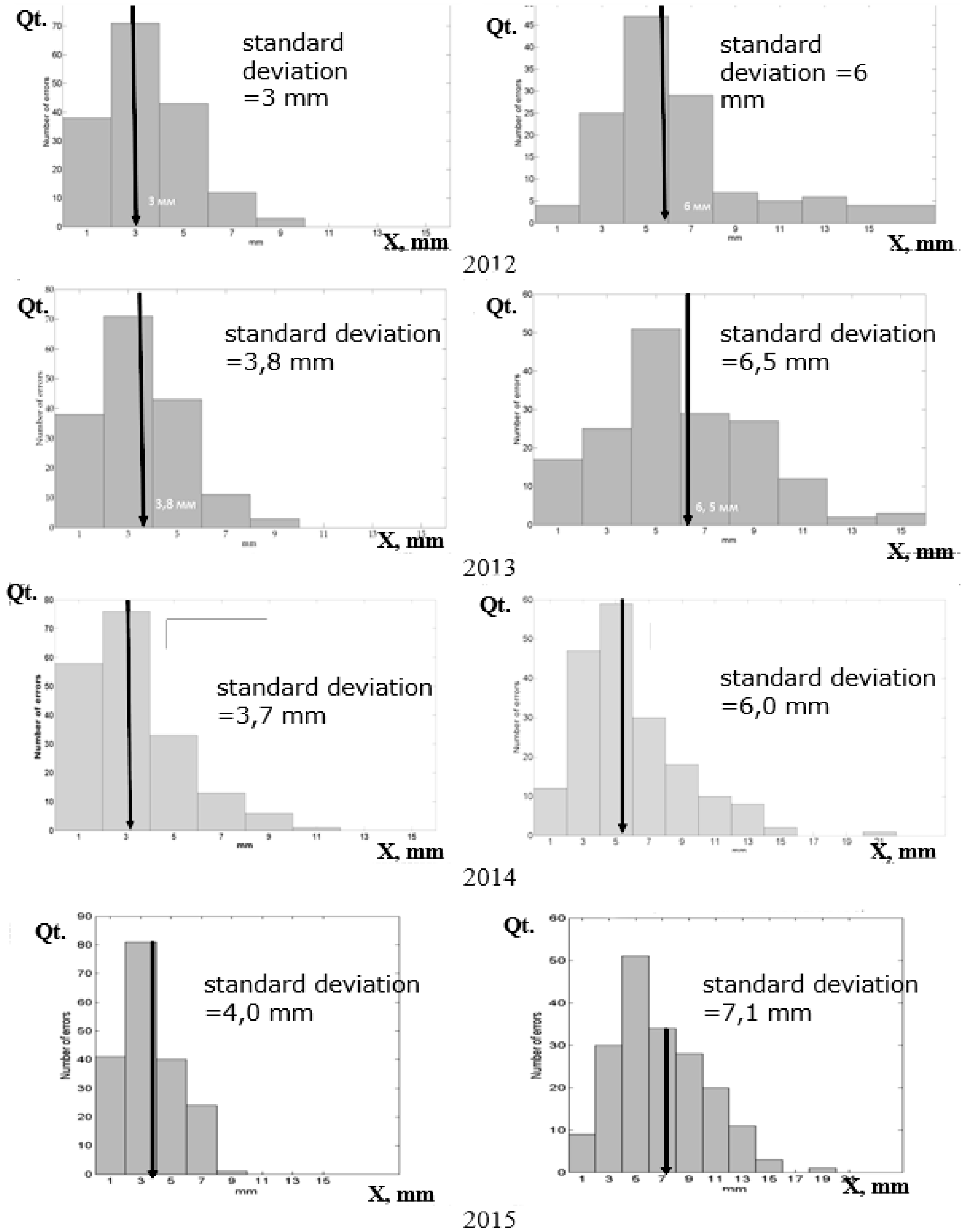

Figure 6. Results of the evaluation of the mean-square error of measurements Horizontal components - left column, vertical components – right [10]

There was also an attempt to find out by the changes of absolute values *ΔL* the main directions of movement associated with the main lines of tectonic forces. This is important to set the boundary conditions for the simulation of stress-strain state of the massif. For this purpose, a comparison of the line lengths for individual epochs of observations was calculated (Figure 5). The arrows in Figure 5, d show the azimuths of changes in the maximum absolute values *ΔL*. Interestingly, these directions coincide with major tectonic fault lines in Figures 2-4. It can be assumed that deformations of the Earth's surface are also associated with shear movements along the faults.

For the quality control and evaluation of the accuracy of the measurement results a network adjustment was performed [6]. Figure 6 shows the estimations of the mean square error (MSE) for the period 2012-2015. The accuracy estimation at the final stage of the equalization calculation provided the most reliable data on the real accuracy of points of the local geodetic network. The MSE of the points' location has shown that the MSE of horizontal and vertical accuracy amounted to 3.0-3.7 and 6.0-6.5 mm, respectively. Thus, it is evident that the greatest *ΔL* changes during the movements' intensification were caused by geodynamic reasons, and not by noise or possible technical errors in observations or calculations.

Not even rate of movements but strain rate is essential to forecast the insulating properties of a rock massif. Therefore the Earth's surface dilatation (Δ) map was constructed (the relative change in the area) (Figure 6). The map showed that the maximum deformations were recorded in the area of Muratovsky and Atamanovsky faults located at the junction of the Siberian Platform and West Siberian plate.

At the "Yeniseisky" station the strain was significantly lower $\Delta=2\cdot10^{-8}$. The work [7, 8] provides the average rate of the relative strain for increased geodynamic hazard areas equal to $5\cdot10^{-4}$-$5\cdot10^{-5}$. Comparing the magnitude of dilatation with these values, it can be argued that the "Yeniseisky" station in the period of observations was characterized by weak activity.

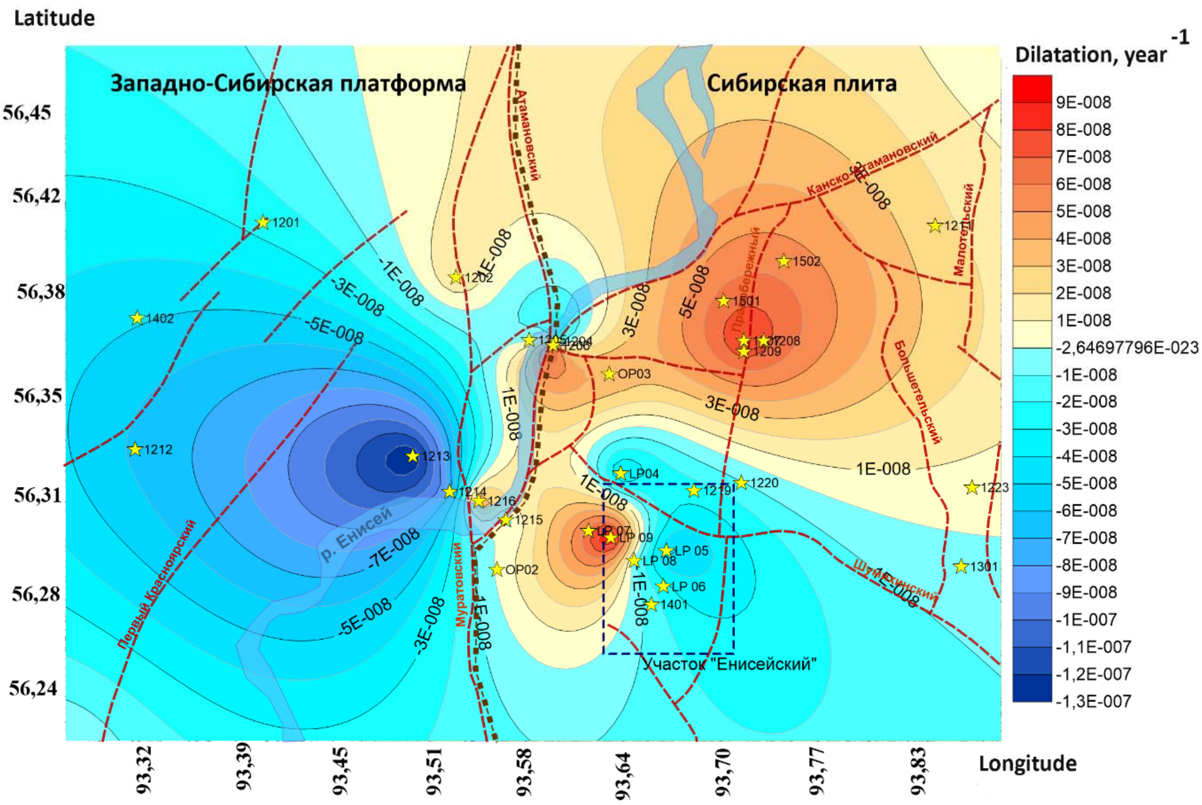

Figure 7. Map of dilatation (strain rate) of the earth's surface for 2010-2015

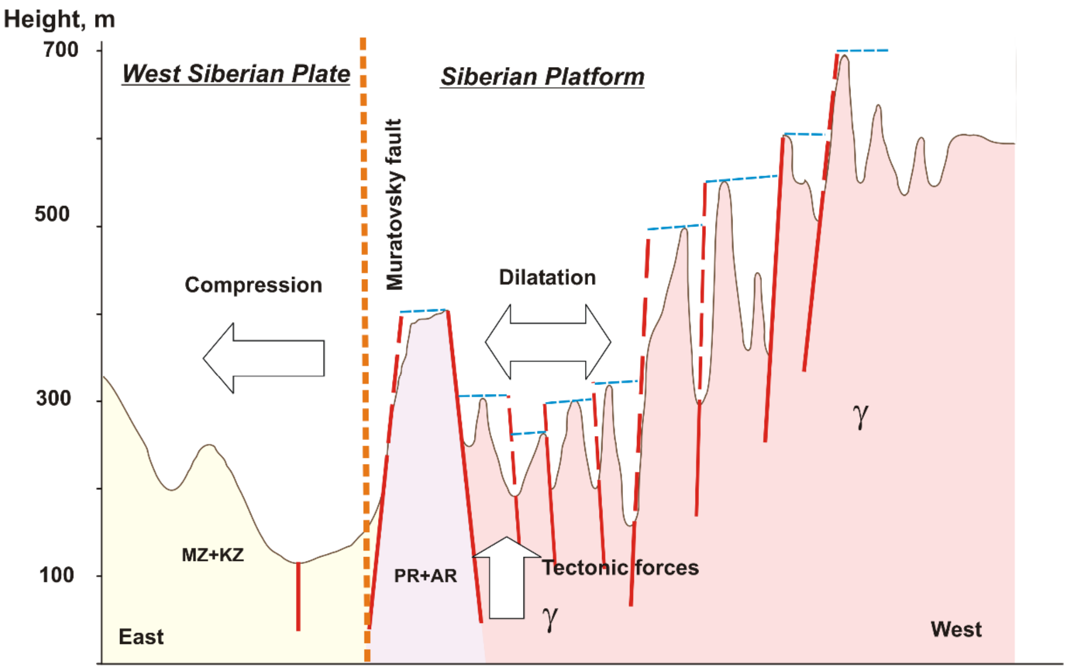

Figure 8. Hypothesis of the geodynamic situation in the southern part of the Yenisei Ridge (the vertical scale is greatly increased relative to the horizontal). The red dotted line - the boundary of two tectonic areas West Siberian plate and Siberian platform

Figure 7 shows the region's longitudinal section from east to west as an alternative interpretation of the cyclical development of modern geodynamic processes in the area (the vertical scale is considerably stretched relative to the horizontal scale). Vertical tectonic strain at the Siberian Plate in the southern part of the Yenisei Ridge leads to the formation of the relative extension zones on the Earth's surface and at the same time to compression on the border of the West Siberian platform. After reaching a certain limit of compression, a relaxation of accumulated stress by right shift occurs along the Muratovsky and Atamanovsky faults. The rock massif returns to its former condition and after a while the geodynamic cycle repeats. These conclusions are confirmed by neotectonic diagram of the Baikal-Yenisei fault in [9], which provides vertical velocities of the Pleistocene period. The scheme is very similar to the dilatation map shown in Figure 7. It can also be assumed that the modern geodynamic regime of the territory is close to the regime that existed, at least in the Pleistocene (from 2.5 mln to 10 000 years ago).

4. Conclusions

The geodynamic testing ground for observing modern crustal movements based on the use of GNSS was established in the area of construction of an underground research laboratory for the study of ecological safety of disposal of high level radioactive waste. For the first time we instrumentally determined the horizontal crustal movements rate for the area, located at the junction of two major tectonic structures — Siberian Platform and West Siberian Plate, in order to assess the intensity and direction of tectonic processes at the present stage of development of the region and the values of the maximum strain rate.

In 2013-2014 an activation cycle was registered, which manifested itself in an increase in the absolute values of changes in baseline lengths and in the sign change (compression-tension) on the right and left bank of the Yenisei River. The annual rate of baselines' change during the activation period increased to 15 mm, with pre-existing baselines in the range from 0 to 10 mm in 2010-2013. The probable reason was the cyclical nature of space-time development of geodynamic movements.

As a result of equalization of observations data we equalized baseline vectors' components and evaluated their accuracy. The mean square errors were in the intervals of 3-4 mm and 6-7,4 mm, respectively. We hypothesized that the modern geodynamic regime of the territory was close to the regime that existed at least in the Pleistocene.

In general, it can be mentioned that was not recorded any anomalous values of modern movements of the Earth's crust, which could confirm the existence of tectonic instability of the geological environment in the southern part of the Yenisei Ridge.

References

[1] Anderson E.B., Belov S.V. and other (2011). Underground disposal of radioactive wastes. M. «Gornaja Kniga», 592 p.

[2] Belov S.V., Morozov V.N., Tatarinov V.N., Kamnev E.N., Hamer J. (2007) The study of the structure and geodynamic evolution of the Nizhnekamsk array in connection with the disposal of high level radioactive waste // *Geoecology*. 2007. No. 2. P. 248-266.

[3] Morozov V.N., Tatarinov V.N. Methods of selecting areas of the earth's crust to accommodate the environmentally hazardous waste // *Geoecology*. M. 1996, No. 6, p. 109-120.

[4] Tatarinov V.N., Morozov V.N., Kamnev E.N., Kaftan W.I., Kagan A.I. (2014). Geodynamic monitoring as a basis for the conservation of the biosphere in the disposal of radioactive waste. *Earth sciences.* No. 3. 2014. P.47-60.

[5] Morozov V.N., Tatarinov V.N. Tectonic processes development with time in the areas of HLRW disposal from expert assessment to prognosis // *Int. Nuclear Energy science and Technology,* Vol. 2. No, 1/2. 2006. Pp. 65-74.

[6] Morozov V. N., Kolesnikov I. Y. and Tatarinov V. N. Modeling the Hazard Levels of Stress-Strain State in Structural Blocks in Nizhnekanskii Granitoid Massif for Selecting Nuclear Waste Disposal Sites. *Water Resources.* Vol. 39, Issue 7. 2012. pp. 756–769. DOI:10.1134/s009780781207007x.

[7] Morozov V.N., Gupalo T.A., Tatarinov V.N. Forecast insulating properties of the rock mass in the placement of radioactive materials in mines // *Mountain Gazette.* 1999, No. 6. p. 99-105.

[8] Tatarinov V.N., Kaftan, V.I., Seelev, I.N. Study of the Present-Day Geodynamics of the Nizhnekansk Massif for Safe Disposal of Radioactive Wastes. *Atomic Energy.* Springer. 2017. Volume 121, Issue 3, pp 203–207. DOI:10.1007/s10512-017-0184-5.

[9] Lobatskaya R.M. The fault-block structure of the Baikal-Enisei fault in the Region of operating nuclear energy facilities. *Geodynamics & Tectonophysics.* 2014;5 (2):547–562. DOI:10.5800/GT-2014-5-2-0140.