ATLANTIS PRESS

Advances in Engineering Research, volume 182

VIII All-Russian Science and Technology Conference "Contemporary Issues of Geology, Geophysics and Geoecology of the North Caucasus" (CIGGG 2018)

Characteristics of Modern Horizontal Movements in Central Sector of Greater Caucasus According to GPS Observations

E.A. Rogozhin
Geophysical Institute VSC RAS
Vladikavkaz, Russia
Schmidt Institute of Physics of the Earth of the RAS Moscow, Russia
cgi_ras@mail.ru

Zaalishvili V.B.
Geophysical Institute - Affiliate of Vladikavkaz Scientific Centre of Russian Academy of Sciences
Vladikavkaz, Russia
cgi_ras@mail.ru

A.P. Mironov
Lomonosov Moscow State University
Sternberg Astronomical Institute
Moscow, Russia

Melkov D.A.
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

V.K. Milyukov
Lomonosov Moscow State University
Sternberg Astronomical Institute
Moscow, Russia
Vladikavkaz Scientific Center RAS
Vladikavkaz, Russia

A.N. Ovsyuchenko
Schmidt Institute of Physics of the Earth of the RAS
Moscow, Russia

A.V. Gorbatikov
Schmidt Institute of Physics of the Earth of the RAS
Moscow, Russia

Dzeranov B.V.
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

***Abstract*—The article highlights the results of the first GPS measurements carried out along a geodetic profile that intersects all major geological structures in the Ossetian region of the Greater Caucasus. The interpretation of the measurement results was made in comparison with the results of neotectonic studies and data on the deep structure. The maximum decrease in the current transverse compression velocities was recorded in the region of the highest rise above the Earth's surface of a low-Q volume of the Earth's crust, which has a widening effect on the entire mountain structure. The presence of significant transverse displacements of the surface reflects the shear component along the largest faults of the Caucasian strike. The previously prognosticated significant decrease in the velocity of horizontal movements at the end of the aftershock process of the catastrophic Racha earthquake of 1991 on the southern slope of the Greater Caucasus was fully confirmed.**

Keywords—tectonics; geodynamics; GPS; structure; Earth crust; Greater Caucasus

I. Introduction

The Greater Caucasus and its Ossetian segment are regions with a complex tectonic structure. The region is also not simple due to high seismicity, the presence of hazardous geological processes, whimsical surface and underground reliefs, the variegated composition of rocks and soil conditions, saturation by minerals, mining waste and high population density [1-5]. This causes great scientific and practical interest in the state of the region and its modern tectonic movements.

According to the plate tectonic concept, this region is a result of interaction between two large lithospheric plates, the Eurasian and Arabian ones. It is believed that the convergence of these plates determines the contemporary geodynamics of the region with the ongoing formation of the fold and thrust structure, complicated system of faults, volcanism, high seismicity, and active crustal motions. Irrespective of the particular interpretation of the tectonic structure of the Greater Caucasus, it is commonly agreed that this structure has been largely formed by the subhorizontal, generally cross strike compressive stresses. These stresses remain critical even at the present stage of tectonic evolution, as is demonstrated by the analysis of the focal mechanisms of the regional earthquakes.

Most perspective investigations of modern geodynamics in the active tectonic provinces are the comprehensive studies using geodetic, geophysical, neotectonic and seismological methods. Geological, geophysical, paleoseismological and GPS observations were fulfilled in Ossetian segment of the meganticlinorium in the last years. The received results allow us to construct a new model of correlations of horizontal present day displacements of the Earth's surface and deep structure of the crust with seismogenerating zones activation processes for this important from point of view of seismic safety region.

II. Materials and Methods

In the Ossetian region of the Greater Caucasus, the Sternberg Astronomical Institute of Moscow University, together with VSC RAS, created a satellite-geodetic network consisting of 25 survey-mode sites for conducting periodically repeated GPS measurements, as well as the continuous station for GPS observations (code VLKK) [6, 7]. The data of two stations that were created by the Geophysical Survey of the RAS (codes ARDN, PRTN) was also used. The assessment of the velocities of modern tectonic movements is based on the analysis of time series of GPS coordinates of survey-mode sites and continuous stations calculated from primary data, which are sets of phase and code measurements at two frequencies lasting three days with a recording interval of 30 seconds UTC + 0 (GMT). For most sites, the periodicity of measurements is a multiple of one year. The GAMIT/GLOBK software package was used to process GPS data [8].

The estimation of the velocities of horizontal movements along the geodesic profile intersecting all the main geological structures of the Greater Caucasus was carried out for the first time. This determines the extraordinary value of the measurements. To interpret the results, a tectonic scheme compiled from data of different-scale geological mapping and our own field observations was used [9]. The profile is located in the area of maximum narrowing of all tectonic zones of the Greater Caucasus. The main moving tectonic boundaries are directly and vividly reflected in the modern relief and deformations of the Late Pliocene–Eopleistocene geomorphological level (Fig. 1).

The projections of the horizontal displacement velocities were extrapolated to a combined structural-geomorphological and geophysical profile along the valleys of the Greater Liakhvi and Ardon rivers (Fig. 2). Geophysical investigations were performed by the microseismic sounding method (MSM) [10] which allows us to adequately identify the configuration of both subvertical and subhorizontal velocity boundaries to a depth of 60 km.

The MS method has several alternatives in the world. With all the variety in the technology of their implementation (seismic arrays or singlepoint measurements), all these approaches have one thing in common — the fact that their underlying model of microseismic field formation requires that the medium is layered necessarily, consistently and locally. Therefore, the horizontal resolution of these methods is 3–5λ (λ is the wavelength of the fundamental Rayleigh mode that interacts with the heterogeneity). In contrast to these approaches, the model of microseismic field formation assumed in MSM does not require the medium to be layered. In this respect, it is believed that the main contribution to the microseismic field is provided by the fundamental Rayleigh modes, whereas the presence of the higher modes is minimal. The role of the informative parameter (the signal) in the MS method is played by the distortion of the amplitude field caused by the interaction with the velocity inhomogeneities. The phase information is not used. The shape and depth of the inhomogeneity is estimated from the surface distribution of the distortions at the frequency at which this disturbance manifests itself.

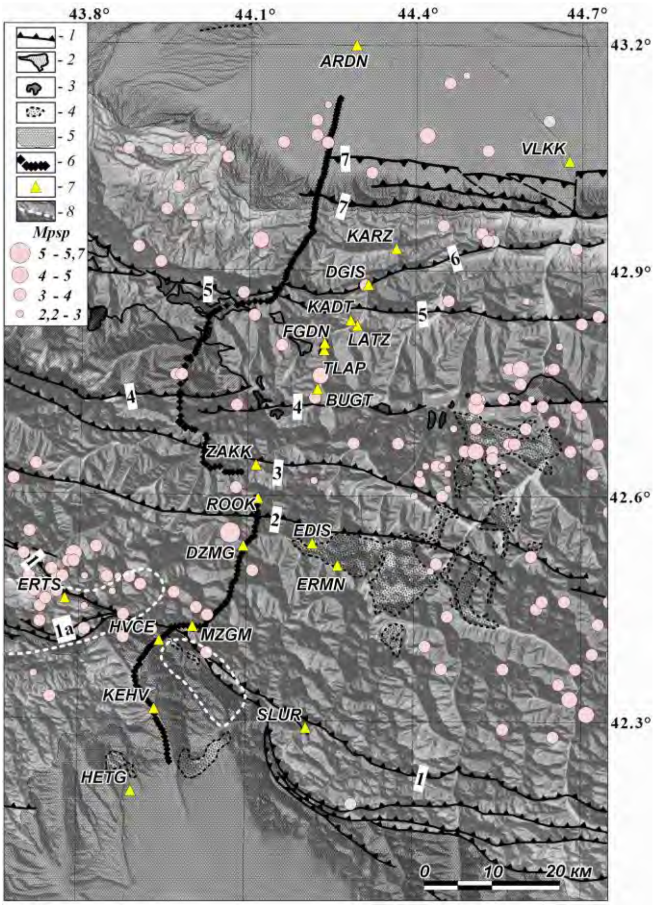

Fig. 1. Tectonic scheme of the region of the Ossetian geodetic network [11]. The circles are the epicenters of earthquakes in 2010-2016 according to the seismological network of the North Ossetian branch of the Unified Geophysical Survey RAS (http://www.ceme.gsras.ru).

1 – main thrust-overlaps; 2 – protrusions of the crystalline basement; 3 – Pliocene-Quaternary intrusions; 4 – Pliocene – Quaternary volcanic; 5 – Oligocene-Pliocene sediments of the Ossetian depression of the Pre-Caucasian trough, Racha-Lechkhumi trough and Trans-Caucasian intermountain depression; 6 – pickets of microseismic sounding profile (MSM) [8, 9]; 7 – points and stations of the Ossetian geodetic network; 8 – contours of the thickening fields of the aftershock epicenters of the Racha (M = 7.1) and Java (M = 6.2) earthquakes.

The numbers label the names of the main faults: 1 – Kakheti-Lechkhumi (Orkhevi, Utsersk), 1a – the southern branch of Kakheti-Lechkhumi (Potskhrevsk); 2 – Gebsk-Lagodekhi; 3 – Main Caucasian (Tib); 4 – Adaykom-Kazbek; 5 – Puysk; 6 – Balta; 7 – Vladikavkaz.

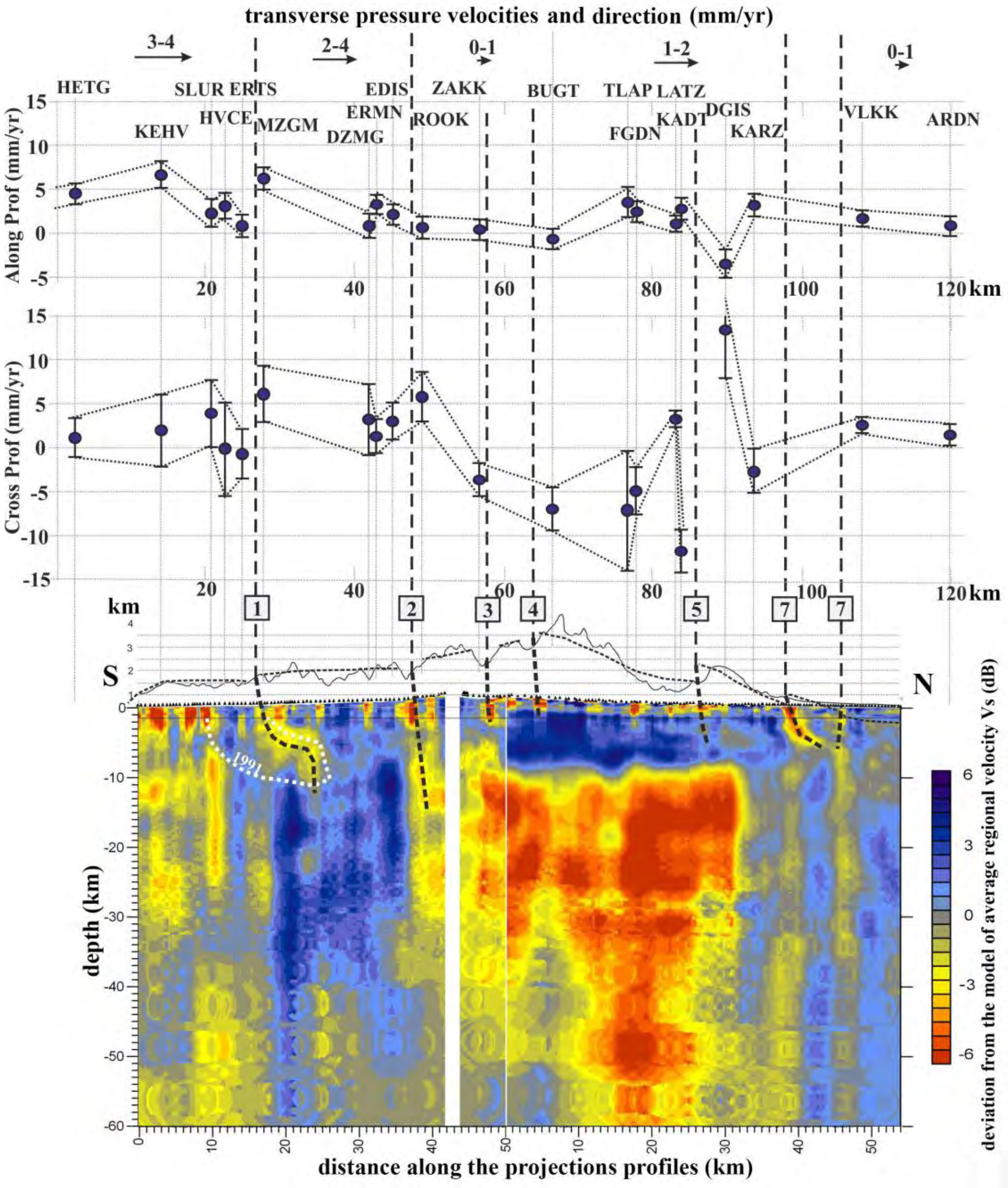

Fig. 2. Structural geomorphological and geophysical profiles combined with longitudinal (Along Prof) and transverse (Cross Prof) projections of horizontal velocities of displacements of points and stations of the Ossetian geodetic network relative to a fixed Eurasia on a profile with an azimuth of 15.88 °.

Latin letters label points and stations of the Ossetian geodetic network (Table I); thick black dotted lines – main faults (numerical designations in Fig. 1); the relief along the geological and geophysical profile and thin black dotted lines are shown - Late Pleiocene – Eopleistocene geomorphological level; the white dashed line is a projection of the contours of the thickening field of the aftershock hypocenters of Racha 1991, and Oni 2009 earthquakes on the geological and geophysical profile; horizontal arrows and numbers above them – the velocity of modern displacements.

It was shown by Gorbatikov and Tsukanov that on the Earth's surface above the high velocity heterogeneities (the velocities of the elastic waves in the heterogeneity are higher than in the hosting medium), the spectral amplitudes in a certain frequency band decrease, whereas above the low velocity structures (where the velocities are lower than in the hosting medium) the spectral amplitudes increase [11]. There is a critical frequency *f* of the Rayleigh wave, for which the distortions from the inhomogeneity that is located at a depth H are maximal, when compared to the similar inhomogeneities located at other depths. This frequency f is linked with depth H and the corresponding velocity of the fundamental Rayleigh mode VR(f) by the formula H ≈ 0.4VR(f)/f. This is confirmed by the studies of geological objects of different scales and origin, as well as by the model calculations. This relationship is used for the inverse procedure of estimating the depth for the unknown inhomogeneity that forms the amplitude distortions that can be observed at frequency *f*.

The composite MSM profile (Fig. 2) was acquired in three steps by the efforts of the expedition parties of IPE RAS and the Center of Geophysical Investigations, Vladikavkaz Scientific Center of the Russian Academy of Sciences. At the first step (2009), the measurements were carried out on the segment of the profile from the town of Ardon to the northern slope of Pastbishchnyi Range. The second and third steps were implemented in 2012 and 2013, respectively. The segment of the profile shot at the second step of the soundings ended on the southern administrative boundary of RNOA; the end of the third segment of the profile corresponds to the northern limit of the town of Tskhinval. Along its path, the composite profile passed through the Rok (Ruk) tunnel, where measurements conducting was technically impossible due to the tunnel's reconstruction.

III. Results and Discussion

Geological objects with relatively high seismic velocities appear in the microseismic field as zones with low amplitudes, and vice versa. In combination with data on the occurrence of tectonic processes in the Quaternary period, the deep MSM profile gives an idea of the sources of modern orogenic movements [10]. The low-velocity body found under the most elevated part of the Greater Caucasus clearly correlates with the region of maximum uplift at the Late Orogenic stage and can be compared with the relatively light, low-Q volume of the earth's crust. In the terminology of V.V. Belousov [12], this body can be interpreted as a consequence of deep diapirism. It is important to note that the maximum reduction in transverse compression was recorded in the region of the highest rise to the earth's surface of a low-Q volume of the Earth's crust.

There is a certain correlation of displacement velocities recorded along and across the geodesic profile. To the south of the Kakheti-Lechkhumi fault zone, where the surface movements transverse to the Caucasian mountain-folding structure have the greatest values, the transverse displacement velocities are 1-5 m/year. To the north, in the most elevated part of the meganticlinorium, where the velocities of modern displacements in the North-North-East direction are significantly reduced, the velocities of transverse movements, on the contrary, increase (5-15 mm/year). And to the north of the zone of the Vladikavkaz fault, transverse velocities are reduced to 1-3 mm/year.

The presence of significant transverse displacements of the surface causes a shear component along the largest faults of the Caucasian strike. Thus during the Java earthquake (15.06.1991) with M = 6.2, according to seismological (source mechanism) and geological and geomorphological data on this section, the seismogenic Kakheti-Lechkhumi fault was a left-side upthrow-shift [9].

It should be recalled that after the strongest Racha earthquake of 1991, a temporary local network of five GPS stations was located in the epicentral area. This network had been recording the horizontal surface movements on the southern slope of the Greater Caucasus and on the Transcaucasian Plate for four years [13]. Apparently, during this period the Dzirul median massif and the Okribo-Sachkhere zone of the Transcaucasian Plate shifted northward at a velocity of 4.2 ± 09 mm/year and immediately to the north of the Kakheti-Lechkhumi fault. The displacements of the tectonic zones of the southern slope to the south and south-south-west were recorded with velocities of 6.8 ± 1.2 mm/year. Consequently, in the focal zone of the earthquake, a reduction of the earth's surface was recorded at a rate of about 1 cm/year. At the same time the northern Caucasian wing of the fault was characterized by a significantly higher horizontal movement velocity.

IV. Conclusion

As is seen from the above data, in recent years the rate of the surface displacement has almost halved and the rapid movements of the southern wing of the meganticlinorium in the southern points have disappeared. At the same time, a sharp decrease in the velocities in the zone of the Kakheti-Lechkhumi fault, in fact, corresponds to the trend that was noted after the Racha earthquake. At the same time, a significant decrease in the velocity of horizontal movements at the end of the aftershock process prognosticated earlier by researchers [13] was fully confirmed.

But the sharp decreasing of velocities of horizontal surface movements in zone of Vladikavkaz active fault may be interpreted as precursor of future strong earthquake especially in correlation with deep seismic calm in this seismogenerating disjunctive structure.

Network operations are intended to develop the safety concept for people living in mountainous areas and for designing standard scenarios of hazardous geological processes (landslides, glacier motion with rock ice slides, earthquakes, etc.) [14-16].

References

[1] A.G. Shempelev, V.B. Zaalishvili, S.U. Kukhmazov, "Deep Structure of The Western Part of The Central Caucasus from Geophysical Data", Geotectonics, vol. 51, pp. 479-488, 2017.

[2] V.B. Zaalishvili, D.A. Melkov, "Reconstructing The Kolka Surge on September 20, 2002 from The Instrumental Seismic Data", Izvestiya. Physics of the Solid Earth, vol. 50, pp. 707-718, 2014.

[3] O.G. Burdzieva, V.B. Zaalishvili, O.G. Beriev, A.S. Kanukov, M.V. Maisuradze, "Mining Impact on Environment on The North Ossetian Territory", International Journal of GEOMATE, vol 10, pp. 1693-1697, 2016.

[4] K.K. Khulelidze, Yu.I. Kondratiev, V.B. Zaalishvili, and Z.S. Bertorozov, "Assessment of indigenous and technogenic deposits of RNO-Alania as possible objects of application of technology of underground and heap leaching," Sustainable development of mountain territories, vol. 8, pp. 46-51, 2016.

[5] V.B. Zaalishvili, O.G. Burdzieva, A.K. Dzhgamadze, "Geothermal Waters of North Ossetia", Ecology, Environment and Conservation, vol. 21, pp. 151-155, 2015.

[6] V.K. Milyukov, A.P. Mironov, G.M. Steblov, V.I. Shevchenko, A.G. Kusrayev, V.N. Drobyshev, and Kh.M. Khubayev, “Modern horizontal movements of the main elements of the tectonic structure of the Ossetian part of the Greater Caucasus using GPS measurements,” Physics of the Solid Earth, No. 4, pp. 68-80, 2015.

[7] V.K. Milyukov, A.P. Mironov, A.N. Ovsyuchenko, E.A. Rogozhin, A.V. Gorbatikov, V.N. Drobyshev, Kh.M. Khubaev, and A.V. Nikolaev, “Velocities of Present-Day Horizontal Movements in the Central Sector of the Greater Caucasus according to GPS Observations and Their Relation to Tectonics and the Deep Structure of the Earth’s Crust,” Earth Sciences Reports, vol. 481, Part 1, pp. 879-882, 2018. DOI: 10.1134/S1028334X18070279

[8] T.A. Herring, R.W. King, and S.C. McClusky, “Introduction to GAMIT/GLOBK,” Department of Earth, Atmospheric, and Planetary Sciences Massachusetts Institute of Technology, 2010.

[9] E.A. Rogozhin, A.N. Ovsyuchenko, A.I. Lutikov, A.L. Sobisevich, L.Ye. Sobisevich, and A.V. Gorbatikov, “Endogenous hazards of the Greater Caucasus,” Moscow: IFZ RAN, 2014.

[10] A.V. Gorbatikov, E.A. Rogozhin, M.Y. Stepanova, Y.V. Kharazova, N.V. Andreeva, F.V. Perederin, V.B. Zaalishvili, D.A. Mel'kov, B.V. Dzeranov, B.A. Dzeboev, and A.F. Gabaraev, “The pattern of deep structure and recent tectonics of the Greater Caucasus in the Ossetian sector from the complex geophysical data,” Izvestiya, Physics of the Solid Earth, vol. 51, No. 1, pp. 26-37, January 2015. DOI: 10.1134/S1069351315010073

[11] A.V. Gorbatikov and A.A. Tsukanov, “Simulation of the Rayleigh waves in the proximity of the scattering velocity heterogeneities. Exploring the capabilities of the microseis mic sounding method,” Izvestiya, Physics of Solid Earth, vol. 47, No. 4, pp. 354-370, 2011.

[12] V.V. Belousov, “Basics of geotectonics,” Moscow: Nedra. 1989.

[13] M.T. Prilepin, S. Balasanyan, S.M. Baranova, T.V. Guseva, A.V. Mishin, M. Nadariya, E.A. Rogozhin, N.K. Rozenberg, Yu.P. Skovorodkin, M. Khamburger, R. King, and R. Reylinger, “Studying the kinematics of the Caucasus region using GSP technology,” Physics of the Solid Earth, No. 6, pp. 68-75, 1997.

[14] V.B. Zaalishvili, N.I. Nevskaya, and D.A. Mel'kov, “Instrumental geophysical monitoring in the territory of northern Caucasus,” Izvestiya-Physics of the Solid Earth, vol. 50, No. 2, pp. 263-272, March 2014.

[15] V.B. Zaalishvili, M.G. Berger, I.N. Maliev, D.A. Melkov, A.S. Kanukov, and V.D. Makiev, “Development of system of instrumental monitoring of Kazbek volcanic center,” Geology and Geophysics of the South of Russia, No. 4, pp. 44-51, 2016.

[16] V.B. Zaalishvili, D.A. Melkov, B.V. Dzeranov, F.S. Morozov, and G.E. Tuaev, “Integrated instrumental monitoring of hazardous geological processes under the Kazbek volcanic center,” International Journal of GEOMATE, vol. 15, No. 47, pp. 158-163, 2018.