The ratio of tectonic structure and modern movements of the crust in area of geodynamic proving ground in Bishkek

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Abstract. According to the various scale GPS measurements, the process of collision between India and Eurasia is still ongoing and is reflected on Central Asia territory. The maximum velocity of shortening on northern component between India and Asia is ~35 mm/year; the longitudinal (east-west) extension of the Tien Shan is ~20 mm/year. The maximum deformations of shortening ~15 mm/year along the north coordinate operate in a narrow fault zone between the Pamir and Tien Shan. Not on all Cenozoic (neotectonic) faults occur modern movements of the earth's crust, these faults may have separate segments of active at different times. The general kinematic tendencies of modern movements correlate well enough with the general kinematic structure of neotectonic faults. In the fault zones at distances from the first hundreds meters to the first kilometers, intense elastic changes in the baseline lengths up to 4 cm (strains of $10^{-4}$) can occur within a week and up to 3-5 months. Such high-frequency elastic events have a different character of manifestations and are 2-4 orders of magnitude greater level than stable many years’ residual deformations.

1. Introduction

On a global scale, the cause of tectonic movements and deformations of the earth's crust in Asia can be represented as the result of a continental collision of India and Eurasia. Peter Molnar and Paul Tapponnier, according to the magnetic anomalies in the oceans, presented this process as the movement of India to arbitrarily assumed fixed Eurasia [1]. Approximately 38 million years ago India slowed down the speed of its movement 2-3 times (from 100-180 to 50 mm/year), which may indicate the time of its collision with Asia. And later to the present, India as the "rigid indenter" continues its movement, deforming the "rigid-plastic body" of Eurasia with the formation of the mountains Himalayas, Tibet, Pamir, Tien Shan, Altai, etc. The width of the India-Eurasia collision zone is estimated at more than 2000 km, where deformations, thickening and displacement of the earth's crust occurred due to folding and faulting.

The method of high-precision GPS positioning allowed us to obtain for geodynamic studies the first data confirming that the Tien Shan is seismically active intercontinental mountain belt and emerged as a result of India’s collision with Asia [2]. This article argues that Tien Shan arose as a result of a crust reduction of ~200±50 km, which is only a small part of India’s total impact on Asia (2000–3000 km). According to the data of the first GPS measurements, the modern rate of reduction of the earth's crust on Tien Shan is 20 mm/year, which is almost half the rate of convergence of India with Eurasia. All these data were obtained by a large international group of scientists based on Bishkek Geodynamic Proving Ground (BGPG).
This BGPG is located on the territory of Tien Shan, in the center of the proving ground is the capital of Kyrgyzstan. For more than 40 years, the Research Station of the Russian Academy of Sciences (RS RAS) has been conducting comprehensive stationary geophysical observations of about 200–300 km around Bishkek city. On the topic of this work, only the results of multi-year space and ground-based geodetic measurements on the territory of the Central Asian GPS network (CAGPSN) in comparison with the tectonic (folded-burst) structure of the earth's crust are considered. RS RAS employees have information on GPS measurements from 1994 to the present for ~700 sites in Kyrgyzstan, Kazakhstan, Tajikistan, Uzbekistan and China (figure 1).

Figure 1. Location of the sites of Central Asian GPS network and the territory of the stationary integrated geophysical measurements (Bishkek Geodynamic Proving Ground).

2. Modern movements of the crust in Central Asia

GPS measurements for 1995-2005 covered the territory from the mountains of Western Kunlun, through the territory between the Pamir and Tarim, through Tien Shan, to Altai and the northern outskirts of Kazakh shield [3]. Values of the velocity vectors of modern movements of the earth's crust relatively stable part of Eurasia decreases from south to north. In the velocity field, there are no pronounced stretching zones, which indicate the impossibility of the realization of the processes of mountain building due to the ascending mantle flows under the lithosphere of these regions. The uneven distribution of movements over the area indicates the discrete nature of the structure of the earth's crust and its deformations.

The project of GPS measurements across the territory of Tajikistan 2007-2011 allowed to significantly quantitatively detailing modern movements in Pamir and adjacent territories [4-6].
Approximately 15 mm/year of shortening falls on the zone of Pamir's thrust on Alay valley and Tien Shan, which is about half of the relative movement of a stable part of Pakistan to the north towards Eurasia. Another 10–15 mm/year shortening is distributed throughout Himalayas and Hindu Kush, a moderate reduction of <5 mm/year occurs north of Trans-Alai Thrust. A slight shortening from north to south occurs within the high Pamir, but within this region a 5–10 mm/year east-west expansion occurs, which is offset by a reduction in east-west in the Tajik Depression. With a few added velocity vectors on the Indian plate [7], the horizontal velocity field will look like this (figure 2).

**Figure 2.** Horizontal velocity vectors between India and Asia based on GPS measurements for 2007-2015.

For figure 2, the observer is on a stable part of Eurasia, while the northern component of the velocity vectors from the Indian plate to the Kazakh shield gradually decreases. Between bold arrows, the difference of the vectors in modulus is ~ 35 mm/year. Stepped speed reductions are observed between the Hindu Kush - Pamir - Tien Shan mountain systems. Asymmetry in the distribution of the velocity vectors is observed to the west and east of the Pamir. At same latitude, velocities in the Tajik Depression are about 2 times smaller than the sizes of vectors in Tarim. At the same time, along the northern component, the velocity vectors in the Pamirs and Tarim are approximately equal, however, Tarim moves somewhat to east from Pamir.
Longer and detailed measurements are carried out on the territory of CAGPSN (figure 3).

![Figure 3](image)

**Figure 3.** Horizontal velocity vectors (~600) for 1994-2016 in the EURA-2008 reference system.

When estimating an error of ~2 mm/year for CAGPSN, the maximum velocity of shortening is ~28 mm/year for northern component at ~1100 km, which corresponds to strain of $-3 \times 10^{-8} \text{ year}^{-1}$. The maximum elongation velocity of ~20 mm/year on eastern component at ~1400 km, which corresponds to strain of $1.5 \times 10^{-8} \text{ year}^{-1}$.

If you apply a special algorithm [8] to a set of horizontal velocity vectors (figure 3), then you can separate quasi-rigid domains (blocks) of the earth's crust that move relative to each other (figure 4).

![Figure 4](image)

**Figure 4.** Displacement scheme of the sides of neighboring domains. Inset, mean directions for different kinematic displacement modes.

The magnitude of the inter-domain displacements is several times greater than the deviation of the velocities from a rigid whole within the domains (on average ~0.35 mm/year). The motion of domains according to kinematic features is carried out according to the system and can serve as an estimate of the directions of the main axes of the strain rate. Comparison of the spatial positions of modern statistically rigid domains and inter-domain zones with neotectonic faults gives grounds to assert with probability 0.99 faults with the same frequency pass both across the domains and between them. But there is a continuity of general directions and kinematics for inter-domain zones and neotectonic faults.

3. **Velocity vectors for local areas**

The maximum values of relative displacements and deformations of the earth's crust in Central Asia are manifested in the junction zone of the Pamir and Tien Shan mountains (figure 5).

![Figure 5](image)
Figure 5. Horizontal velocity vectors in Tajikistan for 2007-2011 in the EURA 2008 reference system. Thick lines - concentration zones > 5 mm/year of mean relative displacement of the earth’s crust (digitals), arrows - kinematics of relative displacements of opposite sides for zone

On the basis of the triangulation network, the moduli of the difference of the velocity vectors between pairs of points were calculated. Triangulation edges with a difference modulus > 5 mm/year form regularly spaced zones. For these zones, the mean values of the directions and the magnitude of the displacements of the nearest benchmarks are determined. In most cases, the zones of concentration of modern crustal movements spatially correlate with the neotectonic faults.

According to the results of 1997-2014 GPS measurements of 36 points of the Bishkek local network, an average decrease in the three components of velocity is observed (figure 6).

Figure 6. Horizontal velocity vectors for 36 points of the Bishkek local GPS network for 1997-2014 in the EURA 2008 reference system. Thick lines - generalized discontinuous boundaries of uneven-age blocks.

From the south to the north, the block of Paleozoic rocks by faults is replaced by a belt of younger Cenozoic sediments, and then in the Chui valley there are only large clastic quaternary formations. Also, on average, all components of velocity (in mm/year) decrease regularly: north (from 2.23 to 0.67), east (from -0.79 to -1.00) and vertical (from 1.01 to 0.05). The upper and lower limits of variation for each velocity component also decrease from block to block from south to north.
4. Observations on detailed geodetic sites

At the BGPG 3 geodesic sites are located in the east-west direction along the active fault zone, at 5–13 km distance each from other. Four types of pulsed (elastic) deformation events have been detected [9] on 44 baselines of these geodesic sites as a result of weekly linear-angular measurements for 2012–2016 (figure 7).

First, it is isotropic type in terms of short-period (6–7 days) synchronous elongations of all baselines in all geodesic sites up to 4 cm and strain up to $2.3 \times 10^{-4}$. The second is that the lengths of baselines anisotropically changes within 3–4 months: the north direction lines are extended to 11 mm ($7.3 \times 10^{-5}$) and the east direction lines are shortened to $-8$ mm ($-4.4 \times 10^{-5}$). In all cases there is a smooth increase or decrease in the length of the lines to the extremum and then a relatively sharp decline to the background values, in the latitudinal direction there is a delay of the deformation event by 1–3 weeks. In the third type, the north direction lines are extended to 9 mm and the east direction lines are extended to 2 mm. For all directions of the baselines within 4–5 months extremes of length changes are shifted to the beginning of the event in time and then there is a smooth transition to background values. The fourth type is that the length of only one baseline of any direction changes noticeably over time. The rates of steady elongation or shortening of baselines to 1–2 mm/year have been calculated using the straight-line approximation method for the values of background variations of their lengths over 5 years of measurements. This corresponds to a strain rate of $10^{-6}$–$10^{-7}$ year$^{-1}$ and is in good agreement with GPS data.

![Figure 7](image)

**Figure 7.** Change in the lengths of mutually perpendicular (N–S and E–W) baselines of Almaly site according to weekly linear-angular measurements.

5. Conclusion

In this paper, the question of the degree of continuity of modern kinematics of movements in relation to the more ancient tectonic structure of the earth's crust in Central Asia is considered. From the data of different-scale GPS measurements, it follows that the collision process between India and Eurasia is still ongoing and is reflected almost throughout the entire territory of Central Asia.

The maximum velocity of shortening on northern component between India and Asia is $\sim$35 mm/year; the longitudinal (east-west) extension of the Tien Shan is $\sim$20 mm/year. The maximum deformations of shortening $\sim$15 mm/year along the north coordinate operate in a narrow fault zone between the Pamir and Tien Shan.
Not on all Cenozoic (neotectonic) faults occur modern movements of the earth's crust, these faults may have separate segments of active at different times. The general kinematic tendencies of modern movements correlate well enough with the general kinematic structure of neotectonic faults. Modern residual deformations can be realized not concentrated, but distributed over a relatively large volume of the earth's crust.

In the fault zones at distances from the first hundreds meters to the first kilometers, intense elastic changes in the baseline lengths up to 4 cm (strains of $10^{-4}$) can occur within a week and up to 3-5 months. Such high-frequency elastic events have a different character of manifestations and are 2-4 orders of magnitude greater level than stable many years’ residual deformations.

Acknowledgments
The research was carried out within the framework of the state task of the Russian Federation for Research station of the Russian Academy of Sciences in Bishkek city, under the program of basic research IX.128, topic: "Study of modern crustal movements in Central Asia using space geodesy" (AAAA-A19-11902019066-3).

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