Stress-strain state of the earth’s crust of the Central Asian mountain belt: distant effect of the tectonic impact of the Indo-Eurasian collision

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Abstract. In recent decades, extensive geological, geophysical and geochronological data have been obtained that characterize in detail the results of the distant tectonic impact of the Indo-Eurasian collision on the lithosphere of Central Asia, which led to the formation of the mountain systems of the Pamirs, Tien Shan, Altai-Sayan region and Transbaikalia from the Late Paleogene (about 25 million years ago). It has been established that the formation of the structure of Central Asia occurred as a result of the transmission of deformations from the Indo-Eurasian collision over long distances according to the "domino principle" through the rigid structures of Precambrian microcontinents located among the Paleozoic-Mesozoic folded belts. The study of peneplain surfaces deformed into simple folds on high-mountain plateaus surrounded by rugged mountain ranges made it possible to reveal the parameters of the deformations of the earth's crust, the interrelationship of the formation of relief and sedimentary basins. Apatite track dating data, structural and stratigraphic analyses of Late Cenozoic sediments in the basins prove a period of intense tectonic activation the entire lithosphere of Central Asia from the Indian continent to the Siberian platform starting from the Pliocene (about 3.5 million years). As a result of reactivation of the heterogeneous basement of Central Asia, high seismicity was manifested, which is concentrated mainly along the border of the microcontinents (Central Tianshan, Junggar and Tuva-Mongolian) and the Siberian craton, as well as in the zones of articulation of regional faults.

1. Introduction
The world's largest Central Asian mountain belt is a natural laboratory for studying the stress-strain state of the Earth's crust, driving forces and mechanisms, the evolution of structure and relief associated with intracontinental tectonics. In recent decades, extensive geological, geophysical and geochronological data have been obtained that characterize in detail the results of the distant tectonic impact of the Indo-Eurasian collision on the lithosphere of Central Asia, which led to the formation of the mountain systems of the Pamirs, Tien Shan, Altai-Sayan region and Transbaikalia from the Late Paleogene (about 25 million years ago). It has been established that the formation of the structure of Central Asia occurred as a result of the transmission of deformations from the Indo-Eurasian collision over long distances according to the "domino principle" through the rigid structures of Precambrian microcontinents located among the Paleozoic-Mesozoic folded belts [1-4]. As a result of compression, folded zones develop into...
mountain systems, and microcontinents serve as the foundation for the formation of Cenozoic basins (Tarim, Tajik, Junggar, etc).

2. Material and methods
The Indian continent collided with Eurasia at the end of the Eocene, over a period of 35 million years the collision boundary moved inward of Eurasia by a distance of more than 900 km (Figure 1).

Figure 1. Neotectonic scheme and geological section of Central Asia (modified after Dobretsov et al., 1996).

Its frontal part, according to seismotomography, sank to a distance of more than 1500 km and settled under Tarim [5]. Stratigraphic, structural and low-temperature geochronology data (track dating of apatite) show that the formation of the modern appearance of the Himalayas and Tibet began in the Oligocene (30-25 million years ago), the Pamirs and the southern Tien Shan began in the middle of the Miocene (18-11 million years ago), the Northern Tien Shan in the late Miocene (12-8 million years ago), in Junggar, the Altai-Sayan region and Mongolia in the Pliocene (6-3 million years ago), in Transbaikalia
in Quaternary time (last 3 million years ago). About 3 million years ago deformations reached a powerful passive stop of the Siberian craton, as a result of which a tense structure of a “compressed spring” was formed between the active “indenter” of the Indian continent and the craton. In this regard, high mountains have grown almost simultaneously throughout the entire territory of Central Asia. The peak of the maximum growth of mountain systems over the past 3 million years is particularly clearly revealed by the data of fission track dating of apatite and the formation of molasses in intermountain basins [6-19].

In the Neogene – Quaternary time, two factors influenced the formation of the structure and geodynamics of the Tien Shan: overthrusting of the Pamir and the subduction of the Tarim Plate. They created various structural and geodynamic provinces separated by the Talas-Ferghana fault zone. In the Pamirs and the Western Tien Shan, which were located near the pressure of the Punjab “indenter”, deformations manifested themselves in the form of thrust-overthrusts, thrusts and folds of northwestern vergence. To the east of the Talas-Ferghana right-hand shift, the general northern direction of compression from the Tarim side caused the Tien Shan to rise mainly along the thrusts and thrust-overthrusts of the northern and north-eastern vergences. In the Pliocene-Quaternary time, deformations manifested themselves in the form of strike-slips and shear-thrusts to the northeast of the Tien Shan and concentrated in the Altai-Sayan mountain region along the border of the Tuva-Mongolian plate (microcontinent) (Figure 1, 2).

Figure 2. Major topographic structures of Central Asia in Altai–Sayan in South Siberia and NE Kazakhstan and Kyrgyz Tien Shan. Background color in function of elevation (from GTOPO-30). Dots showing location of earthquake focal mechanisms with color in function of type and black lines indicating $S_{\text{max}}$ direction (from Harvard CMTS). White lines with dot mark GPS derived slip vectors. Black squares, Novosibirsk (N) and Urumqi (U) towns (Delvaux et al., 2013).
As a result of the collision of the Indian-continent, folds and faults have appeared in the heterogeneous lithosphere of Central Asia. The regime of lithospheric deformation was revealed in the Tien Shan and Altai-Sayan mountain belts (figure 3) [20], including both lithospheric bending (folding) and the formation of fault structures in the upper crust.

Figure 3. Topographic profiles (blue lines) with Fourier transform spectral analysis (red lines). Top panel shows location of profiles. Left column: Tien Shan profiles (TS1–6); right column: Altai–Sayan profiles (AS1–5) (Delvaux et al., 2013).
As shown [21], different folding modes in the lithosphere depend on its structure and rheology: the folding of the upper part of the Earth's crust is monoharmonic, the folding of the lithospheric mantle is biharmonic, the folding of the entire lithosphere is polyharmonic. These three modes control the wavelength of folding, which manifests itself on the surface as bending the peneplain. The parameters of lithosphere bending can be characterized by the lengths of the manifestation of topographic waves, which are measured between the axes of the anticline and syncline folds. The maximum topographic wavelengths are about 200-300 km in the Altai-Sayan region and from 150-200 to 250-350 km in Tien Shan, and they reflect the deformation of the entire lithosphere. The wavelengths in the range of 35-70 km are in both regions along mountain ranges extending steadily in the west-east direction, alternating with Late Cenozoic tectonic depressions. It is likely that their manifestations are associated with the deformation of the upper part of the earth's crust. Over the past 3 million years, during the stage of maximum tectonic compression of the lithosphere of Central Asia, the deformation style was manifested by a combination of long waves of bending of the lithosphere and shorter waves of bending of the upper crust, accompanied by faulting. The axes of the lithospheric folds, as a rule, are perpendicular to the direction of the stress field [20].

3. Results and discussion
It has been revealed that large-scale bends of lithosphere cannot remain for more than 10 million years after the termination of compression [21]. This is due to the gravitational flow of the Earth's crust and erosion of surface, transport and re-deposition of sedimentary material. The erosive surface (peneplain) Central Asia, which has been stable for almost 150 million years, has been significantly disrupted as a result of the Indo-Eurasian collision only over the past few million years. Therefore, the morphology of peneplain is relatively well preserved until now and its fragments can be observed in all mountain systems of Central Asia [20, 22, 23].

The presence of peneplain surfaces deformed into simple folds on high-altitude plateaus surrounded by rugged mountain ranges is a unique information that allows us to study the parameters of deformations of the Earth's crust, the relationships between the formation of relief and sedimentary basins. Thus, the Kurai and Chui basins in the Altai-Sayan region and the Issyk-Kul basin on the Tien Shan are typical intermountain basins that develop under conditions of lithosphere bending [20,24]. Apatite track dating data, structural and stratigraphic analyses of Late Cenozoic sediments in the basins prove a period of intense tectonic activation the entire lithosphere of Central Asia from the Indian continent to the Siberian platform starting from the Pliocene (about 3.5 million years).

4. Conclusion
Thus, the collision of India and Eurasia caused not only the reduction and uplift of the Himalayas and Tibet, but also the continuous interaction between India and Eurasia and the growth of the Tibetan Plateau, which in the Pleistocene began to have an additional impact on the reactivation of lithosphere of the northern part of the Central Asian folded belt (Mongolia, southern Siberia). As a result of reactivation of the heterogeneous basement of Central Asia, high seismicity was manifested, which is concentrated mainly along the border of the microcontinents (Central Tian-Shan, Junggar and Tuva-Mongolian) and the Siberian craton, as well as in the zones of joining of regional faults [4, 19, 25].

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