The magnitude of the transverse contraction of the Middle Tien Shan along the "Karabuk" profile at the late orogenic stage

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Abstract. The detailed geological profile "Karabuk" constructed in recent years, crossing the triad of alpine structures "Naryn Depression - Bajibchetoo Uplift - Atbashi Depression " in the central part of Tien Shan, provides new material for studying the style and parameters of deformations at the late phase of the Indian - Eurasian plate collision. Using original methodological techniques and in accordance with the basic principles of balanced sections method, the horizontal deformation of the rock complex of the Cenozoic sedimentary cover (a meridional reduction in the width of the orogenic belt) was determined, starting from the end of the Neogene. Variations in the thickness of the cover layers determined during the research were taken into account. The presented tectonic reconstruction demonstrates the structure of a single Naryn-Atbashi sedimentary basin before the intense deformations at the late orogenic phase. It is significant, that the magnitude of deformations on individual segments of the profile differs markedly. The cover of the Atbashi depression is more deformed, its width has decreased by 6 km (about 17%) in this section, while the borders of the wider Naryn depression have converged by only 3.7 km (8%). The total South-North contraction of the NAB system measured by us during the Cenozoic is about 10 km (12% of its original width). The values of the contraction from south to north (the horizontal component of the deformation) obtained by us compared with the values given by other researchers.

1. Introduction
The high-altitude mountain area of the Tien Shan was formed at the late stage of the collision of the Indian and Eurasian plates, capturing that segment of the Central Asian Paleozoic folded belt. All crustal complexes, including the Hercynian-Caledonian basement and a multi-kilometer sedimentary cover accumulated at the stage of platform development in the Mesozoic-Cenozoic, were intensively deformed under the conditions of meridional compression. The deformation and reduction of the width of the orogenic belt continue to this day. According to some data, the width of Middle Tien Shan is shrinking by about 20 mm/ear, compensating for about 50% of the modern Indo-Asian convergence [1, 2], which, however, hardly reflects the dynamics of the development of the region's structure during a geologically significant period.

For the Tien Shan as a whole or its individual parts, calculations of the horizontal component of deformation have been repeatedly performed using different methodological approaches. The "straightening" of the folded pre-paleogene penelope on the meridional cross-sections gives a reduction by about 6% of the original length of the profiles [3]. Summing up the assumed displacements from deeper thrusts allowed us to estimate the transverse contraction of the Central Tien Shan for the Late
Cenozoic in the range from 35 to 80 km [4], depending on the inclination of the faults. This means from 20 to 60 % of the meridian contraction of this area. The average speed of the meridional contraction of the Kyrgyz Tien Shan between the Atbashi and Chu depressions for 140 thousand years, summed up by 7 active thrust zones which displace alluvial terraces [5], was determined at 11 mm/year, which is obviously less than the real reduction of the orogenic system, taking into account all deformation zones. In these calculations, the rates of late Pleistocene and modern (determined by GPS-geodesy methods) displacements of are comparable, but the rate of reduction from the end of the Pliocene is assumed to be lower. A significant spread of research results in recent years does not allow us to consider the problem of determining the values and rates of Cenozoic deformation finally solved. Moreover, in most studies, the same assumptions are postulated, concerning, for example, the similarity of the deformation style in the sediments and in the basement rocks, the constancy of the sediment thickness, the inheritance of the structure development, etc.

There is no doubt that the estimation of the total meridional contraction during the Alpine stage largely depends on the details of the study of the geometry and style of deformation structures. The geological profile "Karabuk", designed on the basis of complex geological and geophysical studies, crossing the triad of alpine structures "Naryn Depression - Baibichetoo-Atbashi Depression" (NBA) [6], characterizes in detail the fold-fault structure of the Cenozoic sedimentary cover and provides new source of information for tectonic reconstructions.

The NBA ensemble is located in the central segment of the Middle Tien Shan and is clearly expressed in the modern relief (Fig. 1).

**Figure 1.** The position of the Naryn Depression (1), the Baibichetoo ridge (2) and the Atbashi Depression (3) in the general orogenic structure of the Tien Shan. The fault boundaries of the Middle Tien Shan: the Talas-Fergana fault (TFF), Nikolaev's Line (NL) and Atbashi-Inylchek fault (AI).

1 – generalized direction of the modern compression; 2 – contours of equal shifts (indicated by the size of the horizontal displacements relative to the Kazakh platform, mm/year) according to GPS monitoring [2]; 3 – location of the "Karabuk" profile.

The Naryn and Atbashi intra-mountain depressions are filled with Cenozoic terrigenous rocks, the thickness of which according to geophysical data exceeds 3.5 km. The Paleozoic and Precambrian rocks are exposed in the ridges that frame and separate the depressions. The lithological features of deposits reveal that
during the Oligocene, Miocene and until the end of the Pliocene, a single intracontinental sedimentary basin existed in place of the two depressions. At the end of the Neogene, the basin experiences morphostructural differentiation – it is divided into separate depressions, separated by the Baibichetoo uplift. It was from this time, before and after the deposition of Pleistocene molasses, that the entire complex of sedimentary rocks was intensively deformed and partially denudated in uplifts. The current movement relative to the Kazakh platform of the reference GPS points of geodetic monitoring [2] naturally decreases from south to north, changing in the central part of the Tien Shan from 10 to 4 mm/year (see Fig. 1). This means that the boundaries of the NBA area are approaching by about 6 mm/year. At this rate of convergence, the width of the NBA from the end of the Neogene (when the phase of intense deformations started) could be reduced by 15 km (by 16.6% of the calculated width of 90 km). However, such a scenario does not correspond to the ideas about the development of paleorelief [7] and to the data of our research.

2. Methods
Correctly, the problem of determining the value of the final deformation can be solved in a single cross-section, provided that the structure is two-dimensional. For the presented profile (Fig. 2, A), the two-dimensionality of the structure and the representativeness of the section (its transverse to the strike) were determined according to certain criteria based on the analysis of magnetotelluric sounding data [8] and were justified as a result of geological mapping along the profile line [6].

The methods of tectonic reconstructions used, in particular, in Tien Shan [1, 4, 5], contain certain assumptions about the style of deformations and rheology of rocks. For example, the conservation of the total displacement along faults, the invariance of the thickness of the layers during deformation, the fundamental similarity of the rheological properties of the basement's rocks and the overlying sedimentary cover, and others are postulated. Such postulates allow for tectonic reconstructions based on indirect or few data about the geological structure.

Figure 2. The modern structure of the sedimentary cover of the NBA ensemble. (A) Geological cross-section (symbols: 1 – Quaternary molasses; 2 – Paleogene-Neogene sedimentary layers; 3 – Paleozoic basement; 4 – faults). The vertical and horizontal scales are equal. At the top is a relief with an enlarged vertical scale. (B) The modern structure of Paleogene-Neogene sediment cover, taking into account denudated volumes (reconstruction).

Without dwelling here on the advantages and weaknesses of the methods used, we will highlight some basic provisions. First of all, in almost all reconstructions the invariability of the volume of rocks is assumed, regardless of the style of deformations. Indeed, the practice of structural studies of deformations of sedimentary strata on the Tien Shan [5, 6, 9] shows that in these rock complexes, the volume change during deformation can be neglected. However, deformations of the rocks of the crystalline basement [10] can be accompanied by significant dilation (up to 10% of the initial volume or more). When detailing the deformation structures of the Paleozoic basement surface in various areas
of the Tien Shan, the structures of plastic 3D flow, protrusion into the sedimentary cover, etc. were discovered [11-14]. This fact, along with the duration and uncertainty of tectonic evolution since the early Cenozoic, limits the correctness of using the popular method of "straightening" the surface of pre-Paleogene peneplain to determine horizontal deformation.

Another important point in reconstructions is to take into account the variations of the thickness of stratigraphic series along the profile, which implies a purposeful study of the sections. It is these two provisions – the constancy of the volume of deposits (the square on the section) and the consideration of the variation of thickness - that we took into account in the calculations of deformations of the sedimentary cover. We selected the entire Cenozoic sedimentary cover as the object of research in the section of the NBA system, with the exception of Quaternary coarse-grained deposits lying with unconformity on Pliocene deposits of the upper formation of the Naryn suite. At the first stage of reconstruction, the denuded parts of the cover complex were restored, taking into account the style of deformations determined by us and the trends in the thickness of each formation, determined in the process of complex geological and geophysical studies (Fig. 2, C). The constructed section demonstrates the deformation structure of Neogene-Paleogene layers formed during the Quaternary period. It was used to measure the true cover thicknesses in different segments of the NBA system and the horizontal components of displacements along all faults (Fig. 3). The reconstruction of the pre-deformation structure in the sedimentary basin (Fig. 3, lower contour, orange color) was carried out taking into account the reduction of the distance between the selected sites of thickness measurements. For this purpose, the horizontal displacements and folded deformations of the roof of the cover were summed up. The main criterion for the correctness of the constructions was the equality of the square (specific volume) of the cover deposits on both sections, which required minor correction.

Figure 3. Comparison of the sedimentary cover structure along the "Karabuk" profile before and after the Late Cenozoic deformation.

1 – the modern structure of the cover, taking into account denudated rocks; 2 – the structure of the basin by the end of the Pliocene; 3 – faults; 4 – amplitudes of horizontal displacements on the faults; 5 – measured cover thicknesses; 6 – thicknesses of the cover in paleotectonic reconstruction.

The constructed pre-orogenic section of the NBA system demonstrates the generalized tectonic structure of an earlier stage of development - an unequal concedimentary deflection with the accumulation of a multi-kilometer sedimentary cover in troughs (Fig. 3). For comparison of the NBA ensemble before and after deformation the northern boundaries of the sections are combined. The relief of the basin before the deformation is not shown: according to lithological specificity, its scale by the beginning of the Pleistocene was insignificant.

The total South-North contraction of the NBA system measured by us during the Cenozoic is about 10 km (12% of its original width). For comparison, Figure 3 shows calculations of the NBA reduction based on different criteria. The horizontal reduction calculated by "straightening" the roof of the Naryn suite is close to previous value – 11%. According to the sum of horizontal displacements along all faults, the total reduction of the system is 5%, which indicates a significant folded component of the overall deformation. Obviously overestimated and theoretically not quite correct values can be obtained by "straightening" the surface of the peneplain, the structure of which reflects the integral deformation of all phases of development, including the consedimentary deflection. The length of the foundation/cover
boundary did not change significantly during the final deformation and, perhaps, even slightly decreased due to inverse displacements on the faults.

It is significant, that the magnitude of deformations on individual segments of the profile differs markedly. The cover of the Atbashi depression is more deformed, its width has decreased by 6 km (about 17%) in this section, while the borders of the wider Naryn depression have converged by only 3.7 km (8%).

The values of the contraction from south to north (the horizontal component of the deformation) obtained by us are comparable with the values given by other researchers. In particular, for the Naryn depression, deformation calculations were made [9] based on a series of parallel schematic structural sections, supported by morphostructural studies - measurement of modern vertical movements of the territory based on repeated radar satellite scans of the relief (InSAR-technology). In the same cross-section a reduction in the width of the depression of 2.6 km (about 6%) was obtained for the orogenic stage, which is the smallest value in the series of sections. The authors of these calculations note the lack of information about the geological structure and deep structure. The reduction of the entire system in the range of 5-10 km is also assumed, based on the analysis of the general model of the development of thrusts in the Earth's crust [4].

It can be assumed that the Late Cenozoic deformation of the NBA system, which includes both synclinal and anticlinal structures of regional rank and in the considered section is about half the width of the tectonic zone of the Middle Tien Shan, can characterize the overall deformation of this part of the orogenic structure of the Tien Shan, in proportion to its width.

### 3. Conclusions

The horizontal deformation of the Cenozoic sedimentary cover was determined by an extended continuous profile crossing the key segment of the Middle Tien Shan. The high detail and geological and geophysical validity of this section made it possible to carry out a paleotectonic reconstruction of the sedimentary basin by the beginning of the Late Cenozoic orogeny - the main phase of deformations of the sedimentary complex. The calculated total horizontal deformation (about 12%) along the "Karabuk" profile can characterize the meridional contraction of Middle Tien Shan generally at the late orogenic stage. These calculations are comparable with the previously made values of the reduction of the upper Earth's crust layer in different regions of the Tien Shan.

The presented tectonic reconstruction demonstrates the structure of a single Naryn-Atbashi basin of sedimentation before the beginning of intense deformations in the sedimentary cover at the end of the Pliocene. The morphology of the paleobasin characterizes the stage of long-term sedimentary deflection of the basement surface under conditions radically different from the final phase of deformations, which is the basis for a substantive study of the geotectonic situation in the epoch of the origin and development of the Cenozoic intra-mountain basins of the Tien Shan.

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Acknowledgments

The research was carried out on the topic of the State Task of the Geological Institute of the Russian Academy of Sciences in Moscow.