Geology and depth structures of the main Karatau strike-slip fault, Southern Kazakhstan

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Abstract. The Main Karatau fault is a classical crustal strike-slip zone. It originated as a continental rift structure in the Late Proterozoic and had been developed incessantly for almost 1 billion years as inherited structure. The fault was subjected to polyphase deformations associated with both dextral and sinistral shifts. The Main Karatau fault crosses the Earth's crust, including the structures of granite-metamorphic layer and granulite-basitic layer and fades without crossing the Moho discontinuous. The amplitude of displacement of the Syr-Daria and Chu-Sarysu blocks relative to each other along the Main Karatau fault is estimated at approximately 200 km.

1. Introduction

Starting with the work of A.M. Senger et al. [1], a geological model is being developed for folded Paleozoic sequences of Kazakhstan and Central Asia, where a leading role is given to extended faults with manifestations of Late Paleozoic strike-slip deformations. This fault community (figure1) extends from east to west and includes Irtysh-Zaysan fault, Central Shyngyz fault, Dzhungar fault, Central Kazakhstan fault, Zhalair-Naiman fault, Amu-Darya fault and Mangyshlak fault [2]. Such faults cross through the southern edge of Central Eurasia from Kopetdag to Irtysh River valley at almost equal intervals of 300-500 km. They connect Tien Shan structures, which have a sublatitudinal strike, with Ural structures extending close to the meridional and occupying an intermediate position (figure1).

In accordance with model, it was suggested that primary collage of small continental blocks and collisional terrenes, formed as elongated linearly in the Devonian-Carboniferous-Permian, was disturbed by large amplitude strike-slip faults and associated thrusts, that led to formation of so-called “Kazakhstanian Orocline” (Central Kazakhstan fold belt) curved as a chord [1, 2, and 3].

The role of large scale planetary lineaments in the formation of Tien Shan structures in Hercinian tectonic epoch, including the Main Karatau and Talaso-Fergana faults (figure1), as well as their strike-slip kinematics was realized long time ago, at the end of the first half of the 20th century, please refer to the reviews in the works of V.S. Burtman and V.V. Galitsky [4 and 5]. Then the amplitude of the horizontal displacement of the blocks located on both sides of the faults in late Paleozoic was estimated at 200 km for all distance of their strike. Although later D.V. Alekseev et al. [6] revised the total distances and proposed a complex model of attenuating from south to north shift but for the Talaso Fergana fault they agreed with earliest assessment and left a distance of 200 km but assume that for the Main Karatau fault those distance is only 100 km. E.I. Patalakha and T.V. Giorgobiani [7] indicated that the Main Karatau fault, formed as a rift continental structure during late Proterozoic, also influenced the formation of folding in the Baikal-Caledonian stage of tectogenesis. In the second half of the twentieth century, V.Ya. Koshkin [8] gave evidence of a right shift of the Central
Kazakhstan fault with a distance estimated at 120 km. The scientific literature contains the discussions on the origin of mentioned faults and their influence on formation of geological structure of the territory of Central Asia [2, 3, and 9].

2. Geological framework of the Karatau Ridge

The Karatau mountains (figure 2) in the south of Kazakhstan are presented by multikilometer thickness of terrigenous-carbonate strata [10]. They have been studied during almost 150 years. The age of those deposits for Paleozoic and Mesozoic-Cenozoic is well substantiated biostratigraphically and Late Precambrian is well substantiated by the methods of absolute geochronology [11].

The base of the Karatau section (figure 2) is formed by Bessazian group, composed of crystalline schists, amphibolites, and serpentenites, which are broken by plagiogranites [11]. The isotope age dates vary from 934 Ma to 825 Ma and 775 Ma [11 and 12].

![Figure 1. Position of the Main Karatau fault (highlighted red line) in key tectonic structures of Kazakhstan and adjacent regions (according to [9] amended and revised). Abbreviations: IZF - Intysh-Zaisan fault, CSF - Central Shyngyz fault, MJF - Main Junggar fault, KKF - Kara-Korum fault, ADF - Amu-Darya fault, MF - Mangistau fault, MUF - Main Ural fault, NFT - North Fergana terrane, AIT - Atbashi-Inilchesk terrane, CPS - Central Caspian sag, AASHS - Astrakhan-Aktobe system of depressions and uplifts, SHE - South Emba high. Legend: 1 - blocks with Precambrian continental crust, 2 - Phanerozoic subduction-accretionary sequences, 3 - territory of the Karatau Ridge, 4 - strike-slip faults, 5 - faults without separation, 6 - state border of the Republic of Kazakhstan.](image)

Two carbonate units were successively formed in Karatau during Baikalian and Caledonian tectonic epoch [10 and 11]: Neoproterozoic and Cambrian-Lower Ordovician, each up to 2-3 km thick, as well as two terrigenous units: Neoproterozoic-Ediacaran and Middle-Upper Ordovician flyschoids, each up to 2.5-4 km thick. The base of this section is presented by bimodal basaltic-liparite volcanites with thickness up to 1.5 km and more and age of 700 Ma and Kumysty granitoids where an absolute
age of 725 Ma was determined which correlates to the tops of Tonian [10, 11 and 12]. For the volcanic-sedimentary deposits of the Neoproterozoic of the Malyi Karatau from the Kurgan formation tuffites was obtained the absolute age from zircons of 820Ma and 779Ma [12].

Figure 2. Geological sketch map of the Karatau Ridge.
An age of 570 Ma (corresponding to Ediacaran of the upper Neoproterozoic) was confirmed using K/Ar method in glauconitic sandstones of siliciclastic-carbonate deposits of the Kyrshabakty formation of Malyi Karatau.

Figure 3. Location of the Main Karatau fault A) - Urstata river gully, MKF - abbreviation of the Main Karatau fault. The width of melange and foliation zone is the first tens of meters are shown by parallel dashed lines. The structure is northwest oriented; volcanic deposits of Kainar formation of the Neoproterozoic are exposed on the left and terrigenous-carbonate deposits of Urstata formation (also of the Neoproterozoic) are exposed to the right. B) - Leontiev graben, in the area near Leontievka village. The massive rocks composed of outcropping Lower Carboniferous carbonates are to the left and to the right. The mid part is presented by a hummock composed of the outcrops of weakly lithified Jurassic terrigenous-carbonate strata.

The Precambrian and Lower Paleozoic parts of the section via angular unconformity are separated by marker horizon of the Cryogenian tilloids. The high-carbon siliceous-shale of Kurumsak formation and the phosphate-bearing Chulaktu formation containing biostratigraphic dates of the lower Cambrian Terraneuvian epoch overlapping mentioned unconformity [10 and 11]. The upper part presented by the Cambrian-Lower Ordovician carbonate and overlying Ordovician terrigenous flyshes
is well dated by the fauna of trilobites, graptolites, and conodonts [11]. This early stage ended with folding and had bursted by late Ordovician granitoids in Malyi Karatau.

The accumulation of multikilometer strata of terrigenous-carbonate deposits had been taking place during the Hercynian stage [10]. Red-colored terrigenous sequences of the Middle-Late Devonian, as well as Late Carboniferous and Permian have 2-3 km thickness each, separated by 4 km of Famennian-Carboniferous carbonates, rich in diverse fossil fauna. At the end of the Permian, this stage ended with folding and intrusion of small bodies of granitoids. At the beginning of Mesozoic, Leontiev graben was formed during the dextral strike-slip [3] which was filled with lacustrine-alluvial deposits.

The planetary structure of Karatau is crossed cut by a giant lineament - the Main Karatau fault (figure2, 3 and 4). This fault have forking to the south joining with Talaso-Fergana fault and discordantly cross the entire Tien Shan, Fergana depression and end near Tarim (figure1).

The territory of Karatau is split into a number of structural-formational zones (figure2): North-Western Karatau, Central Karatau, Axial Karatau, South-Eastern Karatau, Leontiev graben, Baizhansai, Kokzhot horst and Malyi Karatau depending on geological structure, completeness of the stratigraphic sequence and lithological-facial composition of the deposits.

3. Depth structure of Karatau and adjacent territory
The territories adjacent to Karatau are characterized by structures (figure4A, B, and C) at the level of the base of the Earth's crust (EC) or the Moho surface (Mohorovicic discontinuity) 37-50 km, the surface of Conrad or the top of granulite-basitic layer (17-23 km) and the surface "F" of the roof of granite-metamorphic layer (1-14 km) [11]. Moho discontinuity is characterized by increase of P-wave velocities from 7.0-7.2 to 8.1-8.2 km/s and rock density increase from 2.9 to 3.5 g/cm$^3$. It was noted that the subsidence of the Moho boundary coincides with the uplifted pre-Mesozoic basement and an increase of thickness of the EC, and their depressions lead to decrease of thickness. The surface M is characterized by deflections in two directions. The submeridional deflections belong to North-Western and South-Eastern Karatau (figure 4A), and the sublatitudinal deflection separates them in the area of Central and Axial Karatau. The uplifts are noted along the margins of the deflections, where the thickness of the Earth's crust is reduced to 38 km. The main Karatau fault evenly intersects both positive and negative structures of the Moho surface by their centers.

The structures of Conrad surface (figure 4B) inherit the orientations of underlying structures, however they are displaced in relation to the underlying structures of Moho surface to the north and east, for closure of the North-Western Karatau, as well as for Baizhansai and Maly Karatau. There is an uplift in Central and South-Eastern Karatau extending towards Syr-Darya and Shu-Sarysu depressions. The amplitudes of altitude differences in the surface of granulite-basitic layer do not exceed 6 km and the relief is smooth. Seismic P-wave velocities along this boundary are characterized by increase from 6 km/s to 6.5-6.7 km/s and density variations up to 0.2 g/cm$^3$. The Main Karatau fault divides the structures of granulite-basic layer at the bend of negative structures into positive ones. They form beaded or en-echelon type propagation.

The granite-metamorphic layer in Karatau (figure4C) is less homogeneous and divided into three sequences based on density and magnetic properties. The lowest sequence is represented by Precambrian metamorphites; the mid sequence is presented by terrigenous-carbonate strata of the Neoproterozoic and Paleozoic and upper sequence is represented by Mesozoic-Cenozoic sedimentary rocks. The amplitude of thickness of the granite-metamorphic layer varies considerably. The minimum thickness of 0-4 km is typical for Central and Axial Karatau, and the maximum thickness up to 15 km is noted in Malyi Karatau and North-Western Karatau. The Main Karatau fault also divides the structures of this layer, forming beaded or en-echelon type propagation of two negative structures of North-Western and Malyi Karatau.
Figure 4. Depth structure of the Earth's crust of the Karatau Ridge territory, each contour coincide but decreased if to compare the figure 1. A-C isohypses of surfaces of the main layers of the Earth's crust, values are shown in kilometers (according to V.N. Lyubetsky et al., [11]): A- Mohorovicic discontinuity, B- surface of Conrad (granulite-basitic layer), C- surface of granite-metamorphic layer. MKF- Main Karatau fault. The black dash-dotted line shows the contours of structural-formational zones.
4. Interpretation

The Main Karatau fault (MKF) together with Talaso-Fergana Fault (TFF) form a single structural line [2, 3]. However the origin of MKF is related to Neoproterozoic, while for Talaso-Fergana fault the first movements are recorded only in Late Paleozoic [2, 5]. The MKF is subconcordant with the pre-Paleozoic and Paleozoic plicative structures (figure1), but the TFF is superimposed against to Paleozoic structures (figure1). The structural elements associated with both folding (ductile) and fault (brittle) tectonics were studied for territory of Karatau Ridge with keen attention paid to their orientation [9].

Two phases of Late Paleozoic deformations which reworked Late Devonian-Carboniferous deposits are revealed. The first phase is associated with sinistral transpression along Karatau fault system, and the later superimposed second phase along same faults, is formed by dextral transpressive inversion [9 and 10]. It reworked the orthogonal folding and formed a basin-and-domal folded interference which is well traced in Central Karatau structural zone.

The strike-slip faults were activated upon resumption of the dextral fault in the Early-Middle Jurassic along MKF which formed the Leontiev graben and the South Turgai depression [5, 6, and 9]. Late Cenozoic deformations outcropped in the uplifts of the mountains and destruction of the Cretaceous-Paleogene peneplain without major tectonic processing.

Since the very beginning of research, there were two competing points of view [4, 5 and 10]: whether the Main Karatau fault sinistral or dextral strike slip?

Considering the Hercynian structures of the Bolshoi Karatau, V.V. Galitskyi [5] suggested that the Main Karatau fault is a sinistral strike-slip fault. He considered the orientation of the fold axes, orientation of grooves on the surface of faults and general direction and orientation of deformations as the arguments. He even then also suggested that the dextral shift along the TFF could have been superimposed and occurred later than the sinistral one.

On the contrary, V.S. Burtman [4] in his studies of Talaso-Fergana fault and its relationship with the Hercynian structures of the Tien Shan, interpreted shear displacements along the fault line as dextral and estimated the distance of displacement of tectonic blocks at 250 km. At the same time, for the late Hercynian stage, he assumed a block displacement of 200 km.

If such displacements are obvious for the route of Talaso-Fergana fault, which has a distinctly superimposed nature, then the propagation of this fault in Bolshoi Karatau, namely the Main Karatau fault, coincides with orientation of Baikalian-Caledonian and Hercynian tectonic structures. The calculation of the amplitude of the shear displacement is not unambiguous here, and as an argument for dextral displacement, V.S. Burtman [4] proposed that Leontiev graben is formed by diverging (pulling) the walls of the blocks along the curvilinear route of the MKF, as well as the structural features of Kelenchek syncline, like drag folds.

Research carried out in Karatau by M.B.Allen et al. [9] at the end of the 1990s showed that at least two phases of deformation occurred in the Late Paleozoic - an early left-lateral compressional shear and a late right-lateral strike-slip, and these data to some extent unite both interpretations, as V.V. Galitsky and V.S. Burtman [10].

Obviously, geodynamic interpretation of the Karatau ridge and understanding of its formation are not possible without palinspastic reconstructions, that is, return of tectonic structures to their original position, preceding large regional tectonic deformations. Referring to the calculations of the distance of dextral displacement of the Syrdarya block of the earth's crust against the Shu-Sarysi block made by V.S.Burtman [4] and knowing that Cenozoic and neotectonic movements along the fault path are noted only for the TFF, we have accepted this 200 km of the Late Permian right strike-slip.

Mentioned reconstructions provide proper alignment of structural zone of North-West Karatau, as well as the Kokzhot zone and structural zone of Malyi Karatau [10]. The entire structure of the Karatau Ridge in this case is presented as a large meaganticlinorium, with most ancient Precambrian strata being exposed in the core together with Lower Paleozoic and Upper Paleozoic strata successively rejuvenating to southwest and northeast directions. The anticlinorium in the center is complicated by large synclinal structure of Baizhansai zone. The plausibility of reconstruction is
confirmed by commensurate length of Leontiev graben and the fact that Devonian redbeds of Mynzhilki anticlinal zone form southeastern centriclinal closure of Baizhansai syncline, similar to Usbhas syncline at northwestern centriclinal closure. The orientation of axial surface of Baizhan syncline coincides with general structural plan of the Hercynides of Bolshoi Karatau and we can interpret it as a complex synclirorian zone with an undulating axial line.

Procedure of returning the blocks to their initial state before the start of dextral shift is also confirmed by the morphology of granite-metamorphic layer surface and surface of granulite-basitic layer (figure 4B and C). If we by trail of Main Karatau fault line will place North-West Karatau opposite Bayzhansai and Malyi Karatau on a distance 200 km, then a single negative structure of both the surface of granite-metamorphic layer and surface of granulite-basitic layer will be formed, which will correspond to the geometry of the Moho surface also with negative structure.

5. Conclusion
In summary we may state that Main Karatau fault is a crustal structure, cutting through sedimentary, granite-metamorphic and granulite-basitic layers and does not drain the Moho surface, with no penetration to upper layers of the mantle.

The geometry of the surfaces of depth structures of the Earth's crust allows us to confirm the previously made by V.S. Burtman's estimate of 200 km of displacement of North-West Karatau, as well as Bayzhansai together with Malyi Karatau relative to each other, along the route of the Main Karatau fault also as a result of dextral strike-slip, as is observed for the tectonic blocks framing the Talas-Fergana fault.

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