Correlation of geological complexes of the Khan-Tengri Mountain massif

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Abstract

Researchers of the border regions of Xinjiang and the Central Asian countries are actively discussing two alternative models for the relationships between the main structural units of the Tianshan mountains. Most researchers believe that the Kyrgyz Middle Tianshan wedges out to the east along the Atbashi-Inylchek-Nalati marginal fault. According to the second hypothesis, the structures of the Middle Tianshan continue within the range Nalati where they are described as Chinese Central Tianshan. Comparing the characteristics of the Paleozoic and Proterozoic sedimentary, volcanogenic, intrusive, and metamorphic formations of these regions leads us to the conclusion that the structural units of the Kyrgyz Middle and most of the Northern Tianshan, including the superimposed Middle-Late Paleozoic troughs, are not continued into China, but are successively cut along the echelon system of conjugated strike-slip faults, united by us into the Frontal Tianshan Dextral Strike-slip (FTDS). And only the northern segment of the Issyk-Kul massif can be considered as an analogue of the Chinese Central Tianshan, displaced along the FTDS to the northwest for a distance of at least 80 km. Therefore, adjacent geological complexes are eroded along the FTDS like the oblique boundaries of convergent lithospheric plates are tectonic eroded.

Key words: structural zonation, Proterozoic, Paleozoic, U-Pb dating, strike-slip faults.

1 Introduction

The Tianshan mountain system, traced from west to east for 2500 km through the territories of Uzbekistan, Kazakhstan, Kyrgyzstan and the northwestern part of the Xinjiang Uygur Autonomous Region of China, is divided into Western, Central and Eastern geographical provinces (Burtman, 2012, 2006), (Fig. 1).

The border of Western and Central Tianshan is denoted by the Fergana and Talas ranges, which form a mountain chain with a northwest strike. Central Tianshan is represented by a series of ranges of sublatitudinal and northeastern strike, up to 340-600 km long, separated by foothill and intermountain depressions. At the eastern border of Kyrgyzstan, the Terskey, Sarydzhaz and Kokshaal Ranges, which are part of the Central Tianshan geographical province, merge into a single knot, forming the Khan Tengri mountain range, which is crowned with the highest peaks of Tianshan (Khan-Tengri peak - 6995 m and Pobeda peak - 7439 m). From the east, the Khan Tengri mountain range is adjoined by the Nalati and Khalyktau Ranges, which make up the Eastern (Chinese) Tianshan (Fig. 1A).

Turns in the strike of the ranges from the northeast (Kokshaal Range) to the latitudinal, and then southeast (Kopyl Range) are due to recent tectonics, which leads to the complication of Paleozoic structures, which are generally characterized by sublatitudinal strike. But to no lesser extent, the problems in deciphering the geological structure of this region are due to the state border with China, and as a result, a very limited exchange of geological information among researchers.

The materials of medium-scale geological surveys and a few thematic surveys of the Khan Tengri massif on the territory of Kyrgyzstan and Kazakhstan were summarized within the framework of the ISTC project KR-920 (Mikolaichuk et al., 2008), and on the northwestern part of Xinjiang and the Nalati Range, in particular, in recent years a series of publications has appeared, which makes it possible to correlate geological complexes located on opposite sides of the border with China. In this publication, we limited ourselves to the analysis of materials from the western part of the Nalati Range, comparable in area to the territory covered by the ISTC KR-920 project (see Fig. 1 and Fig. 2).

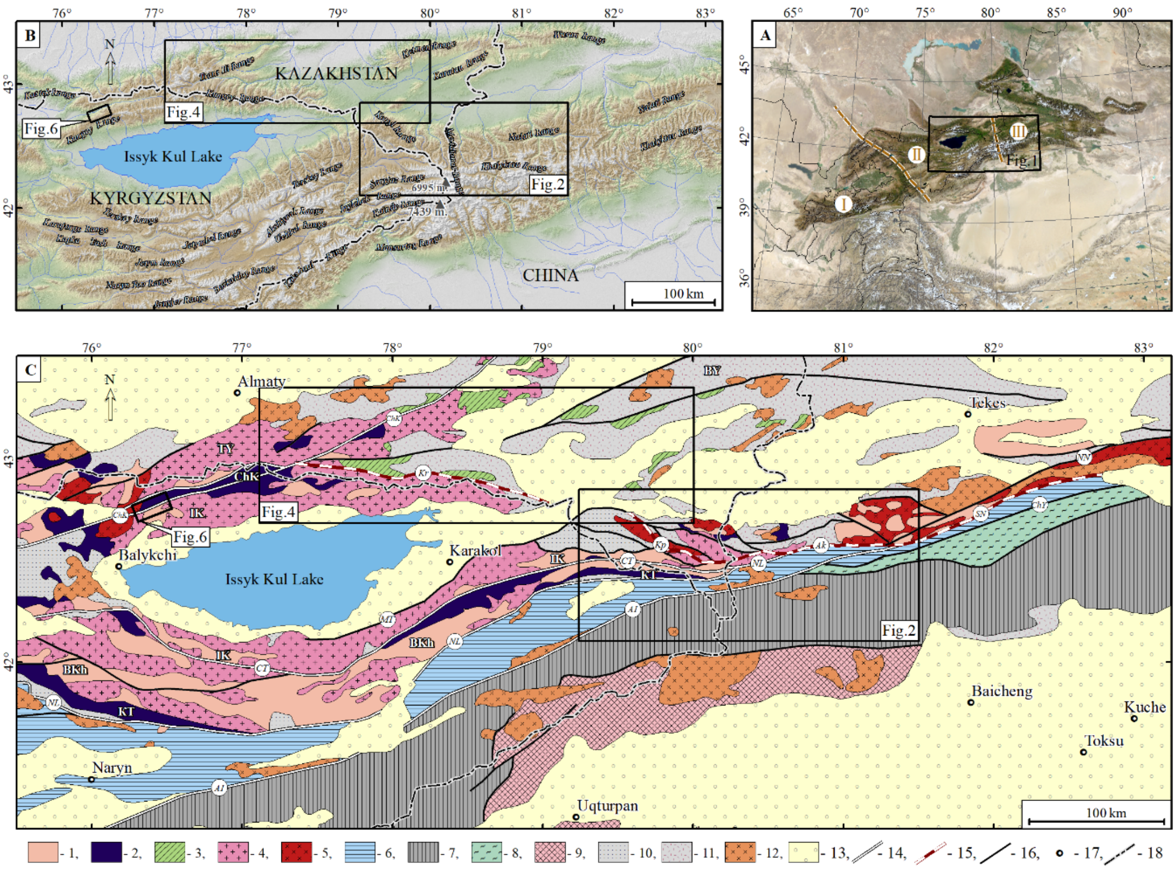

Fig. 1. Orographic scheme (1A) and Tectonic map of the Paleozoic formations of Central and Eastern (1B), modified after (Alexeiev et al., 2019; Mikolaichuk et al., 2020; "XBGMR," 1975-1981). The inset shows a scheme of the geographic provinces of Tianshan after (Burtman, 2006): I - Western, II - Central, III - Eastern

1-5 - Northern Tianshan: 1 - Proterozoic and Early Paleozoic complexes of the North Tianshan microcontinent (tectonic zones: TY-Trans-Yili, IK – Issyk Kul, BKh - Burkhan); 2 - ophiolites and island arc complexes of the Cambrian and Early Ordovician (tectonic zones: ChK - Chiliko-Kemin, KT - Kyrgyz-Terskey); 3-5 - Neoautochthon: 3 - volcanic and variegated terrigenous deposits (O_3-S), 4 - granitoid complexes (O_3-S_1), 5 - granitoid complexes (D_1); 6 - Middle Tianshan; 7-8 - Southern Tianshan: 7 - Late Paleozoic fold-thrust belt; 8 - garnet-mica and blueschists, eclogites (C_2); 9 - Tarim microcontinent; 10-12 Devonian-Carboniferous and Permian volcanic arcs and superimposed troughs: 10 - sedimentary deposits, 11 - volcanic deposits (BY - Balkhash-Yili volcano-plutonic belt), 12 - granitoid intrusions (C-P); 13 - Mesozoic-Cenozoic deposits;14 - Sinistral strike-slip faults: ChK - Chiliko-Kemin, CT-Central-Terskey, NL - Nikolaev Line, AI - Atbashy-Inylchek; 15 – Frontal Tianshan dextral strike-slip fault (segments: SN - South Nalati, Ak - Akeyazi, Kp - Kopyl, Kr - Korumdy); 16 - other faults: NN - Northern Nalati, ChY- Chon Yuldus); 17 - Cities; 18 - State borders

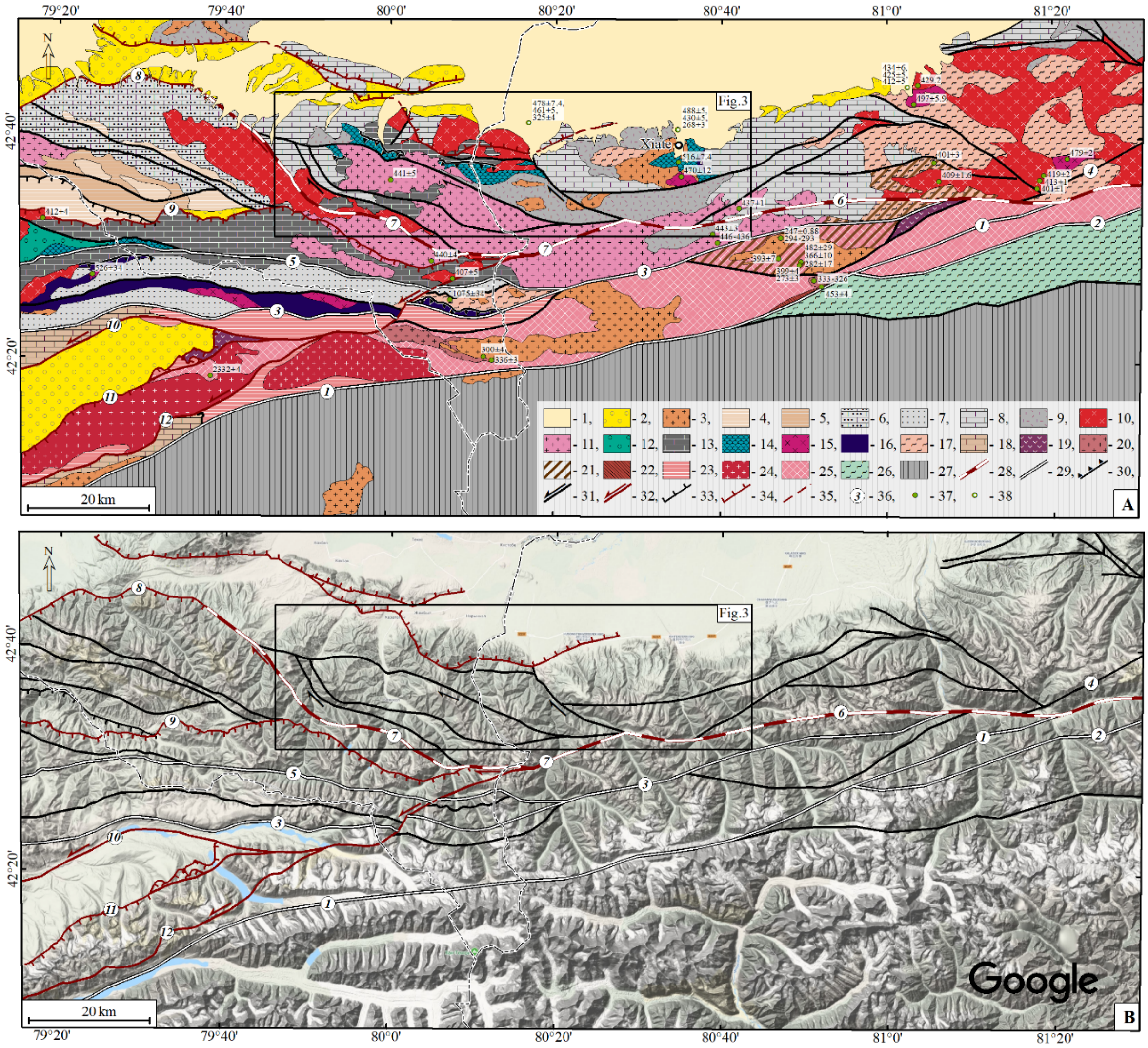

Fig. 2. Geological map (2A) and the Scheme of deciphering faults on a satellite image (2B) of the Khan-Tengri Mountain massif. Compiled after (Chabdarov and Bazhanov, 1971; Gao et al., 2009; Gou et al., 2015, 2012; Gou and Zhang, 2016; Lin et al., 2009; Long et al., 2011; Mikolaichuk et al., 2008; Ren et al., 2011; Wang et al., 2010).

1 - Quaternary deposits; 2 - Cenozoic deposits; 3 - Late Paleozoic granitoids; 4-13 - Northern Tianshan: 4-6 - Tyup trough: 4 - Tekes Formation (C_2-P), 5 - lower Bashkirian deposits, 6 - lower Carboniferous deposits; 7 - deposits of Sonkul-Turuk trough (C_1); 8-9 - Balkhash-Ili volcano-plutonic belt: 8 - Kungei Formation (C_1 v^2-s^1) and its analogues; 9 - Ketmen Group and its analogues (C_1 t^2-v^1); 10 - Early Devonian granitoids; 11-16 - Caledonian complexes: 11 - granitoid complexes (O_3-S_1), 12 - turbidites, conglomerates of the Lower-Middle Ordovician, 13 - Lower Paleozoic shelf (terrigenous-carbonate) deposits; 14 - Lower Paleozoic volcanic deposits; 15 - diorites (Є-O_1), 16 – Ediacaran-Early Cambrian accretionary complex, ophiolites; 17 - Proterozoic metamorphic complexes; 18-22 - Middle Tianshan: 18 - Karatau-Naryn carbonate platform, Middle Paleozoic; 19 - Early Carboniferous volcanic deposits; 20 - Early Carboniferous gneissic granites, granodiorites; 21 - metamorphic complex, Devonian, 22 - Chagawuzi mylonitic pluton, Ordovician; 23 – Ediacarico - Lower Paleozoic deposits, 24 - Mesoproterozoic granites, 25 - Paleoproterozoic metamorphic complexes; 26-27 - Southern Tianshan: 26 - garnet-mica and blueschists, eclogites (C_2); 27 - Late Paleozoic fold-thrust belt; 28 - Frontal Tianshan dextral strike-slip fault (FTDS); 29 - Main (marginal) sinistral strike-slip

faults; 30 - Early Paleozoic overthrust sheet; 31 - Late Paleozoic faults, mainly strike-slip faults; 32 - Cenozoic and reactivated faults; 33 - Late Paleozoic thrusts; 34 - Cenozoic thrusts; 35 - Faults covered by Quaternary deposits; 36 - Fault names mentioned in the text; 37-38 – U-Pb zircon dating (table 1 and 2): 37 - Zircons from outcrops, 38 - Detrital zircons.

2 Methodological approaches to the generalization of initial data

Obviously, only homogeneous data sets are subject to comparison. In our case, initially, they cannot be considered as such. They consist of:

1. The final materials of geological surveys, along with the elucidation of relationships between heterogeneous complexes that incorporate a standard set of stratigraphic, paleontological, petrographic, and geochemical studies, which may not always have been carried out in sufficient volume, but still give a holistic view of the geological structure of the area.
2. Geological research of the Nalati Range is limited by three to four directions, which are far from always interconnected: a) petrological, geochemical characteristics and U-Pb dating of intrusive massifs (Gao et al., 2009; Gou et al., 2015, 2012; Gou and Zhang, 2016; Long et al., 2011; Xu et al., 2013; Zhang et al., 2017), rarer volcanics (Qian et al., 2009; Xia et al., 2004); b) structural position, petrological characteristics, and isotopic dating of eclogites and blueschists (Du et al., 2014; Lin et al., 2009; Wang et al., 2010); c) detailed structural and microstructural studies of tectonites and metamorphic complexes carried out at local test sites (Charvet et al., 2011; de Jong et al., 2009; Lin et al., 2009; Wang et al., 2010); d) U-Pb dating of detrital zircons (Ren et al., 2011; Xia et al., 2014b).

But in general, the characteristics of the formations of the Nalati Range and their analogues within the Kyrgyz-Kazakhstan territory turn out to be comparable if stratified deposits are considered in the rank of series, and intrusive complexes are combined into time series in accordance with the clusters of U-Pb dating of Paleozoic granitoids established for the region (Alexeiev et al., 2019; Huang et al., 2020; Konopelko et al., 2008) and the recommendations of the Petrographic Code (Bogatikov et al., 2008).

Elucidation of fault tectonics, on the contrary, required greater effort within the Nalati Range, which we tried to implement by "solving the inverse problem." With rare exceptions, when the location of faults could indeed be determined from published schemes, the fault network identified during the mapping process in the territory of Kyrgyzstan and Kazakhstan was traced into the Nalati Range using the satellite images (Fig. 2B).

3 Main tectonic units of the region

The Central Tianshan geographical province, is traditionally subdivided into the following tectonic units:

- Hercynian collisional structures of the Southern Tianshan, formed over the Turkestan (South Tianshan) paleoocean (Biske, 1996; Burtman, 2006);
- Middle Tianshan, a fragment of the Precambrian microcontinent, within which in the Ediakaran-Early Paleozoic, and the Middle Devonian-Early Carboniferous, passive margin complexes were formed, associated with the adjacent Saki and Turkestan paleooceans (Alexeiev et al., 2019, 2017; Bakirov et al., 2019; Bakirov and Maksumova, 2001; Ghes, 2008; Mikolaichuk et al., 2020);
- Accreted Caledonian complexes of Northern Tianshan, represented by fragments of Precambrian microcontinents, Early Paleozoic island arcs, ophiolites and eclogites, formed during the closure of the Saki (Terskey) paleoocean (Alexeiev et al., 2019, 2017; Bakirov et al., 2019; Bakirov and Maksumova, 2001; Burtman, 2006; Lomize, 1994; Mikolaichuk et al., 2008; Windley et al., 2007).

The boundaries of the main tectonic units are the Late Paleozoic sinistral strike-slip faults (see Fig. 1B). The Atbashi-Inylchek fault inherits the suture of the Turkestan paleoocean (Biske, 1996; Burtman, 2006; Trifonov and Solomovich, 2018). The Middle and North are separated by the Nikolaev Line, along which the strike-slip component is overlapped on a Late Carboniferous thrust (Khristov, 1970; Mikolaichuk et al., 2020). The strike-slips appeared in the Late Permian - Early Triassic, when most of Tianshan was involved in left-sided displacements (Bazhenov et al., 1999; Burtman, 2006). Notably, the Ar-Ar age of mylonites (synkinematic phengite) in thrusts associated with the Atbashi-Inylchek fault is 265-248 Ma (Rolland et al., 2020). These processes led to a radical structural transformation of the region and the generation of postcollisional granitoid magmatism, which was equally manifested in all three tectonic units (Burtman, 2006; Konopelko, 2011; Seltmann et al., 2011; Solomovich and Trifonov, 2002). Most strike-slip faults from the Late Paleozoic set of structures, which, in addition to the above-mentioned marginal faults, also include the Chiliko-Kemin fault (see Fig. 1B), underwent reactivation at the Cenozoic time (Bachmanov et al., 2008; Bazhenov and Mikolaichuk, 2004; De Pelsmaeker et al., 2015; Macaulay et al., 2014, 2013; Morozov et al., 2014; Rolland et al., 2020; Selander et al., 2012), thereby predetermining the architecture of modern mountain structures of the described segment.

Further away, within Kazakhstan and along the northern spurs of Tianshan, the Caledonides are overlain by volcanic rocks of the Devonian belt (D_{1-2}), which is replaced by the Balkhash-Yili volcano-plutonic belt (D_3-P) to the southeast, fixing the migration of the active margin above the subducting plate of Dzhungaro-Balkhash oceanic basin (Degtyarev, 2012; Ryazantsev, 1999; Windley et al., 2007).

The listed structural units can be traced in the territory of NW Xinjiang, where they are recognized with varying certainty. Researchers of the Southern Tianshan , despite the polemic on the stratigraphy of sedimentary sequences, the age of ophiolites and related to them metamorphic complexes, as well as the direction of subduction zones, are unanimous in their opinion both about the boundaries of this collision belt as well as its formation as a result of a collision of the composite Kazakh Paleozoic continent with the Precambrian microcontinents of Turan and Tarim (Alexeiev et al., 2015; Biske, 1996; Burtman, 2006; Charvet et al., 2011; Gao et al., 2009; Han et al., 2011, 2016; Safonova et al., 2016; Xiao et al., 2013).

The situation with the identification of the Middle and Northern Tianshan complexes in Xinjiang region is much more uncertain. A number of geologists argue in favor of slight penetration of the Middle Tianshan into the territory of China, where it soon wedges out, and continuation of the structures of the Northern Tianshan, together with the Balkhash-Yili belt in the Yili-Central Tianshan block on the territory of China (Alexeiev et al., 2019, 2015; Burtman, 2006; Gou et al., 2015, 2012; Gou and Zhang, 2016; Windley et al., 2007; Xia et al., 2014a; Xiao et al., 2013; Zhang et al., 2017). Some other researchers are of the opinion that the North Nalati Fault is the continuation of the Nikolaev Line in the east and that the Chinese Central Tianshan is an analogue of the Middle Tianshan. In this case, the North Tianshan Caledonian complexes, and the overlying deposits of the Balkhash-Yili volcano-plutonic belt are described as the Kazakhstan-Yili block (Biske, 2018; Gao et al., 2009; Han et al., 2016; Huang et al., 2020; Lin et al., 2009; Long et al., 2011; Qian et al., 2009; Xia et al., 2014a; Xu et al., 2013). But supporters of this model of Paleozoic Tianshan inevitably face the uncertainty of the position of the Nikolaev Line itself, which has arisen in recent years.

V.A. Nikolaev (Nikolaev, 1933), studying Tianshan in the first third of the 20th century, singled out the “Most Important Tianshan Structural Line” (which later received his name), by which he understood the fault that separates the Middle Paleozoic carbonate deposits of the

Middle Tianshan from gray-colored coastal-marine, and subsequently red-colored continental deposits of North Tianshan. But by the end of the same century, priorities had changed, and M.G. Lomize proposed to take the suture of the Terskey (Sayak) paleoocean as the "Most Important Structural Line of Tianshan" (Lomize, 1994). It is this interpretation that appeals to many Xinjiang researchers and is reflected in their tectonic schemes (Gou et al., 2015, 2012; Gou and Zhang, 2016; Qian et al., 2009; Wang et al., 2010, 2020; Zhang et al., 2017), although the boundary between the Middle Paleozoic marine deposits of the Middle Tianshan and the grey-colored and subsequent red-colored continental deposits of the Northern Tianshan remains a stable element of the Paleozoic structure of the region (Alexeiev et al., 2017; Khristov, 1970; Mikolaichuk et al., 2020).

Supporting the conclusion that the Late Permian post-collisional activation completely destroyed the previous Paleozoic structure of Tianshan and the boundaries of the main tectonic units are strike-slip faults of Permian age, Xinjiang researchers insist that all of them are dextral (Charvet et al., 2011; de Jong et al., 2009; Lin et al., 2009; Wang et al., 2010; Xiao et al., 2013).

Along the meridional section of the Kekes River (81°55' E), two pulses of activation of dextral strike-slip faults were established: mylonitized granites with an age of 338 ± 8 Ma are intruded by undeformed syenites of 277 ± 3 Ma (U-Pb dating from zircons) along the Nalati North Fault, and micas from Precambrian paragneisses exposed between the Nalati South and Nalati North faults have an Ar-Ar age of 253.3–252.3 Ma (de Jong et al., 2009; Wang et al., 2010). On rare occasions, however, signs of left-sided displacements are described in Nalati Range, which is interpreted as an early stage of the shear process. Nevertheless, the authors come to the conclusion that, on the whole, the Nalati Fault, the Nikolaev Line as its western extension, and the Main Tianshan Shear Zone located in eastern Xinjiang form a single large-scale Permian-Early Mesozoic dextral strike-slip zone (Wang et al., 2010).

However, the observed structural pattern of the fault network of the Nalati Range convinces us that another scenario for the development of Tianshan in the Late Paleozoic is also possible. Tracing the South Nalati fault on a satellite image, we have found out that in the upper reaches of the Akeyazi River it does not turn to the south-west, as shown in all regional diagrams, but extends along the latitudinal segment of this valley, and having reached the watershed part of the range, the Akeyazi segment (6 in Fig. 2B) splits into a series of relatively short faults with a right-sided strike-slip component. Such “horsetail” structures usually mark the ends of major strike-slip faults (Rastsvetaev, 1987; Sylvester, 1988).

The extreme southwestern fault from this “horsetail” structure, identified by us as the Kopyl fault (7 in Fig. 2), together with the Akeyatszi and South Nalati faults constitute the

Frontal Tianshan Dextral Strike-slip (FTDS), which cuts off all the structural elements of the Northern traced within the Terskey and Kopyl Ranges, including the Nikolaev Line often mentioned in the literature (see Fig. 1 and 2).Only the northwestern slopes of the Kopyl Range are composed of complexes that stretch to the territory of China (Fig. 3). They served us as a test site to decipher the geological structure of the Nalati Range. The final link of the FTDS is the Kurmenty fault separating the Issyk-Kul massif from the Balkhash-Yili volcanic belt, both of which are cut off in the northeast by the Chiliko-Kemin sinistral strike-slip fault (Fig. 1 and Fig. 4).

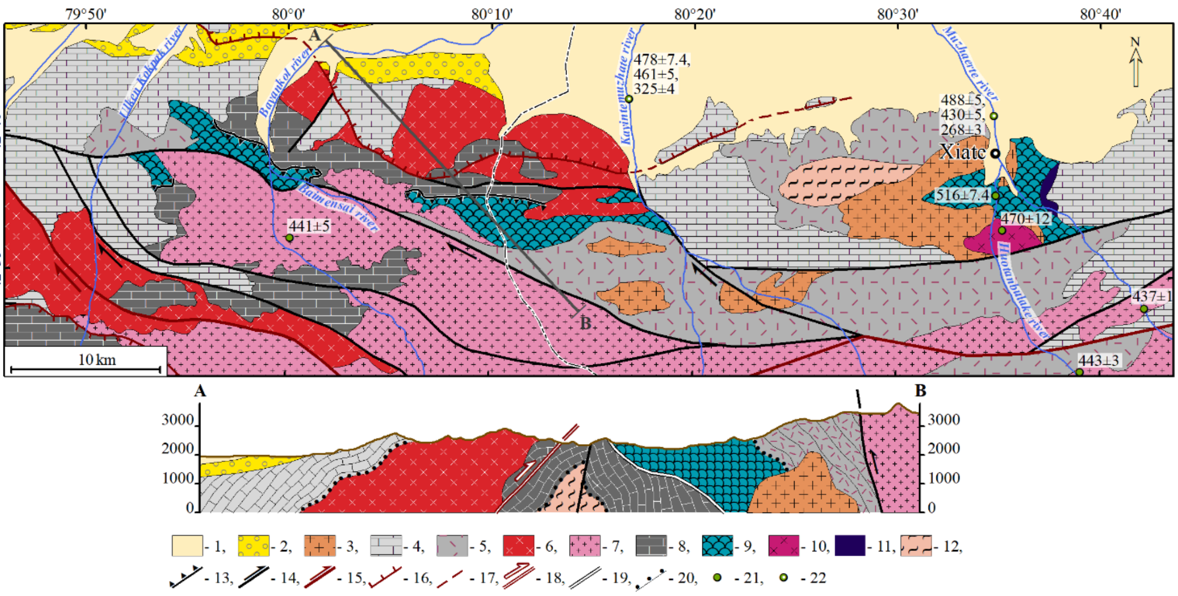

Fig. 3. Geological map of the interfluve Ulken Kokpak - Muzhaerte
1 - Quaternary deposits; 2 - Cenozoic deposits; 3 - Late Paleozoic granitoids; 4-5 - Balkhash-Ili volcano-plutonic belt: 4 - Kungei Formation (C_1 v_2-s_1) and its analogues; 5 - Ketmen Group and its analogues (C_1 t_2-v_1); 6 - Early Devonian granitoids; 7 - Silurian granitoids; 8 - Lower Paleozoic shelf (terrigenous-carbonate) deposits; 9 - Lower Paleozoic volcanic deposits; 10 - Diorites (Є-O_1); 11 - Serpentinites, 12 - Proterozoic metamorphic complexes; 13 - Early Paleozoic overthrust sheet; 14 - Late Paleozoic faults, mainly strike-slip faults; 15 - Cenozoic and reactivated faults; 16 - Cenozoic thrusts; 17 - Faults covered by Quaternary deposits; 18 - 20 - On the geological section: 18 - Cenozoic thrusts, 19 - The base of the overthrust sheet, 20 - Unconformity; 21-22 – U-Pb zircon dating (Table 1 and 2): 21 - Zircons from outcrops, 22 - Detrital zircons.

An analysis of the relationships and interactions between the sinistral and dextral Tianshan strike-slip fault systems can take us far from the stated topic, but it should still be noted that the last two segments from the FTDS largely predetermined the recent tectonics of the area, including the initiation and complication of the structure of intramountain Neogene basins. As a result of the reactivation of the Kopyl fault (7 in Fig. 2) in the Middle-Late

Miocene, the dextral displacement of its southwestern limb was compensated by the thrusting of the Main Terskey Fault (8 in Fig. 2) over 200 km of the Issyk-Kul depression (Chediya et al., 1998; Macaulay et al., 2014, 2013). The deposits of the Terskey Range are upthrown onto the Kopyl Range along the Kubergenta Cenozoic thrust (9 in Fig. 2), almost completely overlapping the Neogene red beds located between them. And the epicenters of the strongest earthquakes in Central Asia that occurred at the turn of the 19th and 20th centuries are localized at the junction of the sinistral Chiliko-Kemin with the dextral Kurmentinsky strike-slip faults (Fig. 4), (Abdrakhmatov et al., 2016).

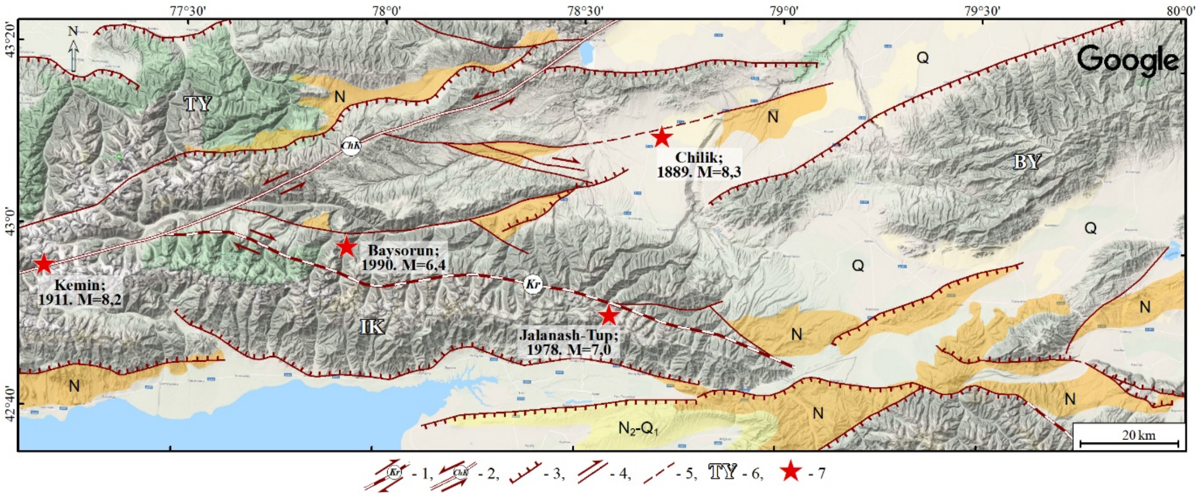

Fig. 4. Tectonic scheme of the eastern part of the Trans-Yili and Kungei Ranges. Compiled according to (Abdrakhmatov et al., 2016; Chabdarov et al., 1962; Chabdarov and Bazhanov, 1971)
1 - Kurmenty dextral strike-slip fault; 2 - Chiliko-Kemin sinistral strike-slip fault; 3 - Cenozoic reverse and thrust faults; 4 - Cenozoic faults, mainly strike-slip faults; 5 - Faults covered by Quaternary deposits; 6 - Paleozoic tectonic zones: TY - Trans-Yili, IK - Issyk-Kul massif, BY - Balkhash-Yili volcano-plutonic belt; 7 - Epicenters of destructive earthquakes. Additional indexes on the schema: N - Variegated Neogene deposits of intermountain depressions, N_2-Q_1 - Conglomerates of the Sharpyldak Formation, Q - Quaternary deposits.

4 Geological characteristics of the border regions of Kyrgyzstan, Kazakhstan, and The Xinjiang Uygur Autonomous Region of China

Obviously, only a systematic description of the complexes that make up the border regions of the Central Asian countries and China can remove the accumulated contradictions in understanding both the relationship between the main structural units of Tianshan and their formational composition. Since within the Southern Tianshan the issues of correlation of the structural complexes of Xinjiang and Kyrgyzstan were discussed earlier (Alexeiev et al., 2015; Biske, 2018), we restrict ourselves to considering only the Middle and Northern Tianshan.

4.1 The Middle Tianshan in most of the territory of Kyrgyzstan is represented by Middle Paleozoic carbonate deposits of the passive margin of the Kazakh paleocontinent (Alexeiev et al., 2017), but east of the 76° meridian, at the level of the erosional cut, a Late Riphean (= Tonian) riftogenic complex appears, overlain by deposits of the Ediakaran-Early Paleozoic passive margin (Bakirov and Maksumova, 2001; Ghes, 2008; Mikolaichuk et al., 2020; Neevin et al., 2011). In the Akshiyryak Range (78°E - see Fig. 1B) and further to the east, metamorphic rocks of the Kuilyu Complex with U-Pb zircon age of 2.3 - 1.85 Ga are exposed (Kiselev et al., 1988; Kröner et al., 2017) (see Fig. 2, Table 1), intruded by 820 ± 20 Ma U–Pb granitoids dated by zircons (Glorie et al., 2011; Kiselev et al., 1993; Kröner et al., 2011b). There are also narrow tectonic blocks bounded by sinistral strike-slip faults (10, 11, 12 in Fig. 2) and composed of the Middle Paleozoic differentiated series of calc-alkaline volcanic rocks or coeval carbonate deposits of the passive margin (Mikolaichuk et al., 2019), (see Fig. 2).

The Kuilyu Complex has been studied in most detail at the junction of the Akshiryak and Sarydzhaz Ranges (see Fig. 1A). Here, at the confluence of the Kuilyu and Sarydzhaz Rivers, a field of gneisses of granodiorite composition, biotite and amphibole-biotite gneisses, amphibolites, garnet-micaceous and pyroxene paragneisses, marbles, quacites, graphite and quartz-biotite schists is exposed. Often, the rocks are intensively mylonitized and injected with granitic migmatites, which, apparently, fix the second age limit of 1.85 Ga, followed by metamorphism of the entire complex (1.83 Ga) under conditions of the amphibolite facies, and then by diaphthoresis to the greenschist facies (Bakirov, 1984; Korolev, 1972; Kröner et al., 2017). Early Proterozoic metamorphites, together with the Late Riphean granites that cut through them, form the watershed part of the Saryjaz Range.

This block, being limited from the south by the Atbashi-Inylchek fault (1 in Fig. 2), and in the north by the Nikolaev Line (3 in Fig. 2), can be traced further to the east along the watershed part of the Nalati Range. On Chinese territory, the eastern segment of the Atbashi-Inylchek fault is known as the Changawuzi fault, and the Nikolaev Line as the Adenbulak fault (Gou and Zhang, 2016). Here, in the upper Muzhaerte River and further to the east, green shales of the Proterozoic Qiongkushitai Group (Gou et al., 2015; "XBGMR," 1981), or Nalati Group (Xia et al., 2014a) are described. Establishing the presence of orthogneisses in the Muzhaerte metamorphic sequence, the authors of the research limit themselves to the investigation of metasedimentary rocks only. According to their mineral paragenesis, the latter correspond to the sillimanite-almandine subfacies of the amphibolite facies of metamorphism. Using the U-Th-Pb monazite method for metapelites of the Muzhaerte sequence, two isochron datings of 376 ± 8 Ma and 280 ± 8 Ma were obtained, the second of which is synchronous with the dating of anatectic granites formed from metasedimentary rocks at a pressure of 7.21 kbar and a temperature of 728° C (Gou et al., 2015, 2012), (samples W8011-W8015 in Table 2).

In the northern part of the belt, the green shales are superposed by metamorphic facies of moderate pressures, represented by biotite-hornblende plagiogneisses, granite-gneisses, metasedimentary rocks with a subordinate amount of marbles and rare lenses of granulites, the Devonian age of which is confirmed by U-Pb and U-Th-Pb dates (see Fig. 2; Table 2) (Gou and Zhang, 2016; Xia et al., 2014a). Despite the fact that significant differences are recorded in the history of the formation of the Kuilu Complex and Qiongkushitai (or Nalati) Group, on both sides of the Kazakh-Chinese border, metamorphites are cut through by a very characteristic complex of Early Carboniferous gneissic granitoids, indicating their belonging to a single tectonic unit - the Kyrgyz Middle Tianshan. In the upper Bayankol River this is the Sarykoinou pluton with an age of 336.0 ± 3.3 Ma (Kröner et al., 2009; Mikolaichuk et al., 2008), and in the upper reaches of the Muzhaerte River, the Changawusi pluton with an age of 333-326 Ma (Gou et al., 2012), which, in turn, are intruded by Permian porphyritic granites with an age of 300–293 Ma (see Fig. 2, Tables 1 and 2). Both intrusions are composed of garnet-bearing gneissic granodiorites and porphyritic tonalites (Fig. 5A), which belong to the tholeiitic or calc-alkaline series in terms of petrochemical characteristics. Based on detailed geochemical studies of the Changawusi massif (Sr and Nd isotope ratios, rare and trace elements in the rock, as well as Hf isotopes in zircons), it is concluded that the gneissic granitoids of the Early Carboniferous were formed as a result of partial melting of the newly formed oceanic crust of the Turkestan paleoocean, during its subduction to the north (Gou et al., 2012). This conclusion is consistent with the presence in the Sarydzhaz Range of a differentiated series of calc-alkaline volcanic rocks with a U-Pb zircon age of 321.3 ± 2.9 Ma (Mikolaichuk et al., 2019).

In this summary, we do not consider post-collisional Permian granitoids, since these are transit complexes equally manifested in all three Tianshan tectonic units. But the anatectic granites of the upper Muzhaerte River deserve special attention (see Table 2). Having been formed at a pressure of 7.21 kbar (Gou et al., 2015, 2012; Xia et al., 2014a; Xia and Zhang, 2021), which corresponds to depths of 27-30 km, they turned out to be brought to the surface. The uplift of the Middle Tianshan to the east is accompanied by a reduction in its width in the same direction. And at 84.5° E, in the western part of the Erben Range, the complexes of the Kyrgyz Middle Tianshan are completely cut off by the South Nalati Fault, and the blue eclogite-bearing and green shists of the South Tianshan are flanked with Neoproterozoic gneisses with an age of 826.3 ± 3.2 Ma and intruding them Silurian granites typical of Central China (Alexeiev et al., 2015).

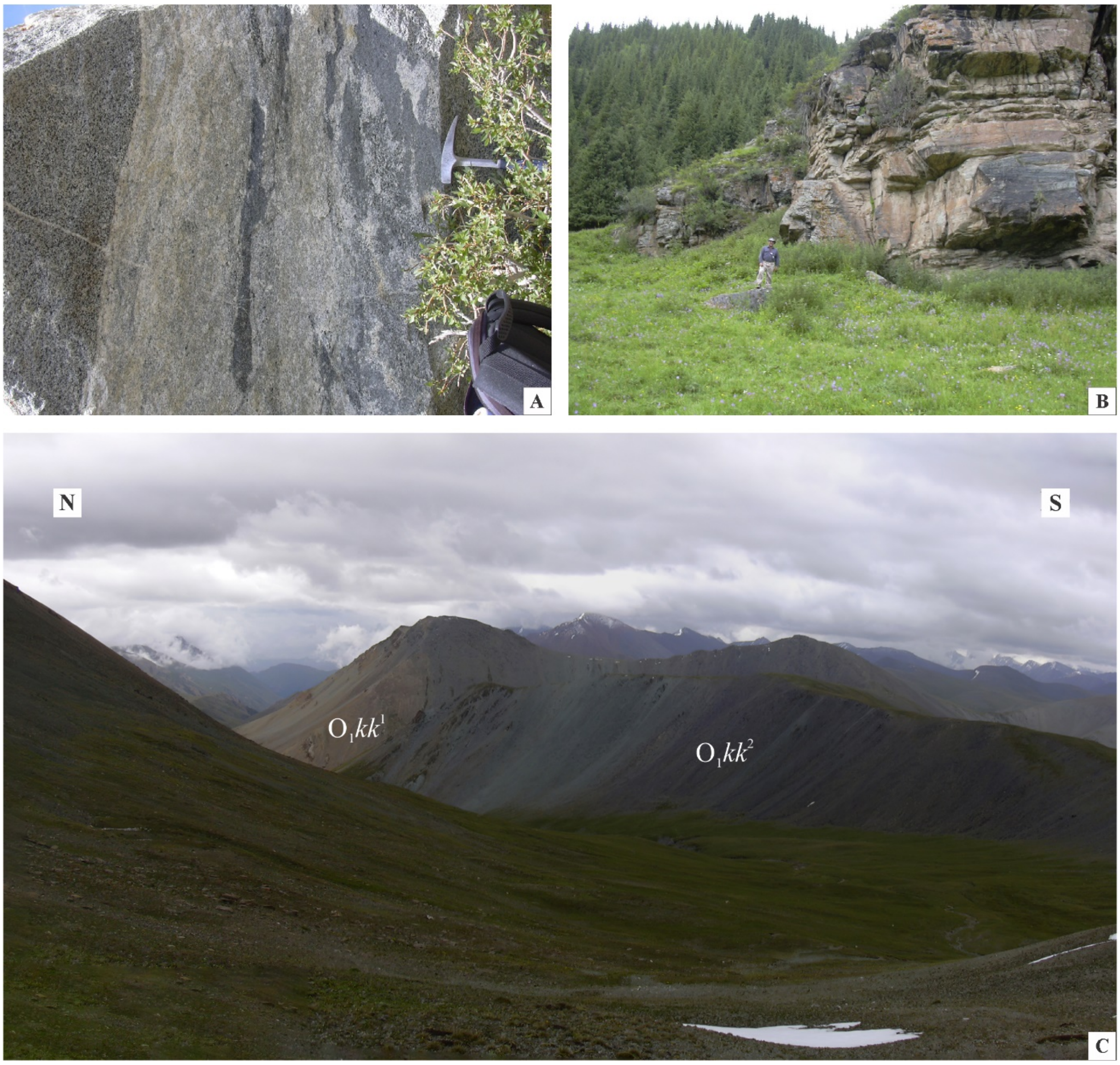

Fig. 5. Photographs of typical outcrops in the Kazakhstan border territory:
5a - gneissic granodiorites of the Sarykoinou pluton, sample MAV 90/07; 5b - quartz and arkose sandstones of the Koichi Formation at the confluence of the Izbushka and Bayankol Rivers; 5c - Deposits of the Dzhergalan group on the right board of Kokchukur River: O_1kk^1 - limestones, marls, arkose sandstones, O_1kk^2 - variegated shales, siltstones, quartz and arkose sandstones

4.2 Caledonian complexes of the Kyrgyz North and Chinese Central Tianshan

4.2.1 The Kyrgyz North Tianshan is represented by the Caledonian complexes that make up the Kyrgyz-Kazakh composite paleocontinent (Bakirov et al., 2019; Bakirov and Maksumova, 2001; Ghes, 2008; Kröner et al., 2013) which are overlain with unconformity by the Middle Paleozoic superposed depressions developing synchronously with the Junggar-Balkhash and South Tianshan hercynides (see Fig. 1A). In the Caledonides of Kyrgyzstan, the Issyk-Kul massif is traditionally distinguished, which is distinguished by a high standing of the crystalline base, and the Burkhan and Kyrgyz-Terskey zones that replace it to the south (Knauf, 1972;

Korolev et al., 1983), (see Fig. 1B). In a number of publications, the Issyk-Kul massif and the Burkhan zone are considered as part of a single North Tianshan (Kokchetav - North Tianshan) microcontinent (Alexeiev et al., 2019; Degtyarev et al., 2013; Windley et al., 2007).

4.2.1.1 The Issyk-Kul massif is composed of Late-Middle Riphean (Tonian-Stenian) amphibolite-facies schists, gneisses, granite-gneisses, and marbles with U-Pb age of 948-1043 Ma based on multigrain zircon samples (TIMS) (Bakirov and Maksumova, 2001; Kiselev, 2014, 1999; Kiselev et al., 1993). Dating of single zircon grains from orthogneisses and migmatized granites (U-Pb SHRIMP II) fixed their age in the range of 1045-1151 Ma (Kröner et al., 2013).

The crystalline basement of the Issyk-Kul massif plunges to the east, and in the border area at the level of the erosional cut, Lower Paleozoic terrigenous-carbonate deposits of the cover appear, which differ little from the coeval deposits of the Burkhan zone. And only the Central Terskey Fault, clearly expressed in the relief, reactivated at the latest stage (Macaulay et al., 2014, 2013), makes it possible to trace these tectonic units along strike (see Fig. 2A, B, fault 5).

But the three-four-phase complexes that make up the Late Ordovician-Early Silurian time series of syncollisional S- and I-type granitoids, gravitating on the TAS diagram to the line of separation of rocks of the normal and subalkaline series are predominantly developed within the massif, as well as in the Burkhan zone traced to the south (Ghes, 2008). Their composition includes gabbroids and diorites of the first phase, coarse-grained porphyritic granodiorites, and granites of the second, and medium-coarse-grained granites of the third phase. The formation of batholiths is completed by fine-medium-grained granites and leucogranites (De Grave et al., 2013; Ghes, 2008; Kiselev, 1999; Konopelko et al., 2008). Remnants of Cambrian-Middle Ordovician granitoids and continental arc volcanics have been identified among the syncollisional batholiths (Alexeiev et al., 2019; Kiselev, 1999). Along the northern and northeastern boundaries of the Issyk-Kul massif, there are small bodies of Early Devonian ultra-acid leucogranites (414±7 Ma), granophyres (421±1 Ma), syenites (401±3 Ma), and subalkaline granites (399±3 Ma), whose appearance is associated with the formation of the Devonian volcanic belt of Kazakhstan (Apayarov, 2010; Apayarov et al., 2019; Mikolaichuk et al., 2008; Solomovich, 1997).

The Early Paleozoic deposits of the eastern end of the Issyk-Kul massif, originally mentioned by V. I. Knauf (Knauf, 1972) as the Dzhergalan zone of the Late Caledonian folding, are more fully developed on the territory of Kazakhstan, where they form a sequence up to 3 km thick. In the visible base of the Dzhergalan Group, thin-layered limestones and marls occur with subordinate layers and lenses of arkose sandstones (250 m). The sequence is built over by variegated (purple, brown, or green-gray) clayey shales and siltstones, alternating with light green or white quartz and arkose fine-grained sandstones (350 - 600 m). The upper part of the sequence, up to 2400 m thick, is composed of gradation-layered polymictic sandstones interbedded with calcareous siltstones, siliceous shales, and cherts. Turbidites contain conodonts and graptolites of Flosian stage and Middle Ordovician, which substantiate the Early Paleozoic age of the series (Mikolaichuk et al., 2008), (Fig. 1, 2).

4.2.1.2 The Burkhan zone is separated from the Issyk-Kul massif by the Central Terskey marginal fault and, in contrast to the massif, is characterized by a wide development of Riphean (Mesoproterozoic) deposits (Korolev, 1972; Korolev et al., 1983). The crystalline base of the Burkhan zone is exposed in the Dzhetymbel Range and is composed of biotite-muscovite, biotite-zoisite-quartz, garnet-amphibole-biotite-quartz schists and porphyroids with uranium-lead age 1113-1017 Ma. The crystalline schists and the unconformably overlying them bimodal rhyolite-basalt series (1093 Ma) are intruded by plagiogranites with an age of 1020 Ma (Kiselev, 2014, 1999). The close age values (207Pb/206Pb ratios) of the listed complexes are explained by the thermal effect of plagiogranites on zircons from host rocks (Kiselev, 2014, 1999). The above dates were obtained from multigrain zircon samples (TIMS method). At the same time, according to the results of dating of single zircon grains (U-Pb SHRIMP II), the age of rhyolites from the rhyolite-basalt series of the Dzhetymbel Range is 1365 ± 6 Ma (Kröner et al., 2013). The overlying Upper Riphean and Lower Paleozoic terrigenous-carbonate deposits (Ghes, 2008, p. 1997; Korolev, 1972; Korolev et al., 1983; Mikolaichuk et al., 1997) are largely intruded by Ordovician-Early Silurian granitoids similar to the batholiths of the Issyk-Kul massif (Ghes, 2008; Kiselev, 1999; Konopelko et al., 2008; Mikolaichuk et al., 1997), and early Devonian intrusions appear only in the area bordering China (Mikolaichuk et al., 2008).

At the eastern end of the Terskey Range, in the basin of the Bayankol River, shales and gneisses with an age of 1075 Ma are exposed (see Fig. 2A, Table 1). The Lower Paleozoic deposits lie Structurally above and are represented by light arkosic and variegated (lilac, brown, green) polymictic sandstones, siltstones with rare gravelstone lenses and thin limestone interlayers (Dzholkolotskaya Formation, 830 m). The top of the section is made up of a thin interbedding of black carbonaceous shales and dark gray, greenish gray, calcareous shales that include a 200-400 m horizon of massive marbled limestones and dolomites (Ashuairyk Formation, 770 - 1360 m) (Korolev, 1972; Mikolaichuk et al., 2008). The Early Paleozoic age of this sequence is assumed based on lithological similarity with the above-described section of the Dzhergalan Group, as well as the faunistically documented Chener Formation of the

Kyrgyz Range (Apayarov et al., 2008; Degtyarev et al., 2013) and the Toraigyr Formation of the Kungei Range (Ogurtsova et al., 1993).

4.2.1.3 The Kyrgyz-Terskey zone is composed of Cambrian-Early Ordovician lavas and oceanic arc tuffs, back-arc ophiolites, and an accretionary complex thrust over the Burkhan zone and tracing the suture of the Terskey (Saka) paleoocean (Alexeiev et al., 2019; Bakirov et al., 2019; Bakirov and Maksumova, 2001; Burtman, 2006; Ghes, 2008; Lomize, 1994; Mikolaichuk et al., 1997). The front line of tectonic nappes, overthrusted from the Kyrgyz-Terskey zone, is fixed by isolated outcrops of allochthonous ophiolite and island-arc complexes of the Cambrian - Early Ordovician, identified within the Burkhan zone (Bakirov et al., 2019; Degtyarev et al., 2013; Ghes, 2008; Lomize, 1994; Mikolaichuk et al., 2008), (see Fig. 1B).

Along the Burkhan zone, the Kyrgyz-Terskey zone is represented by an accretionary complex, into which we combine a series of tectonic plates composed of gabbro, peridotites, serpentinites, polluted basalts, and siliceous schists a few tens of meters thick. Less common are plates composed of lithoclastic tuffs and lavas of basic and intermediate composition, or marbled limestones, up to 150 m thick. The rocks of the complex are sheared and metamorphosed to varying degrees, in rare cases to actinolite schists and amphibolites, and also intruded by bodies of melanocratic tonalites and quartz diorites with an isochronous U–Pb age of 526 ± 34 Ma for zircons (Table 1), (Kiselev, 2014). A block of Cambrian-Early Ordovician pillow lavas, clastolavas, and tuffs of the Turgen'aksu island-arc series, up to 1700 m thick, flanks the Central Terskey fault from the north (Ghes, 2008), and is a tectonic nappe overthrusted from the Kyrgyz-Terskey zone and fragmented by Late Paleozoic faults.

4.2.2 The Chinese Central Tianshan within the considered segment of the Nalati Range is represented by Precambrian crystalline schists, among which at least half of the area is composed of Paleozoic intrusive formations. We also refer to the same structural unit the formations of the northeastern slope of the Kopyl Range, bounded from the southwest by the Frontal Tianshan Dextral Strike-slip (FTDS) (see Fig. 2). Researchers of the Nalati Range, based on the histograms of the distribution of uranium/lead dates, identify a single family of Silurian-Early Devonian granitoids for this region (Huang et al., 2020; Zhang et al., 2017).

However, the similarity of the petrological, geochemical, and age characteristics of the granitoids of the Aktash complex of the Kopyl Range (Table 1) with the plutons developed in the Muzhaerte River (Table 2), (Gou and Zhang, 2016; Long et al., 2011), as well as granitoids of the Alaminsky and Sauruksai complexes (Table 1) with plutons developed in the Bikay River and the Akeyazi River basins (see Table 2), (Gao et al., 2009; Long et al., 2011), convince us that in the western part of the Chinese Central Tianshan, as well as within the Kyrgyz Northern

Tianshan, syncollisional granitoids of the Late Ordovician–Early Silurian time and Early Devonian subalkaline granitoids are most widely represented, among which sporadic remnants of Late Cambrian–Middle Ordovician plutons are found (see Fig. 2; Table 2).

The Lower Paleozoic terrigenous-carbonate deposits of the Bayankol River basin belong to the same structural unit, located to the east of the FTDS (see Fig. 2 and 3). In terms of the structure of the sequence and the complex of algae and acritarchs, they resemble the Toraigyr Formation of the Kungei Range (Ogurtsova et al., 1993). In the middle reaches of the Bayankol River, the Koichi Formation is developed, represented by gray-green thin-bedded siltstones, which up the sequence are replaced by coarse-bedded and massive light gray quartz and arkose sandstones with subordinate interlayers and lenses of gravelstones more than 1000 m thick (see Fig. 5B). In the Bayankol-Baimensai interfluve, the sequence builds up with the Bayankol Formation, composed of carbonaceous shales, siltstones, and thin-layered marmorized limestones (100 m). They are replaced by a horizon of massive light gray dolomitic limestones, but with thin-layered and brecciated textures, identified in the outcrops (310 m). The sequence is completed by interbedded arkose sandstones, siltstones, carbonaceous shales, and dolomitic limestones (60 m). Incomplete thickness of the Bayankol Formation is 470 m. Acritarchs and algae of the Ediakaran-Early Paleozoic age were identified in samples of carbonaceous shales by S. M. Blyakhova (Esmintsev, 1999).

The Bayankol Formation is overlain by a tectonic cover of basalts, which with equal probability could be thrusted over from both the Kyrgyz-Terskey or Dzhalair-Naiman zones (Alexeiev et al., 2019). According to our observations along the right tributaries of the Baimensai River, volcanic rocks are represented here by pillow amygdaloidal basalts that contain scattered swarms of parallel dikes of dolerite composition. The thickness of individual series of dikes is 10–15 m. The apparent thickness of the volcanogenic sequence does not exceed 400 m here. Baimensai basalts are traced as a discontinuous strip in the easterly direction to the Xaite village, where they have been subjected to detailed geochemical and geochronological studies. Their U–Pb age based on zircons from the Xaite basalts is 516.3 ± 7.4 Ma. Based on the results of the study of rare and trace elements, they belong to the MORB type (Qian et al., 2009). The sequence of Early Cambrian basalts is intruded by adakitic diorites with a U–Pb age after zircons of 470 ± 12 Ma (Table 2). The authors believe that the Sr and Nd isotopic composition of the Xiate diorites indicates that their magmas were formed in a continental arc setting (Qian et al., 2009). The presence of 479 ± 2 and 497 ± 5.9 Ma granitoids in the field of Precambrian schists of the Nalati Range (Gao et al., 2009; Xu et al., 2013) suggests that there, as in the North Tianshan segment (Alexeiev et al., 2019), the setting of the continental arc persisted during the Late Cambrian–Middle Ordovician.

The rock complexes framing the Xiate basalt and diorite outcrops have not actually been studied, and their age is assumed by analogy with similar rocks in the adjacent areas (Qian et al., 2009). In this regard, our attention was drawn to the field of felsic volcanic rocks overlying crystalline schists in the Kayintemuzhate-Muzhaerte interfluve and undoubtedly being a source of drift for a sample of detrital zircons with a pronounced grain peak of 488 ± 5 Ma (sample 08ZS4, Table 2), (Ren et al., 2011). A site similar to the Kayintemuzhate-Muzhaerte interfluve is known at the northwestern end of the Issyk-Kul massif. Here, in the southern wing of the Chiliko-Kemin fault, the Late Cambrian tuffs of rhyodacites of the Karakorum Formation with an age of 489 ± 2 Ma (Alexeiev et al., 2019) are overlain by the Toraigyr Formation of quartzites, carbonaceous shales, and limestones. Structurally above them occurs a tectonic cover composed of mylonitized rocks of the ophiolite association (see Fig. 6) (Ghes, 2008; Mikolaichuk, 1998; Ogurtsova et al., 1993). Autochthonous and allochthonous formations are intruded by Late Ordovician granitoids with an age of 445 Ma (De Grave et al., 2013).

The above data give grounds to believe that the tectonic unit, described as the Chinese Central Tianshan, is the eastern continuation of the Issyk-Kul massif, displaced along the FTDS to the southeast at a distance of at least 80 km.

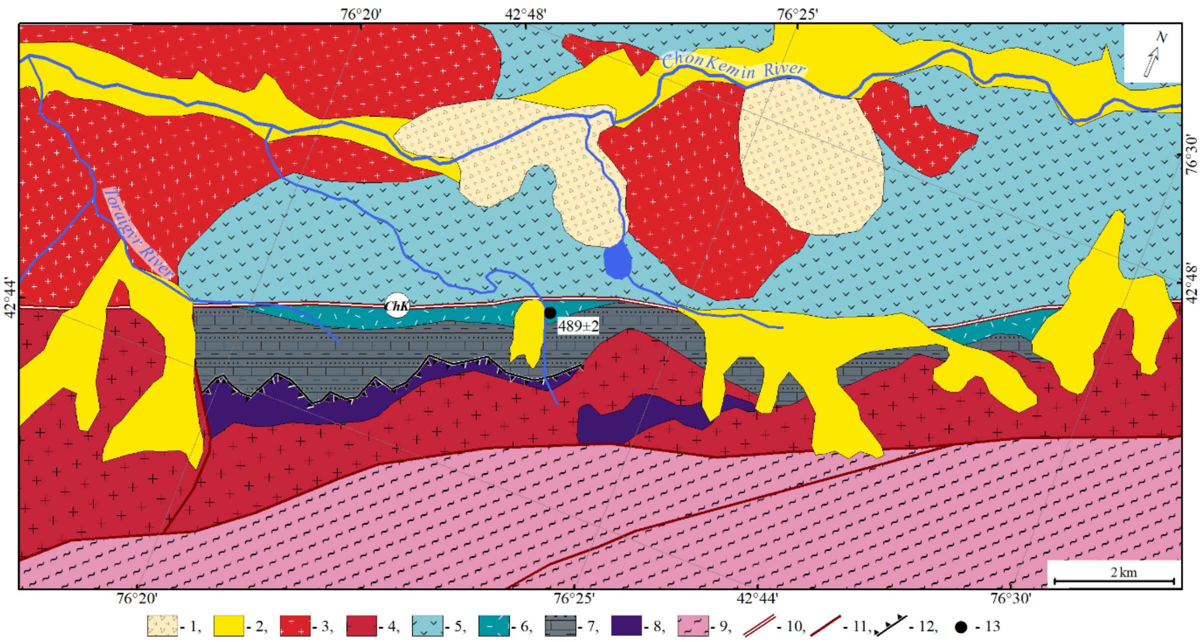

Fig. 6. Geological map of Issyk-Kul massif on the left side of the Chon Kemin River
1 - Seismodislocations, Holocene; 2 - Quaternary alluvial and glacial deposits; 3 - Early Devonian granitoids; 4 - Late Ordovician granitoids; 5 - Chiliko-Kemin tectonic zones:

andesite-basalt calc-alkaline series (Є-O_1); 6-9 - Issyk-Kul massif: 6 - Karakorum Formation, lavas and tuffs of rhyodacites (O_1), 7 - Toraigyr Formation, quartzites, carbonaceous shales and limestones, dolomites (O_1), 8 - Ophiolite association: gabbro, pyroxenites, basalts and blastomylonites after mafic (Є ?), 9 - Proterozoic metamorphites; 10 - Chiliko-Kemin sinistral strike-slip fault; 11 - Late Paleozoic and Cenozoic faults; 12 - Early Paleozoic overthrust sheet; 13 - U-Pb age of dacitic tuffs in Ma, sample Mik22 by (Alexeiev et al., 2019).

4.3 Middle-Late Paleozoic superimposed troughs of Northern Tianshan

4.3.1 The Sonkul-Turuk trough is formed in the late Tournaisian (C_1) in the rear of the carbonate platform of the Middle Tianshan, where it is filled with turbidites and olistostromes brought from the north. The deep-sea turbidite trough is filled with sediments from the Late Tournaisian to Serpukhovian (C_1) inclusive, with a total thickness of up to 3 km. In the upper parts of the sequence, shallow marine sandstones and shales of Bashkirian age are developed (Alexeiev et al., 2017; Khristov, 1970; Mikolaichuk et al., 1995). In the Turuk segment of the trough, which is traced along the southern slopes of the Terskey Range (Fig. 2), lower Paleozoic deposits of different ages or Devonian monzonites are unconformably overlain by polymictic unsorted conglomerates (up to 250 m), which along strike are often replaced by arkose sandstones and gravelstones. The overlying thin-layered sandstones and siltstones are identified as the Turuk Formation with a thickness of 1000-1300 m. The gray-green color of the rocks predominates, rarely lilac and brown. The sequence of the formation is completed by a horizon of dark gray shales with intercalations of pelitomorphic limestones. Based on a few finds of brachiopods and floristic remains, the age of terrigenous deposits is estimated as Late Visean (Dzhenchuraeva et al., 2015; Mikolaichuk et al., 2008).

Above, with a gradual transition, carbonate deposits of the Ayusai Formation occur. Black clayey limestones (40 m) are overlain by gray massively layered organogenic limestones with remains of brachiopods and corals, alternating with light gray massive crinoid marbled limestones or dark gray dolomitic limestones (400-580 m). In the upper part of the formation, the role of terrigenous deposits increases. Dense greenish-gray calcareous siltstones appear. Dark gray thinly bedded calcarenites occur above, alternating with brachiopod limestones (300-500 m). The sequence of the formation is completed by black carbonaceous limestones interbedded in equal amounts with calcareous siltstones (450-550 m). The total thickness of the formation varies within 1150-1600 m. The Late Visean - Serpukhovian age of the Ayusai Formation is substantiated by numerous collections of brachiopods and foraminifers (Dzhenchuraeva et al., 2015; Mikolaichuk et al., 2008).

4.3.2 The Tyup trough is superimposed on Early Paleozoic granitoids and Early-Middle Devonian volcanic rocks in the eastern part of the Issyk-Kul massif. It can be traced in a northwestern direction, plunging under the Cenozoic deposits of the Issyk-Kul depression. Sedimentation within the trough proceeded against the background of repeated reactivation of subparallel faults of northwestern strike, which was reflected in the thicknesses and facies of the Late Devonian, Early Carboniferous, and Permian deposits (see Fig. 2, Fig. 7A), (Galitskaya-Gladchenko, 1958; Knauf, 1972). The southwestern side of the trough is filled with gravel-pebble coastal-marine deposits devoid of organic remains, which presumably correspond to the Late Devonian Kyzyldzhar Formation (Galitskaya-Gladchenko, 1958; Mikolaichuk et al., 2008).

To the northeast, in the Kopyl Range, Silurian granites and coarse clastic deposits of the Kyzyldzhar Formation with unconformity and basal conglomerates up to 15 m thick are overlain by terrigenous deposits reaching 1250–1650 m in thickness, which are identified as the the Kopyl Formation (Mikolaichuk et al., 2008). Its lower part is represented by dark gray and black thinly bedded sandstones and siltstones with numerous plant remains. The upper part is dominated by arkose and essentially quartz sandstones of brown and pinkish-brown color. Based on the few finds of foraminifera and remains of terrestrial flora, its age is determined as Tournaisian-Visean (Chabdarov and Sevastianov, 1971; Skrinnik and Esmintsev, 2008).

Above lies the Kokpak Formation, which differs from the underlying deposits in the appearance of limestone and calcarenite interbeds in the sequence. The thickness of the deposits varies within 1500-1700 m. The fauna of brachiopods and foraminifers was collected throughout the sequence, which makes it possible to date the Kokpak Formation to the Late Visean and the entire Serpukhovian (Chabdarov and Sevastianov, 1971; Galitskaya-Gladchenko, 1958; Skrinnik and Esmintsev, 2008). Predominantly terrigenous deposits are built up by the Kokdzhar Formation with a gradual transition. The latter is composed of alternating light gray pelitomorphic and organogenic limestones and dolomites with rare interlayers of arkose sandstones. Up the sequence, the role of dolomites increases. The maximum thickness of the described deposits reaches 530 m. Numerous collections of foraminifers characterize the Early Bashkirian age of host rocks (see Fig. 7A), (Dzhenchuraeva and Getman, 2019). The sequence is further built up by the Tyup Formation (180-250 m), composed of red-colored conglomerates, gravelstones and sandstones, among which lenses and interlayers of limestones appear in the upper part. To the northeast, in the middle reaches of the Karkara River, red-colored conglomerates of the Tyup Formation overlie Silurian granites transgressively, where their thickness does not exceed 30 m (see Fig. 7B).

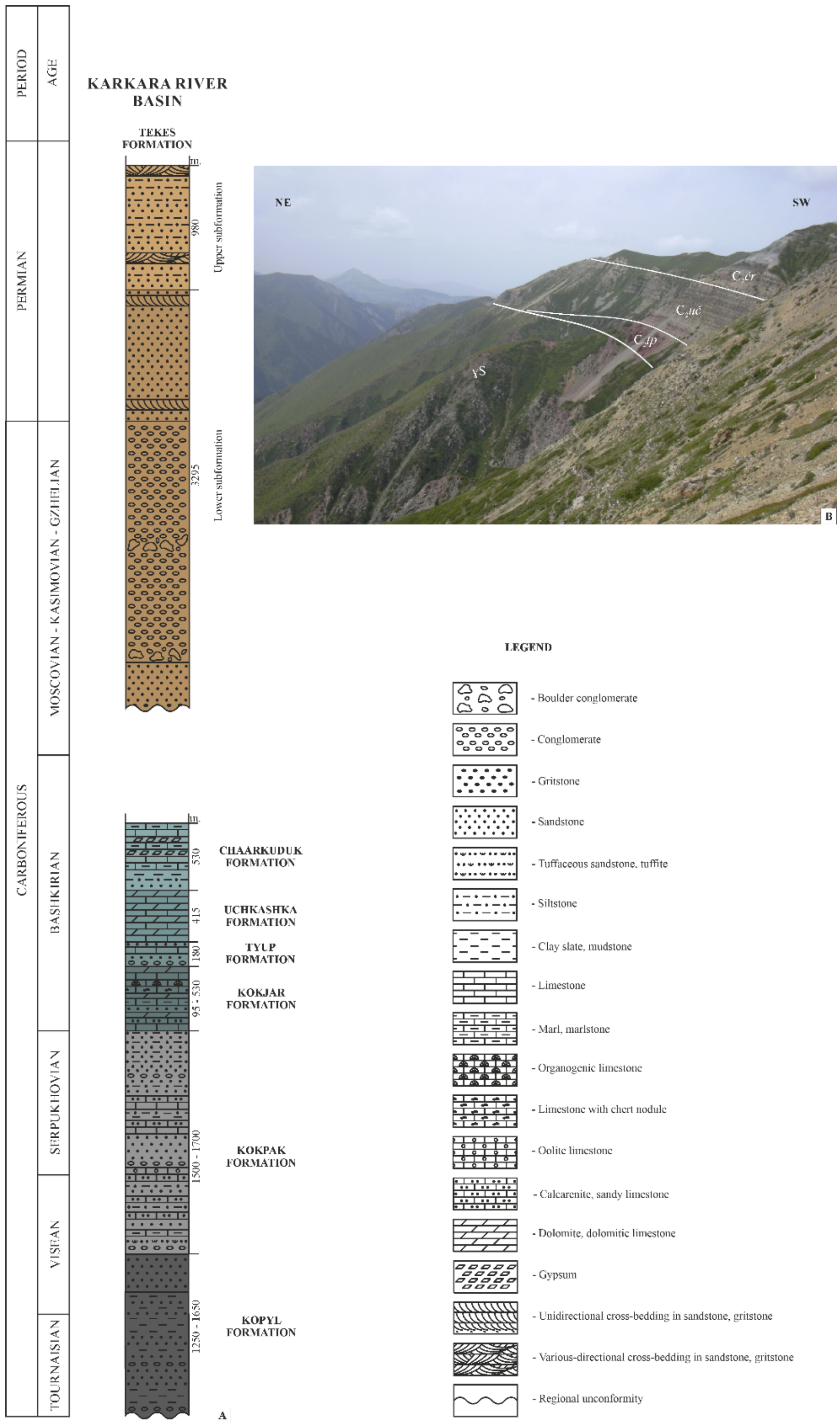

Fig. 7. Carboniferous and Permian deposits of the Tyup trough in the basin of Karkara River: 7A - Stratigraphic column, compiled according to (Dzhenchuraeva and Getman, 2019; Esmintsev, 2000; Galitskaya-Gladchenko, 1958; Skrinnik and Esmintsev, 2008); 7B - Transgressive overlay of red-colored conglomerates of the Tyup Formation on Silurian granitoids on the left side of the Karkara River.

Above lies the Uchkashka Formation of beige thick-layered limestones and dolomitic limestones (110-415 m) and the Chaarkuduk Formation, represented by interbedded variegated (brown, blue, green) sandstones, siltstones, mudstones, light gray marls and limestones with interlayers of dirty gray, white and pink farinaceous gypsum, conformably overlying the deposits of the Uchkashka Formation. Near the Chaarkuduk pass, the deposits of the formation reach a maximum thickness of 530 m. A rich complex of Early Bashkirian foraminifers was collected throughout the sequence, which belong to the zones: Plectostaffella bogdanovkensis - Pseudostaffella praegoskyi, (Dzhenchuraeva et al., 2015; Dzhenchuraeva and Getman, 2019; Galitskaya-Gladchenko, 1958).

The sequence of the Tyup trough ends with the Tekes Formation, which overlies with unconformity both the Lower Carboniferous and Lower Bashkirian deposits in the Tyup-Tekes interfluve (see Fig. 2). The lower subformation is represented by red-colored conglomerates and sandstones, the upper one by variegated siltstones and sandstones (Esmintsev, 2000). At the base of the lower subformation lies a unit of red-colored medium-coarse-grained arkose and quartz sandstones with lenses of gravelites and conglomerates 200-600 m thick. Cross-bedded textures are often found. Up the sequence, there are unevenly sized pebble, often boulder, conglomerates with lenses and cross-beds of sandy-gravelites (1000-1900 m). They are built up with unevenly grained arkose sandstones (1000-1800 m), in which, along with parallel-bedding, both uni- and multidirectional cross beddings are observed. Interlayers and lenses of gravelstones, small-pebble conglomerates, as well as limestones are found among sandstones. The upper subformation conformably, with a gradual transition, overlies the lower one and is mostly represented by gray, greenish-gray and crimson sandstones, siltstones with sporadical interlayers of gravelstones and limestones. Multidirectional crossbedding is observed in sandstones with a thickness of cross-bedded series of a few centimeters. The incomplete thickness of the described deposits is 635-980 m. Early Bashkirian foraminifers and algae were identified in pebbles from the lower subformation, and in the upper subformation, Permian palynological complexes were identified and flora remains were collected, based on which the Moscow-Permian age is accepted (Dzhenchuraeva and Getman, 2019; Esmintsev, 2000; Skrinnik et al., 1998).

By the nature of sedimentation and thickness distribution, the Tyup trough resembles the Givetian-Early Carboniferous grabens of the Sarysu-Teniz watershed, the distinguishing feature of which is compensated shallow-water terrigenous-carbonate sedimentation, with a contrasting distribution of sediment thickness, varying within 600–4000 m. Their appearance is explained by the formation of extension structures in the places of the sharpest bend of the Kazakh orocline (Daukeev et al., 2002; Degtyarev, 2012; Levashova et al., 2012).

4.4 The Balkhash-Yili volcano-plutonic belt was initiated and formed during the bending of the Kazakh orocline, unconformably overlying the Middle Paleozoic turbidites and tuffaceous-terrigenous sequences of the Dzhungar-Balkhash Hercynides and the underlying Caledonian formations (Degtyarev, 2012; Levashova et al., 2012; Ryazantsev, 2001; Wang et al., 2007; Windley et al., 2007). It should be noted that if the Silurian and Devonian formations of the northern branch of the orocline were turned around 160-190° clockwise, the turn of the Carboniferous deposits of the Balkhash-Yili belt did not exceed 40° to the same direction. In the Permian, the configuration of the Kazakh orocline remained virtually unchanged (Levashova et al., 2012; Wang et al., 2007).

Within the territory under consideration (Fig. 1B, C; Fig. 2), the Carboniferous and Permian formations of the Balkhash-Yili belt are traced along the northwestern flank of the FTDS, forming the southern branch of the orocline, the orientation of which remained unchanged throughout the entire Carboniferous and Early Permian time (Levashova et al., 2012). Their exposures on both sides of the Kazakh-Chinese border are reliably correlated with each other.

On the territory of Kazakhstan, the most complete sequences of the southern branch of the Balkhash-Yili belt are described in the Ketmen Range (Fig. 1). Tournai-Lower Visean deposits, up to 3000 m thick, are identified as the Ketmen Series. Terrestrial volcanic rocks of basalt-andesitic composition up the sequence are replaced by rhyolites, dacites, their tuffs and ignibrites. In the sandy-siltstone interlayers present among the volcanics, spore-pollen complexes and remains of the terrestrial flora of the Tournai-Lower Visean age were established. They are overlain, with erosion and a horizon of polymictic conglomerates at the base, by organogenic limestones of the Kungei Formation (up to 1000 - 1200 m) of the Upper Vizean-Lower Serpukhovian that occasionally includes horizons of ash tuffs. The Kungey Formation is built up by gray-colored terrigenous deposits of the Dalashik Formation with a thickness of 800 - 2000 m with subordinate horizons of tuffites and limestones, characterized by brachiopods and goniatites of the Upper Serpukhovian-Lower Baskirian. (Chakabaev et al., 1981; Skrinnik and Esmintsev, 2008).

East of the Chinese state border, in the Wusun Range, Early Carboniferous volcanogenic deposits are described under the name of the Dahalajunshan Group. Here, early Carboniferous volcanics of the calc-alkaline and alkaline series overlie the Mesoproterozoic metamorphites with unconformity. The lower part of the sequence is dominated by felsic volcanics and their tuffs interbedded with terrigenous-carbonate deposits characterized by the Tournaisian fauna. At the upper part of the Dahalajunshan Group, a homodromous succession of volcanic deposits is observed: basalts, andesites, trachyandesites, and dacites. According to U-Pb dating of zircons, several eruptive events with ages of 355-350 Ma, 337 Ma, and 325 Ma are identified in this part of the rock sequence. The thickness of volcanic deposits along the Tekes sequence reaches 7500 m. The volcanics are overlain with erosion by the marine terrigenous-carbonate deposits of the Akeshake Formation, with Visean corals and brachiopods (Su et al., 2022, 2018; Xia et al., 2004).

The Early Carboniferous volcanic stage ended with intense tectonic deformations of stratified deposits (Su et al., 2022), and the intrusion of the Late Carboniferous Belbulak complex, composed, in the Ketmen Range, of large-medium crystalline pinkish-gray biotite and biotite-hornblende granites (Chakabaev et al., 1981), which marks the end of the collision of the Katyrasan-Kotanemel volcanic arc and the Kazakhstan paleocontinent, identified as the Saurian folding (Tevelev, 2001). Chinese researchers, however, believe that the Early Carboniferous volcanics of the Wusun Range and the sedimentary rocks associated with them represent a back-arc structure (Su et al., 2022).

The granitoids of the Belbulak complex and volcanic rocks of the Lower Carboniferous are overlain with angular unconformity by terrestrial basalts, andesite-basalts, and trachyandesites of the Degeresk Formation (up to 400 m). The Lower Bashkirian age of the latter is based on a palynological complex established in terrigenous layers present among volcanics and not exceeding 10% of the volume of the formation. The Late Paleozoic sequence is completed by the Kugalinskaya Formation (200-950 m) composed of lacustrine predominantly terrigenous deposits containing numerous flora remains and palynological complexes of Late Carboniferous and Early Permian age. The upper part of the formation is composed of brown, lilac-pink tuffs, tuff lavas, and dacitic and rhyolitic ignimbrites (Chakabaev et al., 1981; Skrinnik and Esmintsev, 2008). In the Wusun Range, they are correlated with alkaline and calc-alkaline bimodal volcanics of the Late Carboniferous Yishijilike Formation (which include basalts, basaltic trachy-andesites, dacites and rhyolites), with a U-Pb zircon age of 322 to 313 Ma (Su et al., 2022, 2018). The Yishijilike Formation is unconformably overlain by the Permian Wulang conglomerates, indicating the completion of the Andean-type continental marginal belt (Su et al., 2022, 2018; Tevelev, 2001).

To the south, in the Kopyl and Nalati Ranges (see Fig. 2), the volcanic rocks of the Ketmen and Dahalajunshan Groups unconformably overlie formations and intrusive complexes of Precambrian, Early Paleozoic, and Silurian age, whereas their thickness is reduced to 1000-1350 m. The Paleozoic sequence is completed by the carbonate deposits of the Kungei and Akeshake Formations (700–1600 m), transgressively overlying the Early Carboniferous volcanic rocks and underlying them Early Paleozoic and Precambrian deposits (Mikolaichuk et al., 2008; Skrinnik and Esmintsev, 2008; “XBGMR,” 1981).

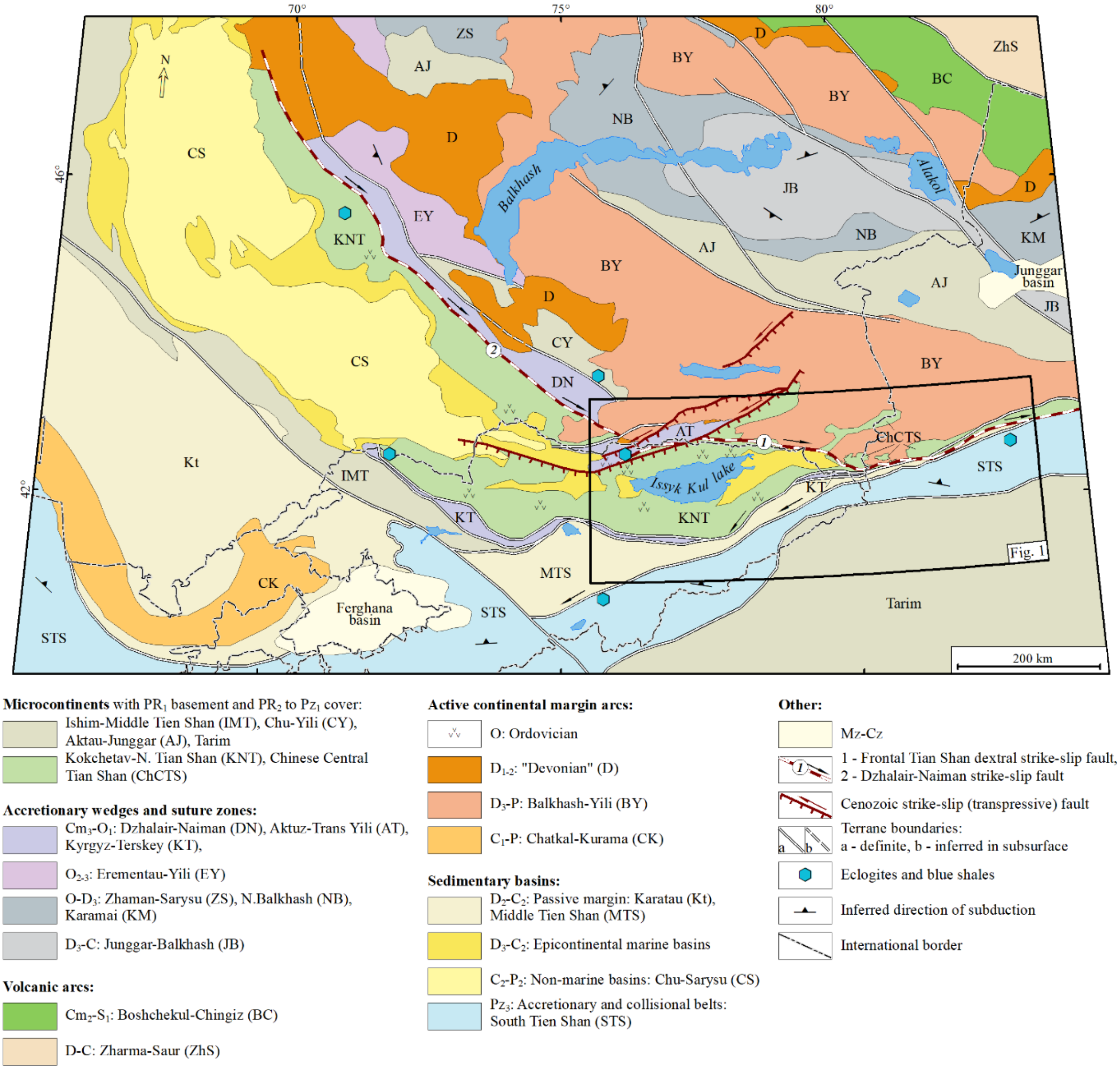

Fig. 8. Tectonic scheme of Paleozoic Southern Kazakhstan and Tianshan, modified after (Windley et al., 2007; Kröner et al., 2011a)

5 Conclusions

1. Comparing the structural features of the border regions of Kyrgyzstan, Kazakhstan and Xinjiang suggests that the structures of the Kyrgyz Middle and most of the Northern

Tianshan, including the superimposed Middle-Late Paleozoic troughs, cannot be traced to China, but are successively cut and displaced along the FTDS.

2. Virtually every publication on the Narat Range and adjacent areas is completed with a geodynamic reconstruction based on the petrological characteristics of the igneous rocks, with an assumed subduction under the Chinese Central Tianshan from both the Tarim and/or the Dzungaria. And only in a few works (Huang et al., 2020; Xiao et al., 2013) an attempt is made to take into account the Kazakh orocline in paleoreconstructions, the northeastern branch of which turned out to be 160-190° rotated relative to the southwestern branch during the Middle-Late Paleozoic (Degtyarev, 2012; Levashova et al., 2012; Wang et al., 2007).

But we consider these reconstructions of the Kazakh orocline incomplete since they do not account for the subsequent strike-slip displacements. Within the domain which inherited the folded structures of the Kazakh orocline (Central Kazakhstan and Chinese Central Tianshan,), first dextral strike-slips appeared in the Late Permian - beginning of the Triassic (Charvet et al., 2011; Chitalin, 1996, 1991; de Jong et al., 2009; Lin et al., 2009; Wang et al., 2010; Xiao et al., 2013), whereas the territory of the Kyrgyz Tianshan at the same time was dominated by the sinistral strike-slips (Bazhenov et al., 1999; Bazhenov and Mikolaichuk, 2004; Biske, 1996; Burtman, 2006). The latter were reactivated at the latest stage of tectonic development (Bachmanov et al., 2008; Bazhenov and Mikolaichuk, 2004; Burtman, 2012; Macaulay et al., 2014, 2013; Morozov et al., 2014; Rolland et al., 2020; Selander et al., 2012).

3. The tectonic reduction of most of the structural units of the Kyrgyz Middle and Northern Tianshan took place along the FTDS which manifests itself at the collision boundary of two structural domains characterized by differently directed mass movements. The kinematics of the junction of the "dextral domain" of the Chinese Central Tianshan with the "sinistral domain" of the Kyrgyz Tianshan is similar to the interaction of oblique boundaries of convergent lithospheric plates (Díaz-Azpiroz et al., 2016), along which tectonic erosion of adjacent geological complexes prevails (Safonova and Khanchuk, 2021).

4. The continuation of the FTDS within the limits of the Southern and Central Kazakhstan is apparently the Dzhalair-Naiman dextral strike-slip (see Fig. 8), with which it seems to have been a single structure before it was broken and displaced relative to it in the Cenozoic along sublatitudinal transpressional faults that control the formation of the northern ranges of the Kyrgyz Tianshan (Kendyktas, Trans-Yili and Kungei Ranges) on the border with the Yili Depression (Grützner et al., 2019, 2017; Selander et al., 2012).

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Table 1 U-Pb zircon ages of intrusive and metamorphic complexes within the Terksey, Sarydzhaz and Kopyl Ranges

Sample no.	Latitude	Longitude	Age in Ma	Rock type	Complex	Laboratory, method	Reference
7TS304	42.31024	79.64671	2332±4	Migmatized gneiss	Kuilyu	Beijing, SHRIMP II	Kröner et al., 2017
1433	42.427156	80.124926	1075±34	Gneiss	Sarytor	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008
36-83, 77-87, 77-87/1-4	42.457807	79.407524	526±34	Quartz diorite	Central Turuk	Institute of Geology, Bishkek, TIMS	Kiselev, 2014
277	42.484301	80.087052	440±4	Granodiorite	Aktash	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008
13573	42.604014	80.002831	441±5	Granite	Aktash	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008
1233	42.539317	79.305353	412±4	Granite	Alama	Institute of Geology, Bishkek, TIMS	Severinov, 1990; cited in Mikolaichuk et al., 2008
11432-1, 11432-3, 11432-4	42.458533	80.129215	407±5	Quartz monzodiorite, granosyenite	Sauruksai	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008
1211/1-4, 13042, 13571	42.424622	80.113428	376±8	Monzodiorite, granosyenite	Donarcha *	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008
MAV90/07	42.337770	80.208713	336±3	Granite-gneiss	Sarykoinou	Beijing, SHRIMP II	Kröner et al., 2009; Mikolaichuk et al., 2008

1-1	42.343107	80.192371	300±4	Granite	East Sonkul	KazIMS, Almaty, TIMS	Esmintsev, 1989; cited by Mikolaichuk et al., 2008

Note:
* Donarcha complex is represented by small bodies and is not shown on geological maps

Table 2 U-Pb zircon ages of the Nalati Range

Sample no.	**Latitude**	**Longitude ***	**Age in Ma**	**Rock type**	**River or *Pluton***	**Laboratory, method**	**Reference**
DV44 - DV48	42.633076	80.5817003	516±7.4	Basalt	Muzhaerte River	Beijing, SHRIMP	Qian et al., 2009
08ZS1-1	42.71953	81.054538	497±5.9	Biotite monzogranite	Akeyazi River	Northwest University, China. LA-ICP-MS	Xu et al., 2013
BK7	42.638357	81.363404	479±2	Granite	Bikai River	Beijing, LA-ICP-MS	Gao et al., 2009
DV49	42.612044	80.5869455	470±12	Diorite	Muzhaerte River	Beijing, SHRIMP	Qian et al., 2009
W8034	42.4490319	80.8688832	453±4	Mylonitic monzodiorite	***Chagawuzi mylonitic pluton***	Beijing, LA-ICP-MS	Gou and Zhang, 2016
D1011-D1012	42.514046	80.660447	446-436	Quartz monzonite	Muzhaerte River	Beijing, LA-ICP-MS	Gou and Zhang, 2016
D1021	42.526352	80.650791	443±3	Quartz monzonite	Muzhaerte River	Beijing, LA-ICP-MS	Gou and Zhang, 2016
XT17	42.564782	80.7036161	437±1	Hornblende granodiorite	Muzhaerte River	Beijing, LA-ICP-MS	Long et al., 2011
08ZS2-1	42.74722	81.062355	429.2	Gabbro	Akeyazi River	Northwest University, China. LA-ICP-MS	Xu et al., 2013
BK15	42.613732	81.315147	419±2	Granodiorite	Bikai River	Beijing, LA-ICP-MS	Gao et al., 2009

BK14	42.606064	81.306973	413±1	Granite	Bikai River	Beijing, LA-ICP-MS	Gao et al., 2009
AK8	42.605725	81.105128	409±1.6	Diorite	Akeyazi River	Beijing, LA-ICP-MS	Long et al., 2011
BK13	42.594187	81.302388	401±1	Granite	Bikai River	Beijing, LA-ICP-MS	Gao et al., 2009
AK 224 Zircon core	42.632691	81.095682	410±3	Granodioritic gneiss	Akeyazi Valley	Beijing, LA-ICP-MS	Xia et al., 2014 a; Xia and Zhang., 2021
AK 224 Zircon rim	42.632691	81.095682	401±3	Granodioritic gneiss	Akeyazi Valley	Beijing, LA-ICP-MS	Xia et al., 2014 a; Xia and Zhang., 2021
X06-zircon core	42.4812151	80.825406	399±4	Migmatite (melanosome)	Muzhaerte River	Beijing, LA-ICP-MS	Xia et al., 2014 a; Xia and Zhang., 2021
X06-zircon rim	42.4812151	80.825406	273±3	Migmatite (melanosome)	Muzhaerte River	Beijing, LA-ICP-MS	Xia et al., 2014 a; Xia and Zhang., 2021
W8024	42.4904006	80.78287767	393±7	Metapelite	Huotanbulake River	Beijing, LA-ICP-MS	Gou et al., 2015
WQ003	42.4863652	80.8276069	482±19; 366±10; 282±17	Metapelite	Muzhaerte River	Beijing, EMP monazite dating (U–Th–Pb)	Gou et al., 2015
W8028, W8037	42.458158	80.8541804	333-326	Gneissic granodiorites	***Changawusi***	Curtin University, Australia. SHRIMP-II	Gou et al., 2012
W8027, W8206	42.521032	80.7872674	294-293	Granodiorite	***Alasan***	Beijing, LA-ICP-MS	Gou et al., 2012
no number	42.487389	80.6601527	299±5	Anatectic migmatites (granites) **	Dongdeguli River	Beijing, LA-ICP-MS	Xia and Zhang., 2021

W8011	42.4943404	80.8211962	275±3	Anatectic migmatites (granites) **	Muzhaerte River	Beijing, LA-ICP-MS	Gou et al., 2015
W8015, W8017	42.4927340	80.7759197	266±13 278±3	Anatectic migmatites (granites) **	Huotanbulake River	Beijing, LA-ICP-MS	Gou et al., 2015
X07	42.4812151	80.82540595	273±3	Anatectic migmatites (Granitic vein) **	Muzhaerte River	Beijing, LA-ICP-MS	Xia et al., 2014 a
XT18	42.521032	80.7872674	247±0.88	Hornblende granodiorite	***Alasan***	Beijing, LA-ICP-MS	Long et al., 2011
08ZS3	42.743972	81.058083	434±6;425±5; 412±5 **Peak values: 421**	Detrital zircons	Akeyazi River	Beijing, LA-ICP-MS	Ren et al., 2011
08ZS4	42.66733	80.5793611	488±5;430±5 268±3 **Peak values: 422, 290**	Detrital zircons	Muzhaerte River	Beijing, LA-ICP-MS	Ren et al., 2011
08ZS5	42.69028	80.279889	478±7.4;461±5; 325±4 **Peak values: 475, 345**	Detrital zircons	Kayintemuzhate River	Beijing, LA-ICP-MS	Ren et al., 2011

Notes:
* The coordinates are obtained by a graphical method from the figures given in the publications
** Migmatites as small bodies are not shown in Fig. 2