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Geology, tectonics and magmatism of the Northern Tien Shan

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ABSTRACT VOLUME

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Content

Geology and tectonics of Northern Kyrgyz Tien Shan

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The Central Asian Orogenic Belt (CAOB) is the world largest accretionary orogens on Earth, that had a long accretionary history of up to 800 million years, beginning in the Tonian by the opening and widening of the Paleo-Asian Ocean (Zonenshain et al., 1990) and ending in the collision of the Siberian, Tarim and North China cratons and the younger Kazakhstan continent in late Permian to early Triassic time. The orogen consists of several distinct branches of which the Tien Shan is one of the major belts, and covers a vast terrain in Uzbekistan, Kyrgyzstan, Kazakhstan and China. The Tien Shan orogen is a perfect laboratory for understanding the geodynamic evolution of the western CAOB.

The Kyrgyz North Tien Shan (NTS) is located in the southwestern CAOB. It represents an early Paleozoic accretionary collage built upon a Precambrian basement. That collage has a complex fold-and-thrust structure and includes fragments of Precambrian microcontinents and Early Paleozoic oceanic and island-arc ophiolites. The basement of the NTS consists of Meso- to Neoproterozoic gneisses and supracrustal rocks assigned to the North Tien Shan microcontinent. The metasedimentary strata and granite–gneisses crop out in the Makbal and Burkhan anticlinoria in the western part of the Kyrgyz Range, south of Issyk-Kul Lake. All those units were amalgamated during several accretionary events during the Cambrian and Ordovician and underwent further reworking in island-arc and collisional settings during the Middle and Late Paleozoic. The whole structure of the collage was strongly folded and uplifted during the Cenozoic as a result of the India-Eurasia collision. The NTS is separated from the Middle Tien Shan by the Nikolaev Line. The NTS microcontinent, as well as other microcontinents in the western CAOB, was probably rifted off the Rodinia supercontinent in late Neoproterozoic early Cambrian time, which breakup formed an oceanic basin surrounded by ensimatic active margins with back-arc basins (Cambrian-early Ordovician?), ensialic active margins (middle-late Ordovician), and passive margins.

The NTS microcontinent is bounded by the Djalair-Naiman and Kyrgyz-Terskey ophiolite suture zones in the north and south, respectively. The ophiolites, oceanic and supra-subduction, were originated in the Terskey Ocean and at its Pacific-type active margins. Fragments of a Cambrian-Ordovician magmatic arc have been found and identified on a distance of more than 1000 km within a relatively narrow zone extending from the western Kyrgyz Range to the Chinese Central Tien Shan. The arc magmatism ceased in the Late Ordovician after the closure of the Terskey Ocean and collision of the North Tien Shan microcontinent with the Aktau-Junggar microcontinent. The Kyrgyz-Terskey ophiolite suture zone consists of Cambrian ophiolites, early Ordovician magmatic and sedimentary rocks of oceanic origin and middle Ordovician flysch and volcanogenic-sedimentary formations at the southern flank of the NTS. Previously, these rocks were interpreted either as an independent oceanic arc that docked to the southern margin of the NTS microcontinent in the late Cambrian or Early Ordovician, or as the southern parts of the NTS continental arc, locally extending into the back-arc basin. The oldest arc volcanic sequences occur in the central and eastern parts of the KT zone in the Kapkatas and Terskey ranges. In the Sultansary area of the Kapkatas Range, the lower part of the section consists of tholeiitic arc-related massive and amygdaloidal pillow basalts of the Beltepshi Fm. Upward the section they change to weakly differentiated calc-alkaline volcanic rocks of the Sultansary Fm., represented by agglomerate and lapilli tuffs, andesites, and dacites, intercalated with tuff breccias, tuffaceous sandstones, and limestone horizons in the upper part of the section. The geochemical characteristics indicate that the volcanic rocks of the Beltephsi and Sultansary fms. formed in a supra-subduction setting whereas positive whole-rock εNd values of +5.3 and +3.7 for basalts and andesites, respectively, indicate a juvenile magmatic source (Alexeiev et al., 2023).

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Alexeiev, D.V., Kröner, A., Kovach, V.P. et al., 2019. Evolution of Cambrian and Early Ordovician arcs in the Kyrgyz North Tianshan: Insights from U-Pb zircon ages and geochemical data. Gondwana Research 66, 93–115.

Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: a plate tectonic synthesis. Geodynamic Monograph. American Geophysical Union, Washington, Geodynamics Series 21, 242 p.

Geomorphology and Quaternary Geology of the Issyk-Kul Basin

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Issyk-Kul is a terminal lake in the Kyrgyz Republic in Central Asia. The lake has a length of 182 km and a width of up to 60 km, an area of 6236 km^2 and a volume of 1736 km^3. It is the second-largest mountain lake in the world, the third-largest brackish-water lake (salinity 6g/L), the seventh-deepest lake (maximum depth 668 m), and the tenth-largest lake by volume (Podrezov et al., 2020). The lake is located in a tectonic basin between the Terskey-Alatoo and Kungey-Alatoo Ranges of the Tien-Shan Mountains. The oldest Mesozoic sediments in the basin were uplifted during the Cenozoic collision of the Indo-Australian and Eurasian tectonic plates, which activated its fault tectonics; the region is now very seismically active. The sediment accumulation in the lake probably began in the Miocene, and the lake has its current appearance since mid-Pleistocene (Trofimov, 1990). The current water level of Lake Issyk-Kul is referenced to 1606 m a.s.l. on the topographic maps. The lake level change histor is known from the late Pleistocene, when the highest lake level was at 1640 m a.s.l.. The lake dropped to 110 m from the modern level at the end of the late Pleistocene. The lake became high in the Holocene with the highest stands 8.3-6.9 and 1.4-1.2 ka BP, while the level could not be higher than 1620 m a.s.l. – the Chu River outflow from the basin. The most recent rise occurred around the XVIII century AD according to historical maps, and the lake level has been steadily declining since then.

Our study contributes to a better understanding of the latest transgression of the Issyk-Kul, whose traces are represented by a wave-erosion scarp at an altitude of 1619 m a.s.l. and 10-13 accumulative coastal bars on the beach. Two sites were studied in detail on the south-eastern and south-western shores of the lake in 2021 (see Figure). Site 1 gave us opportunity to date the mollusk shells collected from the oldest (10), middle (5), and pre-modern (2) shorelines. The calibrated ages (median values) were 1337, 1420, and 1772 AD, respectively. The effect of old carbon (freshwater reservoir effect) of Issyk-Kul has been estimated by dating shells of dead mollusks from modern shoreline and carbonates precipitated on modern water plants; their ^{14}C ages are 94 ± 38 and 83 ± 40 BP, respectively. These dates are outside the IntCal20 (95 yrs BP) and MARINE20 (603 yrs BP) calibration curves. So we used 95-year value and the IntCal20 curve, which returned the calibrated age of 1835 AD. The value of 186 years (the difference between 2021 and 1835) was subtracted from the above dates to correct this effect. Thus, the adjusted ages are 1523 AD for the maximum of the last transgression, 1606 AD for the middle level of the transgression, and 1958 AD for the pre-modern shoreline.

Our new geochronological results paint the following picture of the latest transgression of Lake Issyk-Kul. The lake was lower than today in the Middle Ages and earlier times. We cannot reconstruct the rise of the level with certainty and assume that it was lower than 1600 m a.s.l. in the late XV century AD. The rapid, over 30-40 years, transgression to 1619 m a.s.l. led to flooding of populated shores and strong wave erosion formed the 10-m high above the coastal zone. The peak of the transgression was in the early XVI century AD and then the lake went into a regressive phase. The lake became eight meters lower during the next one hundred years and reached 1611 m a.s.l. in the early XVII century AD. The rate of the subsequent lowering was slower, and the lake reached 1608 m a.s.l. in the middle of the XX century AD. That is three meters of decrease took about 350 years. The rate of decrease by two meters in the last 65 years looks about the same as in the first stage of the regression.

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Podrezov, A.O., Ari J. Mäkelä, A.J., Mischke, S., 2020. Lake Issyk-Kul: Its History and Present State. In: Mischke, S. (ed), Large Asian Lakes in a Changing World. Natural State and Human Impact. Springer, Cham.

Trofimov, A.K., 1990. Quaternary deposits of the Issyk-Kul depression related to its tectonics. Proc. Acad. Sci. Kirghiz SSR, 1, 87–95 (in Russian).

Neoproterozoic tectonics, paleoenvironment and early life in the Yangtze Block, South China

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The correlation between Neoproterozoic tectonics, paleoenvironment and early life are crucial for understanding the evolution of the Earth's habitability. The Yangtze Block preserves plenty of essential records to investigate these topics. The early Tonian tectonics of the Yangtze Block was characterized by exterior spreading to its west and north, and coeval interior subduction along its eastern margin, resulting in the passive continental marginal basins on the western and northern margins, and arc-related basins along the eastern margin. In the middle Tonian, the long-term exterior subduction-accretion on the west and north resulted in numerous arc-type igneous rocks and associated clastic deposits. In the east, the continuous interior subduction generated an active continental margin, with back-arc and retro-arc basins filled with volcanic and clastic rocks, and finally led to the collision between the Yangtze and Cathaysia blocks at ca. 820 Ma. Some typical Neoproterozoic microfloras were flourishing. During the late Tonian, the exterior subduction generated the arc-related volcanic basins in the western and outer northern margins, while the interior post-collisional rifting resulted in a rift basin in the eastern margin, filled by shallow-marine to bathyal facies sediments. Influenced by the marginal volcanism, the paleoclimate was warm and humid in the early period, and transition to rather cold and dry in the late period. The microfloras remained the dominant paleontological taxonomy, but some macroalgal fossil fragments appeared. In the Cryogenian, along with termination of the exterior subduction, most parts of the Yangtze Block entered an extensional tectonics. Together with global paleoclimate cooling, the various tectonic backgrounds and paleogeographical frameworks of individual margins accumulated different glacial-interglacial sequences on the eastern, northern and western margins. These multi-stage deposits record paleoclimate cycles of cold-dry glacial periods and warm-humid interglacial periods. Subject to more extreme paleoclimate and paleoenviron- ment, early life was still dominated by microfloras (Monosphaeritae and Prismatomorphitae of Sphaer- omorphida) with minor macroalgal fossil fragments. During the Ediacaran, the entire Yangtze Block evolved into an extensional-subsidence tectonics, with carbonate platform (inner shelf and outer shelf) to abyssal-bathyal (slope-basin) facies gradually

developing from northwest to southeast. Episodic atmospheric and oceanic oxygenation events resulted in positive shifts in paleoclimate and paleoenvironment. The advantageous conditions induced several global Ediacaran biotas on the Yangtze Block, which are known as the prologue and first phase of the Cambrian explosion, including the Lantian, Weng'an, Miaohe, Shibantan and Gaojiashan biotas. The transition from the Ediacaran to Cambrian constitutes a critical inflection point in geological history, marking a co-evolution of organisms and paleoclimates that flourished by mutations. Appropriate external conditions made the early life further radiate, and the second and third phases of the Cambrian explosion were unveiled. They are represented by the Meishucun small shelly fossils (SSFs) on the western margin, and the Chengjiang biota and the contemporaneous Qingjiang biota on the western and northern margins of the Yangtze Block, respectively. Such manifestations indicate that the Cambrian explosion in the Yangtze Block was most likely related to the Neo- proterozoic subduction and continental arcs, which could provide sufficient nutrients for the later early life radiation.

HP-UHP metamorphic complexes of Kyrgyz Tien-Shan

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The Kyrgyz North Tien Shan (NTS) is located in the southwestern Central Asian Orogenic Belt. It represents an early Paleozoic accretionary collage built upon a Precambrian basement and later undergone deformations in middle-late Paleozoic and Cenozoic times (Bakirov, 1999). That collage has a complex fold-and-thrust structure and includes fragments of Precambrian microcontinents (the basement) and Early Paleozoic oceanic and island-arc ophiolites (Djalair-Naiman and Kyrgyz-Terskey suture zones). The basement of the NTS consists of Meso- to Neoproterozoic gneisses and supracrustal rocks assigned to the North Tien Shan (Issyk-Kul) microcontinent. The Mesoproterozoic rhyolite-basalt formations, black shales and schistosed granitoids, Neoproterozoic quartzites and metamorphic schists and lower Paleozoic volcanic and terrigenous formations crop out among numerous and voluminous Paleozoic granitoids (Bakirov et al., 2017; Orozbaev et al., 2010; 2015). The metasedimentary strata and granite–gneisses crop out in the Makbal and Burkhan anticlinoria in the western part of the Kyrgyz Range. All those units were amalgamated during several accretionary events during the Cambrian and Ordovician and underwent further reworking in island-arc and collisional settings during the Middle and Late Paleozoic. The whole structure of the collage was strongly folded and uplifted during the Cenozoic as a result of the India-Eurasia collision. The North Tien Shan is separated from the Middle Tien Shan by the Nikolaev Line. The North Tien Shan microcontinent, as well as other microcontinents in the western CAOB were probably rifted off the Rodinia supercontinent in late Neoproterozoic early Cambrian time, which breakup formed an oceanic basin surrounded by ensimatic (intra-oceanic) active margins with back-arc basins (Cambrian-early Ordovician?), ensialic (continental) active margins (middle-late Ordovician), and passive margins.

We studied eclogites and related high-pressure metamorphic rocks occur in the Aktyuz area, Zaili Range of the Northern Kyrgyz Tien-Shan, which are located in the south-western segment of the Central Asian Orogenic Belt. The Aktyuz area includes the Aktyuz Formation and the Kemin Series (Bakirov, 1978; Bakirov et al., 2003). The Aktyuz Formation consists mainly of pelitic and granitic gneisses containing lenses and layers of eclogite, garnet amphibolite, and amphibolite bodies. The Kemin Series includes the Kopurelisai, Kapchygai and Kokbulak Formations. The

Kopurelisai Formation consists of metagabbros, metabasalts, serpentinites and metapelites, and these are probably constituents of an ophiolite (Bakirov et al., 2003). The Kapchygai Formation is composed of basic migmatites, amphibolites, metagabbros, eclogites, serpentinites and talc schists. The Kokbulak Formation consists of pelitic and carbonaceous migmatites, pelitic gneisses, siliceous schists and marbles. The Kemin Series is intruded by granitic rocks ranging from Proterozoic to Lower Paleozoic in age (1296 ± 96 Ma, 743 ± 33 Ma and 532 ± 46 Ma; Kiselev, 1999).

Eclogites are preserved in the cores of garnet amphibolites and amphibolites that occur as boudins and layers (up to 2000 m in length) within country rock gneisses. The textures and the mineral chemistry of the Aktyuz eclogites, garnet amphibolites and country rock gneisses record three distinct metamorphic events. In the eclogites, the first medium-pressure and high-temperature metamorphic event of amphibolite/epidote-amphibolite facies conditions (T = 560-650°C, P = 4-10 kbar). The eclogites also record the second high-pressure and low-temperature metamorphism with a prograde stage passing through epidote-blueschist facies conditions (T = 330-570°C, P = 8-16 kbar) to peak metamorphism of the eclogite facies (T = 550-660°C, P = 21-23 kbar) and subsequent retrograde metamorphism to epidote-amphibolite facies conditions (T = 545-565°C and P = 10-11 kbar) that defines a clockwise *P-T* path. The third high-pressure and high-temperature metamorphic event is obtained from the garnet amphibolites and surrounding country rock gneisses. The peak mineral assemblage of the country rock gneisses indicates T = 635-745°C and P = 13-15 kbar. The three metamorphic events inferred for the Aktyuz high-pressure metamorphic rocks occurred in three distinct tectonic settings: i) metamorphism along the hot hanging wall at the inception of subduction, ii) subsequent subduction zone metamorphism of the oceanic plate and exhumation, and iii) continent-continent collision and exhumation of the entire metamorphic sequences.

Bakirov, A.B., 1978. Tectonic position of the metamorphic complexes in the Tien-Shan. Ilim, Frunze, 262 pp. (in Russian).

Bakirov, A., 1999. The evolution of Tien-Shan lithosphere. Proceedings of National Academy of Sci- ences, Kyrgyz Republic, pp. 3–14.

Bakirov, A.B., Tagiri, M., Sakiev, K.S., Ivleva, E.A., 2003. The Lower Precambrian rocks in the Tien Shan and their geodynamic setting. Geotectonics 37, 368–380.

Kiselev, V.V., 1999. U–Pb (po zirconam) geochronologiya magmaticheskih proyavlenyi Severnogo Tyan-Shanya. Kyrgyz Respublikasynyn Uluttuk Ilimder Akademiyasynyn Kabarlary, Special issue ‘‘Problemy geologii i geografii v Kyrgyzstane’’, 21–33.

Orozbaev, R.T., Takasu, A., Bakirov, A.B., Tagiri, M., Sakiev, K.S., 2010. Metamorphic history of eclogites and country rock gneisses in the Aktyuz area, Northern Tien-Shan, Kyrgyzstan: a record from initiation of subduction through to oceanic closure by continent–continent collision. *Journal of metamorphic Geology 28*(3), 317-339.

Orozbaev, R., Hirajima, T., Bakirov, A., Takasu, A., Suga, K., Yoshida, K., Sakiev, K., Bakirov, A., Hirata, T., Tagiri, M., Togonbaeva, A., 2015. Trace element characteristics of clinozoisite pseudomorphs after lawsonite in talc-garnet-chloritoid schists from the Makbal UHP Complex, northern Kyrgyz Tian-Shan. *Lithos 226*, 98-115.

Simulation analysis of 3D stability of a landslide with a locking segment: a case study of the Tizicao landslide in Maoxian County, southwest China

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Rock bridges, also known as locking masses in landslides, affect the three-dimensional (3D) stability and deformation patterns of landslides. However, it is always difficult to simulate rock bridges with continuous grid models in 3D landslides due to their discontinuous deformations. Tizicao landslide, located in Maoxian County, southwest China, is a typical landslide with a super-large rock mass volume of about 1388 × 104 m^3 and a locking segment. To explore a better rock bridge model used to simulate 3D stability and deformations of the Tizicao landslide, this study introduced three rock bridge models into the FLAC3D program, including the intact rock mass model (IRMM), the Jennings model (JM), and the contact surface model with high strength parameters (CSM-HSP). The CSM-HSP model was eventually used in the FLAC3D program to obtain the 3D deformation characteristics of the landslide. In addition, the two-dimensional (2D) stability of the Tizicao landslide was analyzed using the GeoStudio program. The simulation results indicate that the Tizicao landslide is generally stable under current conditions owing to the existence of the locking segment in its southern front. This inference is consistent with the field deformation and monitoring data. It was found that the general stability and local deformations of the landslide are influenced by the locking segment according to the com- parison between the 2D and 3D stability.

There was a linear relationship between the locking ratio and the factor of safety (Fos), which applied to the 2D stability analysis of the land- slides with a locking segment each, while there existed an approximate quadratic parabola suitable for the 3D stability of the landslides. Finally, this study analyzed the laws of the 3D Fos varying with the locking ratio and strength parameters of the locking masses and the sliding surface. Furthermore, it explored the advantages and disadvantages of the three rock bridge models in the simulation of the 3D stability of land- slides with a locking segment.

Gold deposits of Kyrgyzstan

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Kyrgyzstan is in the Central Asian region and completely composed by Tien-Shan mountain system. The geological structure of Tien-Shan is unique. Rocks of all ages from AR, PR up to modern and different geodynamic environment are occurred in such small territory (0.2 million sq. km). About 100 gold deposits are present in Kyrgyzstan, including several large deposits. The Kumtor deposit – one of them with 1000 tons of gold. Almost all deposits were formed generated in PZ and are formed in various geodynamic environments. Formation of most of deposits has a long and multistage character. To construct genetic models of the deposits we need to conduct a multiple-factor analysis of various data. There is the Copper-Gold Porphyry Ore Belt in the North Tien-Shan (Djenchuraeva et el., 2013). The largest gold-copper porphyry deposits are in the Kyrgyz ridge, which has latitude trend. Copper porphyry deposits of the island arc ($Є_3$-O_1) (Andash, Taldy-Bulak, Uzunbulak, Karakol etc.) are in the west part of ridge. Gold porphyry deposits of active continental margins (D-C) (Taldy-Bulak Levoberezhny etc.) are in the east part.

Taldybulak Levoberezhny (Au 115t) – gold-porphyry deposit is characterized by development of metasomatites of large volumes in ore zones and adjacent areas. There are 4 zones of the metasomatic column. Rear zone D is composed by feldspathic metasomatite. Zones B and C are main zones of the metasomatic column, since there are gold ore bodies here. Berezites and listvenites are in these zones, and quartz-tourmaline metasomatites are added in zone B. There are pyrite, chalcopyrite, rarely galena, sphalerite, arsenopyrite and others ore minerals.

Berezites (quartz+sericite+pyrite) and listvenites (quartz+carbonate+fuchsite) are gold-bearing metasomatites with gold grade from 0.1 to 2-5 ppm. Quartz-tourmaline metasomatites are developed in the monzo- diorites, they are formed after berezites and listvenites. Ore minerals are presented by pyrite and chalcopyrite. Gold grade is up to 15-20 ppm. Quartz-gold-sulfide mineralization and quartz-tourmaline veins with sulfides are formed at the last stages of the quartz-tourmaline metasomatic process. Frontal zone A consists of barren argillizites, which are on the exocontact of monzodiorite apical part. Barren quartz-carbonate veins are the latest hydrothermal products.

Gold of the I generation is in zones B and C, and gold of the II generation in zone B. The sulfides concentration in the ore ranges from 2 to 40%. Pyrite prevails; it is main mineral-concentrator for gold.

The established sequence ore-bearing metasomatite formations causes a line of trends. Temperature of homogenization and decrepitation of gas-liquid inclusions from quartz of these rocks is reduced from early to late formations. The chemical composition of inclusions is also naturally replaced in time. The quantity of gases and water decreases. Degasation of solutions take place. Barron quartz has less amount of gases. The basic part of gases is represented by CO_2 (60-95 %). The isotope composition of sulfide sulfur also has trend. The ore bodies contain is 2-4% pyrite. Mineralization is represented by native gold of I generation in quartz-feldspar metasomatites and beresites. It has rather high finest. Gold of II generation is connected with quartz veins with more lower finest. Gold grades reach up to 200 ppm, average gold grade is 9 ppm. Ore bodies have lens like form with thickness up to 30 м, and length up to 250 m. They were traced to the depth up to 300-400 m.

Andash, Taldy-Bulak (Au 150 t), Uzunbulak, Karakol – typical copper porphyry deposits, but gold mineralization is main metal here. The metasomatic model of this group is shown at the fig. 3. Gold is in propylite, phyllic metasomatite and argillizite.

Makmal (Au 80 t) – gold deposit in the skarns, generated at the post-collision tectono-magmatic activization in Permian. Host rocks are composed of limestones, dolomites with siliceous, siliceous-coal stratums and lenses (C_1t-v). Intrusion of granites was in the Permian period. Metasomatites and ore mineralization was formed during penetration of granite intrusion under influence postmagmatic solutions in the following sequence: albitites in granites, garnet-pyroxsen skarns with magnetite ore – at contact of intrusion, quartz-feldspar metasomatites with gold mineralization, which are developed in granites, dykes and skarns, greisens with Sn-W mineralization – in granites and skarns, berezites with gold mineralization – on granites. Hydrothermal processes is finished by adjournment gold-bearing and hungry quartz veins.

Kumtor gold deposit (Au 1000 t) - black shale hosted gold deposits is generated at the postcollision tectono-magmatic activization in Permian (Ivleva, Pak, 2014). The ore district is associated with a hanging wall of the NE Kumtor fault. Host rocks are composed of Jetymtau Suite (Vdz) containing siltstone, tilloids, carbonaceous siliceous shales, rhythmites of carbonate-shale and pyrite-microquartzite composition. The major ore-hosting formation is carbonaceous rocks with dispersed pyrite mineralization and chalcophile specialization. Gold mineralization occurs due to formation of various metasomatic rocks. There is the following sequence of metasomatites and mineral associations distribution:

1) pre-ore stage – sericitolites (quartz-micaceous association);

2) ore stage:

i) potassium feldspathoid;

ii) albitite;

iii) quartz-carbonate metasomatites;

3) post-ore stage – quartz-carbonate vein association.

The main ore mineral in all metasomatites is pyrite, its average concentration is 12%. Pyrite is a major mineral-concentrate of gold. The favorable coincidence of ore-generating processes of different geodynamic environments leads to the formation of polygenetic and polychronicle large gold deposits with coincidence different ore formations. In all deposits ore formation is accompanied by successive series of metasomatic altered rocks.

Djenchuraeva R., Pak N., Usmanov I., 2013. Deposit Types of Copper-Gold Porphyry Belt in the North Tien-Shan//Problems Ore genesis and geochemistry. Moscow. 76-84 (in Russian).

Ivleva E., Pak N., 2014. Model of formation of super large gold deposits Kumtor//Giant gold deposits in Central Asia. Almaty. 107-110 (in Russian).

Clastic terrigenous rocks in Pacific-type orogenic belts and their significance

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The subduction of oceanic crust and the formation of associated magmatic and sedimentary complexes on the Pacific-type convergent margins (PCM) are the most important processes in the geological history of the Earth. Magmatic arcs formed at PCM can be destroyed by the subduction or surface erosion (Scholl, von Huene, 2007). The destruction of supra-subduction igneous rocks and the transportation of eroded material into the fore-arc basin and deep-water trough leads to the formation of specific clastic rocks- greywacke sandstones. Such sandstones are almost identical in composition to the igneous rocks of the parental arcs and contain detrital zircons, the age of which corresponds to the time of supra-subduction magmatism. On the contrary, the sandstones of the continental arcs reflect in their composition an increase in the proportion of sialic sources and contain older detrital zircons than the associated subduction igneous rocks. In case of partial or complete disappearance of supra-subduction rocks due to subduction erosion or their hidden under thrusts, greywackes carry the most important information. If the geochemical characteristics of sandstones correspond to the average composition of the mafic and intermediate island-arc magmatic series, their isotopic composition corresponds to the juvenile crust (positive eNd(t) in whole-rock and eHf(t) in zircons), and the distribution of U-Pb ages of detrital zircons has a unimodal character, then the initial arc was intra-oceanic. If the composition of sandstones assumes the dominance of andesites and acidic differences in the sources area, their values of eNd(t) and eHf(T) have negative values, and the distribution of U-Pb ages of detrital zircons is polymodal, then the continental arc (or active continental margin) was most likely destroyed (Dickinson, Suczek, 1979). In the process of subduction and accretion, sandstones accumulating in the deep-sea trough are part of the accretionary prism along with rocks of oceanic origin.

In intra-continental orogens, such as the Central Asian Orogenic Belt (CAOB), the largest Phanerozoic orogen in the world, formed during the evolution and closure of the Paleo-Asian Ocean (Zonenshain et al., 1990), sandstones are part of accretionary complexes, and are also widely developed in sections of fore-arc and back–arc basins. Due to the complex structure of the CAOB the question of the nature (juvenile or recycled) and the balance of the crust is still debatable. The main obstacle in solving this issue is the process of erosion of island arcs composed of magmatic complexes with juvenile characteristics. This factor affects the balance of juvenile and recycled crust and its shift in favor of the latter, which can lead to erroneous interpretations.

U-Pb dating of detrital zircons and a comprehensive study of the composition of clastic rocks allows us to establish the nature of the parental magmatic arc. So the results of the study began to be brought quite accidentally and to a constant change in the data on U-Pb dating, including geochemical and isotope data, for a several regions of China, the Altai Mountains, Mongolia, Kyrgyzstan and Transbaikalia. At the same time, there are still practically no study considering the entire set of data on such rocks (geological, petrographic, geochemical, isotopic) (Safonova, Perfilova, 2023), although they play an important role in constructing paleotectonic reconstructions of the Pacific-type convergent margins.

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Dickinson W.R., Suchek K.A., 1979. Plate tectonics and sandstone composition. Bulletin of the American Association of Petroleum Geologists, 63(12), 2164-2182.

Safonova I., Perfilova A., 2023. Preserved and disappeared intraoceanic arcs of the Paleoasiatic Ocean: data from Kazakhstan. National Science Review 10(2), nwac215.

Scholl D. V., von Huene R., 2007. Recycling of the Earth's crust in modern subduction zones in relation to the past — problems of growth and preservation of the continental fundamental crust, geochemistry of the mantle and reconstruction of the supercontinent. Memoirs of the Geological Society of America, 200, 9-32.

Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: a plate tectonic synthesis. Geodynamic Monograph. American Geophysical Union, Washington, Geodynamics Series 21, 242 p.

Composition of the clastic rocks of Northern Kyrgyz Tien Shan

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The structure of the Tien Shan belongs to the southern part of the Central Asian Orogenic Belt, formed as a result of the evolution and closure of the Paleo-Asian Ocean (Zonenshain et al., 1990). The Kyrgyz part of the Tien Shan is traditionally divided into three tectonic segments, which are called the Northern, Middle and Southern Tien Shan. The Northern and Middle Tien Shan are separated by the Terskei-Karatau fault ("Nikolaev Line"). The Kyrgyz Northern Tien Shan is a part of the Kokchetav-North Tianshan active margin, which is represented by tectonically combined fragments of Precambrian crust with Early Paleozoic ophiolites, island-arc and metamorphic complexes combined in the Early Paleozoic and significantly processed island-arc and syn-collisional granitoid magmatism in the Ordovician-Silurian period. Clastic rocks were selected along the Kyrgyz range of the Northern Tien Shan at the Belogorka and Ala-Archa sites.

Petrographic description of clastic rocks has shown that they are characterized by a wide range of grain sizes from fine- to coarse-grained, the degree of roundness of fragments from angular to subangular, the sorting of clastic material is medium and low. Mono- and polycrystalline quartz, plagioclase, potassium feldspar, muscovite, biotite, fragments of volcanic, metamorphic and sedimentary rocks were identified in the thin-sections. Rutile, apatite and zircon are present as accessory minerals. Secondary changes are represented by the processes of chloritization and sericitization. According to the classification (Shutov, 1967), the rocks are feldspar-quartz and quartz-feldspar greywackes.

According to the concentrations of the major oxides, sandstones are characterized by an increased content of SiO_2 (72.9-84.0 wt. %) at TiO_2 values (0.3–0.5 wt. %), Al_2O_3 (5.2–10.6 wt. %), Fe_2O_3 (3.0–4.1 wt. %) and MgO (0.8–1.8 wt. %). For a detailed study of the composition of sandstones and rock characteristics in the source area, the petrochemical modules of Yudovich were calculated (Yudovich, Ketris, 2000). The studied sandstones are characterized mainly by low and medium values of AM (0.07–0.20), TM (0.03–0.06), HM (0.14–0.39), MM (0.09–0.57), increased values of FM (0.09–0.57) and high values of FM (0.60-2.35), which indicates increased ferruginosity and a predominantly weak degree of chemical weathering of the initial rocks. There is a direct relationship between FM and TM, which indicates that sandstones are sedimentary rocks of the first cycle, i.e. petrogenic. According to the classification diagrams of F. J. Pettijohn most of the sandstones are greywackes. Negative trends on TiO_2, Al_2O_3, Fe_2O_3, and MgO relative to SiO_2 are observed on Harker variational binary diagrams. Similar patterns are typical for igneous rocks of the island-arc origin. According to the values of the petrochemical indexes CIA and ICV, it was found that the studied sandstones are characterized by an immature nature and a low content of clay minerals. This confirms the conclusion that sandstones belong to immature sediments of the first sedimentation cycle.

The rare earth element spectra normalized by chondrite and multielement spectra normalized by primitive mantle are similar to similarly normalized spectra of PAAS (Post-Archean Australian Shales). The spectra of the distribution of the concentration of rare earth elements (REE) showed a predominantly negative Eu anomaly (Eu/Eu* = 0.62–0.89), close to that for PAAS (Taylor, McLennan, 1985). According to the values of the ratios ($(La/Yb)_n$ = 7.27–12.31), it can be assumed that the protoliths for most of the samples were intermediate and acidic rocks. On the multielement spectra, negative Ta-Nb anomalies are distinguished for all samples: $(Nb/La)_{pm}$ = 0.26-0.49, $(Nb/Th)_{pm}$ = 0.11-0.19. There is also a negative anomaly in Ti: $(Ti/Y)_{pm}$ = 0.15-0.82. Such characteristics are typical for island-arc igneous rocks.

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Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: a plate tectonic synthesis. Geodynamic Monograph. American Geophysical Union, Washington, Geodynamics Series 21, 242 p.

Shutov, V.D., 1967. Classification of sandstones. Litologia i Poleznye Iskopaemye 5, 86-102. (in Russian)

Yudovich Y.E., Ketris M.P. Fundamentals of lithochemistry. St. Petersburg: Nauka, 2000. 479 p. (in Russian)

Taylor S.R., McLennan S.M., 1985. The Continental Crust: Its Evolution and Composition. Blackwell, London, 312 p.

Statistics and comparison of ancient and modern glaciers in Gongga Mountain area, Hengduan Mountains, Sichuan, China

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This study is a part of a project aimed to reconstruct late Pleistocene glaciation in mountain systems of Central Asia. We investigate local centers of glaciation in test regions in order to justify our elaborated GIS technology.

The Gongga Mountain represents a center of glaciation in the Hengduan Mountains – a structure separating the eastern side of the Tibet and Himalaya high-mountain region and the Sichuan Basin. The Hengduan Mountains consist of many mountain ranges stretching from north to south. Their formation was the result of a collision between India-Australia and Eurasia tectonic plates during the Cenozoic Era. The continuous tectonic stress has led to significant topographical differentiation of the mountains. Their deep valleys are the pathways of the largest rivers in South-East Asia: Yangtze, Mekong, and Salween, and their summits are covered by glaciers that have been important river feeders since the Ice Age. Modern glaciers occupy tops of the ranges at 5000 m a.s.l. and higher. Several centers of modern glaciation exist in the Hengduan Mountains, and Gongga is the largest among them.

Mount Gongga, 7,556 m a.s.l., is the highest peak in the Hengduan Mountains and this center of glaciation extends for 60 km from north to south. The Gongga Massif is asymmetric: its western slope are steeper than eastern. The Randolf Glacier Inventory database counts 76 modern glaciers in it. They form on the walls of ancient glacier cirques and some glaciers fill these cirques and flow down the valley; the glaciers are mostly single and some of them are dendritic. The largest glacier is 12 km long. Lowest altitude at which the glaciers end is 3007 m a.s.l. (according to COPDEM30). The largest glacier is 27.6 km^2 and there are 43 glaciers smaller than 1 km^2. The total area of the modern glaciers is 189.54 km^2.

In our study of the maximum extent of the late Pleistocene glaciation, we found traces of 75 ancient glaciers in the Gongga Massif. There were 10 large dendritic glaciers, stretching from 7 to 17.5 kilometers (see Figure). They occupied the main valleys and most of them ended in the middle of the valleys at altitudes between 2700 and 3300 m a.s.l.; only a few glaciers descended to the valleys bounding the massif in the west. In addition, there were 65 lesser dendritic and single glaciers. The areas of the 10 largest glaciers are between 78 and 12 km^2 and the area of all 75 glaciers is 503 km^2.

Conclusively, during the late Pleistocene, the glaciers covered 2.7 times more land than modern glaciers. This value is not high. We explain this phenomenon by the high altitude of the Gongga Massif, which allows for relatively large modern glaciers, on the one hand. The position of the massif in the relatively warm low-latitude area of the Earth limited, on the other hand, the formation of the late Pleistocene glaciers.

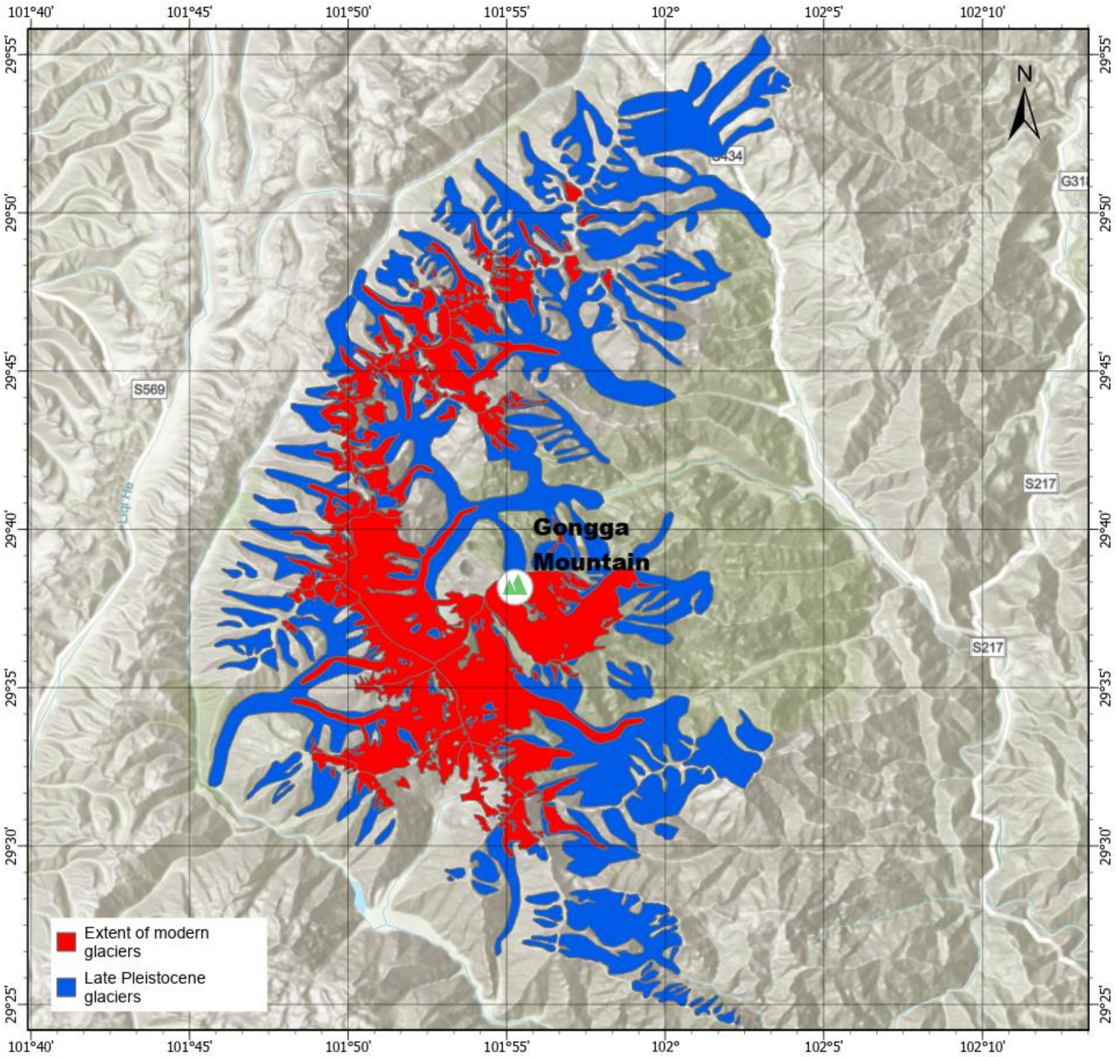

Figure. Extent of modern (red) and late Pleistocene (blue) glaciers in the Gongga Massif. Background is ESRI shadow relief map.

Neoproterozoic mafic to felsic magmatism of the Longmenshan Thrust Belt, western Yangtze Block: from supra-subduction to extensional settings

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The Longmenshan Thrust Belt (LTB) is located in the western margin of the Yangtze Block, at the junction zone between the Sichuan Basin and Songpan-Ganze terrane. The western Yangtze Block, a core of the South China Craton, consists of Proterozoic mafic-ultramafic plutons and granitoids intrusions, Paleozoic volcanogenic-sedimentary formations linked to the evolution of the Tethys Ocean, and Mesozoic continental sedimentary cover. The LTB is dominated by Neoproterozoic granitoids and mafic dikes and early-middle Paleozoic volcanogenic-sedimentary units. It has a complicated thrust-nappe structure that formed in Mesozoic to Cenozoic time during the early Mesozoic orogeny, late Mesozoic post orogenic extension and Cenozoic duplexing (Xue et al., 2022). The LTB is characterized by multiple NE trending faults zones and is a tectonically and seismically active area. Previous U-Pb geochronological data show that the Neoproterozoic magmatism of the western Yangtze Block during ca. 910-730 Ma (Xiong et al., 2023). We studied Neoproterozoic mafic to felsic plutonic intrusions and dikes exposed in the southern part of the LFB, near Ya'an City of the Tianquan County, Sichuan Province. The study area is located within the Xianshuihe fault zone and its stratigraphy also includes Ordovician carbonates, siliciclastic rocks (conglomerate, sandstone, siltstone and mudstone), chert, and Silurian siliciclastic rocks (sandstone, siltstone, mudstone shale), and subordinate Mesozoic sedimentary strata. We sampled plutonic magmatic rocks, gabbroids and granitoids, exposed along the Da and Laba rivers. The gabbros typically occur as separate stocks and dikes cutting the grantioids. The sampled rocks were studied for U-Pb ages, major and trace element composition, Hf-in-zircon and whole-rock Nd isotopes.

According to the TAS classification, the samples are gabbro and monzogabbro, gabbrodiorite and monzodiorite, diorite and monzonite. The gabbroids are high-Ti and low-Ti. We separated zircons from high-Ti monzogabbro and monzodiorite and low-Ti gabbro, gabbrodiorite, diorite, and monzonite and performed their U-Pb dating. The low-Ti gabbro, gabbrodiorite, diorite and monzonite yielded mean U-Pb zircon ages of 816 ± 3, 813 ± 3, 809 ± 3 and 807 ± 3 Ma. The two high-Ti gabbroids yielded similar weighted mean ages of 787 ± 3 and 783 ± 3 Ma.

The groups of gabbroids (gabbro, gabbrodiorite, monzodiorite) and granitoids (diorite and monzonite) are characterized by variable compositions each. The low-Ti gabbroids show the lower concentrations of TiO_2 = 1.0-1.5 wt.% and FeO = 7.2-8.8 wt.% compared to the high-Ti gabbros (TiO_2 = 2.0-3.4, FeO = 11.5-11.9 wt.%). The granitoids can be divided into low-Si diorites (including monzodiorite) and "normal" diorites including monzonite. The low-silica diorites are characterized by higher concentrations of FeO (6.4-9.3 wt.%), MgO (2.7-5.7 wt.%) and CaO (5.2-6.9 wt.%) compared to the diorites (FeO = 5.2-7.3, MgO = 2.3-2.7, CaO = 2.7-4.5 wt.%). According to the alkalis-FeO-MgO classification, the subalkaline samples belong to the calc-alkaline series. In the low-Ti rocks, the concentrations of CaO and FeO decrease with increasing SiO_2 suggesting fractionation of olivine or orthopyroxene and clinopyroxenes. Such a correlation is not observed in the high-Ti gabbro indicating that the crystalline differentiation was not hardly responsible for the observed compositional variations.

The high-Ti gabbro are more enriched in the rare-earth elements (REE) compared to the low-Ti gabbro (ΣREE = 157 vs 88). They are typically enriched in light REE (LREE; La/Yb_N = 3.0-9.7), show a notable differentiation of heavy REE (HREE; Gd/Yb_N = 1.5-2.7) and have Zr/Nb ratios spanning 8.7-27.0. They are weakly depleted in Nb (Nb/Th_N = 0.3-1.0, Nb/La_N = 0.3-0.9). The low-Ti gabbroids are also enriched in LREE (La/Yb_N = 2.6-9.4), are characterized by moderately differentiated HREE (Gd/Yb_N = 1.3-2.2), but have higher Zr/Nb ratios (19-34). They are also depleted in Nb, but to a higher degree (Nb/Th_N = 0.2-0.3, Nb/La_N = 0.2-0.5) that is typical of suprasubduction igneous rocks (Pearce, 1982).

The low-silica diorites are also enriched in rare elements (La/Yb_N = 2.9-10.7) and have differentiated HREE (Gd/Yb_N = 1.0-2.5) and moderate Zr/Nb (18-33). The rocks are also depleted in Nb (Nb/Th_N = 0.2-0.6, Nb/La_N = 0.3-0.4). The diorites have similar features, but higher Zr/Nb (23-48) suggesting more evolved character. They are also enriched in LREE, moderately differentiated in HREE (La/Yb_N = 3.0-6.0, Gd/Yb_N = 1.6-1.8) and depleted in Nb (Nb/Th_N = 0.2-0.4, Nb/La_N = 0.3-0.4).

All groups are characterized by positive εNd(t) values: 3.9-6.0 for the high-Ti gabbros, 3.1-4.3 for the low-Ti gabbroids, 4.3-4.4 for the low-silica diorites and 1.9 for diorite. The zircons from a low-Ti gabbro, low-silica diorite and diorite yielded positive εHf(t) values of 10.3, 11.2 and 11.1, respectively.

Thus, the Tianquan study area of the Longmenshan thrust belt obviously hosts at least two magmatic series of rocks: an older calc-alkaline series (816 to 807 Ma) represented by low-Ti gabbroids and diorites and a younger alkaline series (787-783 Ma) of high-Ti gabbro and monzodiorite. The calc-alkaline igneous series was evolving during almost 10 myr through crystalline differentiation from gabbro to diorite suggesting one or more intermediate chambers. The plutonic rocks of this series are characterized by typical features of supra-subduction igneous rocks: wide ranges of concentrations of most major oxides, medium to low concentrations of TiO_2, enrichment of LREE, depletion in Nb-Ta. The parental melts were derived from mantle wedge juvenile mantle sources (εNd(t) = +1.9-4.4; εHf(t) = +1.9-4.4), possibly, lherzolite or harzburgite (Gd/Yb_N = 1.3-2.2). They could be emplaced in a tectonic setting of a young active continental margin or evolved/mature island arc. The parental melts of the younger high-Ti gabbroids could be formed by mixing of enriched and depleted mantle sources (εNd(t) = +3.9-6.0) in an extensional tectonic setting. The extension was probably provided by active margin rifting or intra-arc rifting that has been fixed before in the western Yangtze for the 790-780 Ma time period (Wu et al., 2024).

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Pearce, J.A., 1982. Trace element characteristics of lavas from destructive plate boundaries, In: Thorpe, R.S. (Ed.), Orogenic Andesites and Related Rocks. John Wiley and Sons, Chichester, England, pp. 528-548.

Wu L., Zhao G., Gao J., Dong X., Zhang A., Peng T., 2024. Intra-arc rifting induced the fragmentation of microplate from the continental margin. Geological Society of America Bulletin.

Xiong F, Zhong H, Huang H, Liu X., Hou M., 2023. Petrogenetic and tectonic implications of Neoproterozoic igneous rocks from the western Yangtze Block, South China. Precambrian Research 387, 106977.

Xue Zh., Lin W., Chu Y., Faure M., Chen Y., Ji W., Qiu H., 2021. An intracontinental orogen exhumed by basement-slice imbrication in the Longmenshan Thrust Belt of the Eastern Tibetan Plateau. Geological Society of America Bulletin 134 (1/2), 15-38.