Southwest Jiaotong University
Institute of Geology NAS KR
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# Geology, tectonics and magmatism of the Northern Tien Shan

## 1st International Geological Field Training School

**Guide-book** (Geology Group)

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September 7-15, 2024
Bishkek, Kyrgyzstan

## Preface: goals and objectives of the Field Training School

The 2024 International Geologic Field Training School (FTS) will be held in Bishkek, Kyrgyzstan, and in the mountains of Northern Kyrgyz Tien Shan, during September 7-15, 2024, organized by the Institute of Geology, National Academy of Sciences Kyrgyz Republic (IG NAS KR) and co-sponsored by the South-West Jiaotong University, Chengdu, China (SWJTU) and North-West University, Xi'an, China (NWU).

Bishkek, the capital of Kyrgyzstan, as a starting point of the Field School, provides a good opportunity from the logistic point of view because Kyrgyzstan occupies a large territory stretching from the Tarim northern margin in the south to the Balkhash fold-belt in the north (Fig. 1). Thus it covers all tectonic units traditionally assigned to the Tien Shan orogenic collage. The workshop has been jointly organized by the Southwest Jiaotong University in Chengdu, China, Northwest University in Xi'an, China, and Institute of Geology of the National Academy of Sciences of Kyrgyz Republic.

The Field Training School in Kyrgyzstan (FTS) will be held in the Northern Tien Shan (NTS) located in the southwestern Central Asian Orogenic Belt. NTS represents a terrane built upon a Neoproterozoic basement and including a big varieties of rocks formation of late Neoproterozoic to Mesozoic age (Bakirov et al., 1980; Bakirov and Maksumova, 2001). In 2024, we will focus on early Paleozoic supra-subduction magmatic and clastic formations, middle-late Paleozoic intra-plate igneous formations and ore deposits. The main goal of the School is to teach students and early-career scientist to do geological survey in such complicated geological structures.

The Central Asian Orogenic Belt (CAOB) is the world largest accretionary orogen on Earth, and its evolution has been a matter of considerable debate, particularly since the provocative model of Sengör et al. (1993) was published. The orogen 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; Dobretsov et al., 1995) 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. However, the progress in research in this huge orogen is hampered by the existence of different scientific concepts, logistic difficulties, an uneven distribution of high-quality field and laboratory data, and language barriers (Natalin et al., 2019).

International cooperation is therefore required to study the CAOB, that huge and interesting orogenic belt, in general, and the Tien Shan Orogen, in particular. It is now important that not only researchers from different countries continue their collaboration and compare and contrast geological units of the CAOB that extend across political borders, but to involve early carrier scientists and students into the research programs. A very important issue of future studies in the Tien Shan is to see, recognize and understand important field relationships and to try and correlate small-scale tectonic and magmatic units in an outcrop to link them with large-scale tectonic units from one country to another.

The tectonic basin of Lake Issyk-Kul and its bounding Terskey Ala-Too and Kungey Ala-Too ranges are of great interest for the post-collisional intracontinental development of NTS. The Cenozoic India-Eurasia collision has reactivated NTS's tectonics and enforced its topographical differentiation. A lake probably occupies the Issyk-Kul basin since Miocene, while the modern deep lake appeared in the middle Pleistocene (Trofimov, 1990). The knowledge about the history of the lake, its transgressions and regressions, remain very limited (Podrezov et al., 2020) and debatable. So, new discoveries are possible. The Issyk-Kul basin also keeps a thick layer of piedmont slope and loess sediments, which experience tectonic processes, denudation and erosion. They form a unique badland landscape between the mountains and the Lake. Quaternary loose deposits are subject to large-scale landslides triggered by earthquakes, which cause rock collapses. The glaciers melt-waters of the surrounding ranges serve important sources of water for the Lake and agents of modern geomorphological processes. They were much more active during the Ice Age. These ranges show magnificent examples of late Pleistocene glacial and outwash sediments and landforms.

Thus, the FTS will be an important step in learning and teaching real field geology, discussing and hopefully reconciling differences of opinion and interpretation of the Tian Shan orogen, and this will no doubt lead to increasing cooperation between scientists from Kyrgyzstan, China, Russia, and Kazakhstan.

For the recently established geology research group at the Faculty of Geoscience and Engineering in the Southwest Jiaotong University of China led by Prof. Inna Safonova and for the group of Prof. Rustam Orozbaev from the Institute of Geology of the National Academy of Sciences of the Kyrgyz Republic it is a challenge to host this meeting and organize the field school together with the Northwest University of China.

This event will also create a new platform for the Kyrgyz geological sciences and facilitate international cooperation. The program of the Field School is promoting a multidisciplinary earth system research that aims at a process-based understanding on all scales and is focused on regional and cross-border activities in Central Asia.

We trust that this Field School will enhance scientific collaboration and lead to new multidisciplinary (including not only geochemistry, petrology, structural geology and geomorphology, but also geohazards and environmental science) and integrated research. The workshop in Bishkek after the field excursion will hopefully lead to new research partnerships and will hopefully lead to a widening of international students exchange programs.

Inna Safonova
Sergei Krivonogov
Rustam Orozbaev

**FTS Program**

The School will commence with introductory lectures and an ice breaker on September 7, in-field classes for 6 days during September 8 to 13, 2024. Then, the School is followed by a one-day session of students' reports in the Institute of Geology NAN KR, Bishkek, and a farewell party on the 14$^{th}$ of September 2024. The FTS will provide an excellent platform for getting practical and scientific knowledge on the geology and tectonics of orogenic belts (Geology Group) and related sedimentary basins (Geomorphology and Environment Group) under the patronage and supervision of renowned geoscientists.

The participants of the Geology Group will have a chance to study field outcrops in relation to the early Paleozoic evolution of the Terskey Ocean (Stops 1-3) and late Paleozoic and Mesozoic intra-plate magmatism of the Northern Tien Shan (Stops 4, 9) (Fig. 1). The participants of the Geomorphology and Environment Group will study Quaternary sedimentation environments and geomorphs in the Chu River Valley (Stop 5) and at the Southern shore of Lake Issyk-Kul (stops 6, 7). Both groups together will visit the Kumtor gold deposit mine (Stop 8) with on-route observation of the Barskoon valley, moraines, glaciers.

## Content

# Introduction to the geology of North Tien Shan

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; Bakirov & Maksumova, 2001). 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 (Fig. 1). 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.

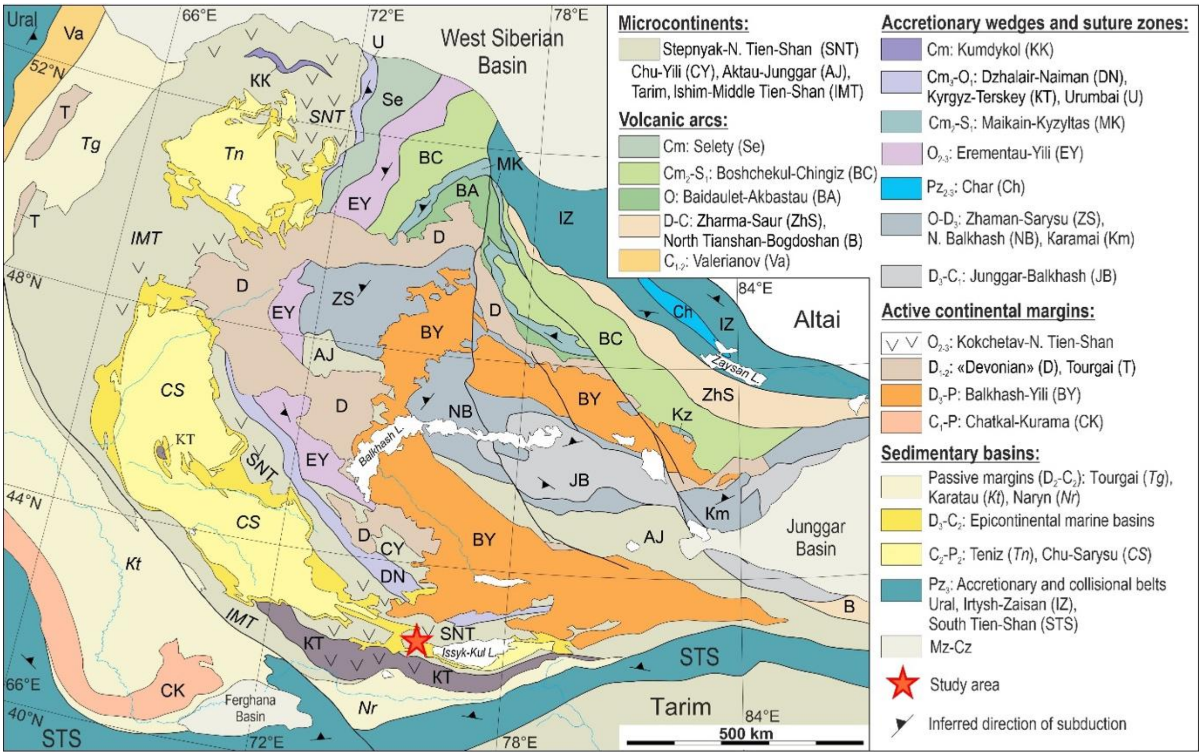



**Fig. 1.** Tectonic map of the main components of Central Asian Orogenic Belt (CAOB). Modified after (Windley et al., 2007).

The North Tien Shan 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 (Fig. 2) extending from the western Kyrgyz Range to the Chinese Central Tien Shan (CTS). The arc and the active margin underwent several structural reorganizations including shifts of subduction polarities due to Early and Middle Ordovician episodes of accretion. 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.

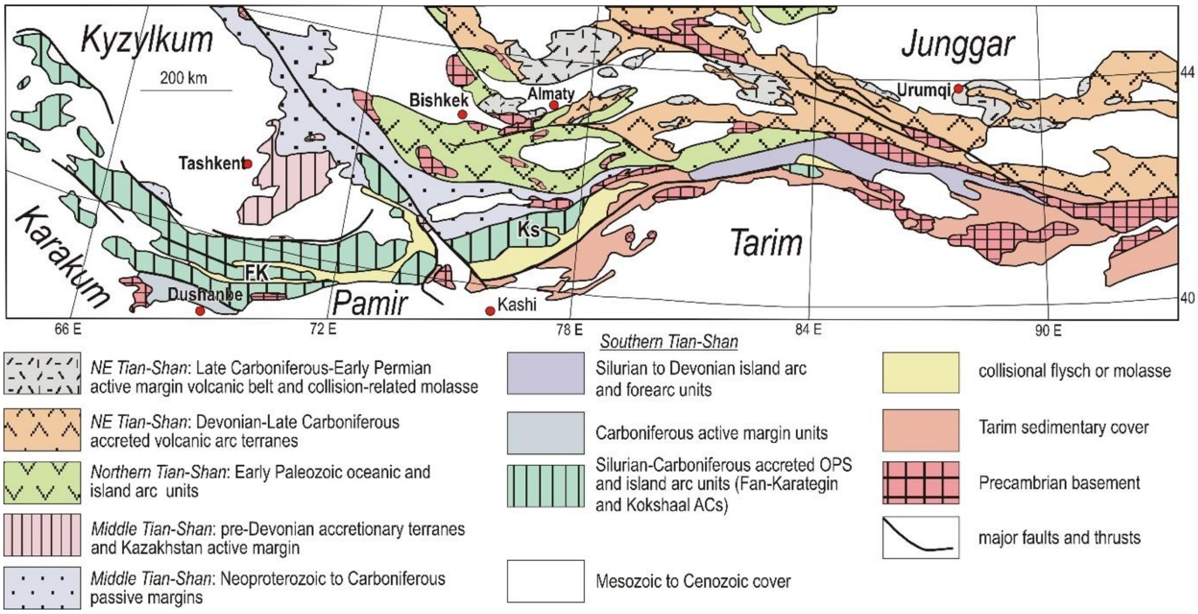



**Fig. 2.** Tectonic scheme of the southern Kyrgyz Tien Shan (modified from Biske and Seltmann, 2010). Ks = Kokshaal; FK = Fan-Karategin; OPS = Ocean Plate Stratigraphy (Safonova et al., 2016b).

The Kyrgyz-Terskey ophiolite suture zone (Fig. 3), a focus of the Field School, consists of Cambrian ophiolites, early Ordovician magmatic and sedimentary rocks of ocean plate stratigraphy (Safonova et al., 2016a) and middle Ordovician flysch and volcanogenic-sedimentary formations at the southern flank of the NTS.

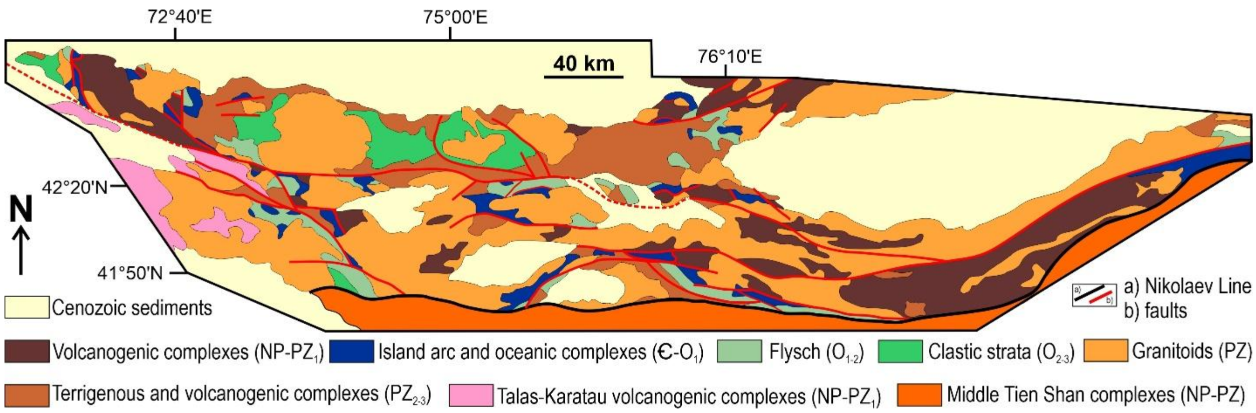



**Fig. 3.** Neoproterozoic and early Paleozoic complexes of the Northern Tien Shan (Degtyarev, 2012).

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).

## Localities and objectives

**Fig. 4.** Location of stops. Stars for groups: yellow – Geology Group, pink – Geomorphology and Environment Group (see another Guide-Book), blue – Kumtor Mine.

### Stop 1-1, Belogorka section

The section is located 5 km SE of Belogorka Vil. (Figs. 4, 5A, B). According to the geological map there are Early Ordovician volcanic rocks and siliciclastic formations ($O_1$de). The section is well exposed and consists of late Ordovician conglomerate, sandstone, siliceous mudstone and tuff, which carry no fauna, but are conformably overlain by middle Ordovician sedimentary rocks and intruded by early Carboniferous plagiogranite and Qu-porphyry to form hornfels. The dominant lithologies are clastic rocks (the lower part of the section) and mafic to andesitic volcanic to subvolcanic rocks (dolerite, basalt, andesibasalt, trachyandesite) (Fig. 5C). The clastic rocks are dominated by sandstones. The medium-large grained greenish-grey greywacke sandstones occur as thick beds intercalated with lilac siliceous mudstones and as 1-2 meters' thick lenses in volcanic rocks. The mafic to andesitic volcanics occur in cold contact with the sandstones (Fig. 5C). The sandstones are often sheared to acquire SN-striking schistosity. They are cut by a doleritic dike. There are also conglomerates and volcanic breccia. The andesibasalt and andesite typically have porphyric structure. The porphyric volcanic rocks often carry phenocrysts of plagioclase (up to 5 mm long), clinopyroxene (up to 1 cm) and amphibole (up to 5 cm) (Fig. 5D). The groundmass is chloritized. In places, it is hard to differentiate the greywackes from volcanic rocks. According to our unpublished data the volcanic rocks are of supra-subduction origin and the sandstones are greywackes.

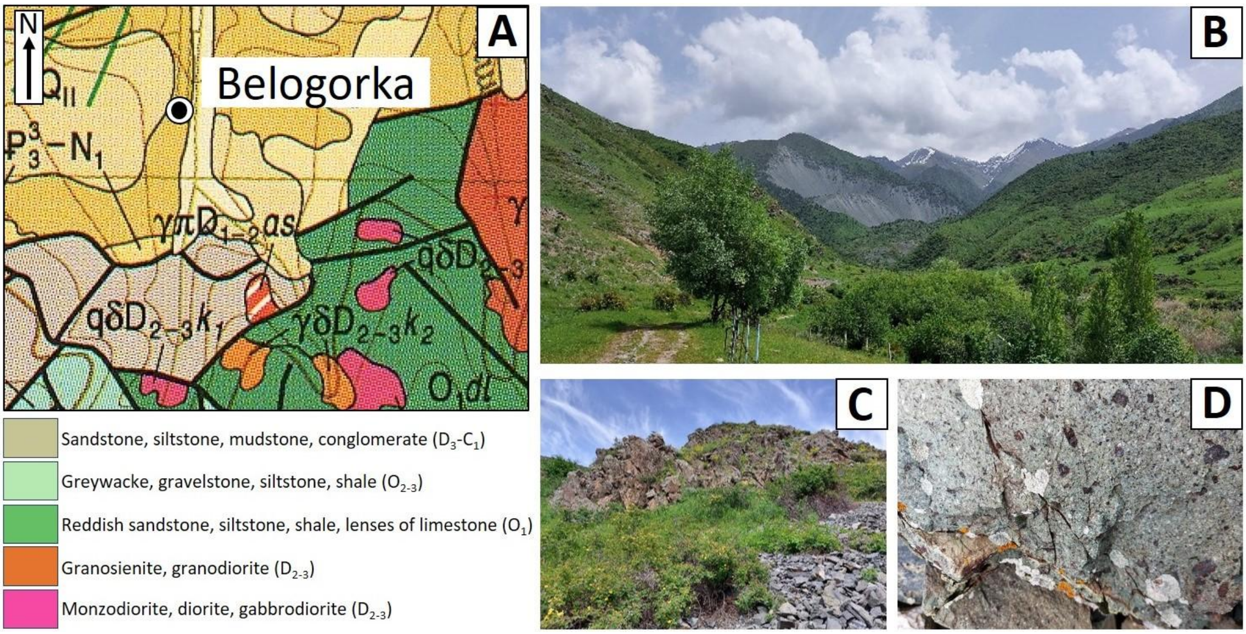



**Fig. 5.** Belogorka Section. A, a fragment of the geological map; B, general view, C, greywacke sandstones and mafic volcanics; D, porphyric andesite.

**Stop 1-2, Ala-Archa section**

The geological map (Fig. 6) shows Devonian volcanogenic formations ($D_{1-2}$as), early Ordovician ($O_1$dl) and middle-late Ordovician ($O_{2-3}$ cn) clastic rocks in the Ala-Archa River valley (Fig. 7). There are also biotite- and amphibole-granites intruding Cambrian (?) to Ordovician conglomerates, sandstones, and shales.

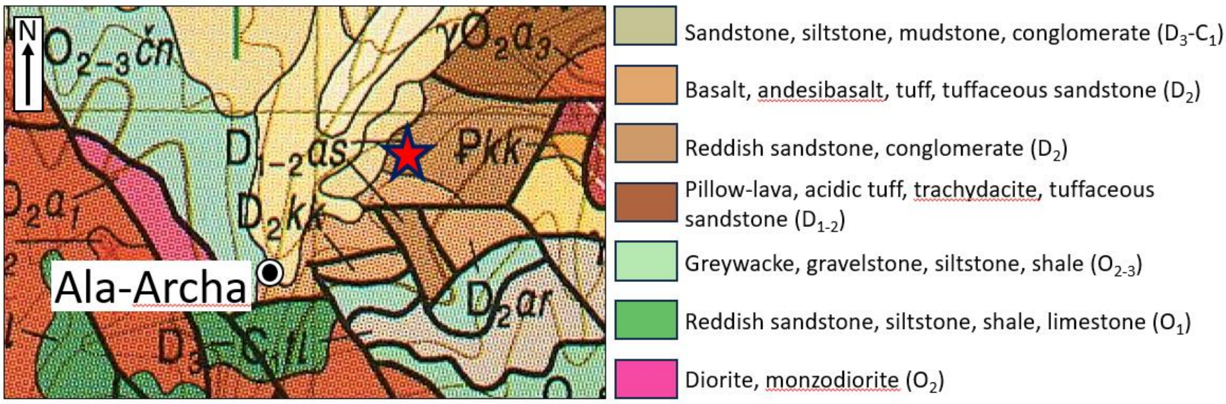



**Fig. 6.** A fragment of the geological map near Ala-Archa.

Near the main road (to the Ala-Archa Resort area), there are outcrops of Devonian (?) dolerites, porphyric basalts (with phenocrysts of clinopyroxene) and amygdaloidal volcanics (Fig. 7A) overlain by conglomerates, sandstones and siltstones. The amygdaloidal volcanics carry calcite and zeolites in vesicles. Up the stream, there are dominantly granitoids, turbidites (?) and pillow-lavas (Fig. 7B). The Devonian pillow-lavas occur as thick, up to 30 meters lava flows. The basalts are strongly altered that is typical of pillow-lavas, in general. The turbidites occur as slightly rounded boulders at the sides of the river canyon (Fig. 7C). Up the stream/section, there are outcrops of dark-brown and greenish-grey sandstones, which have banded textures resembling turbidites (Fig. 7D).

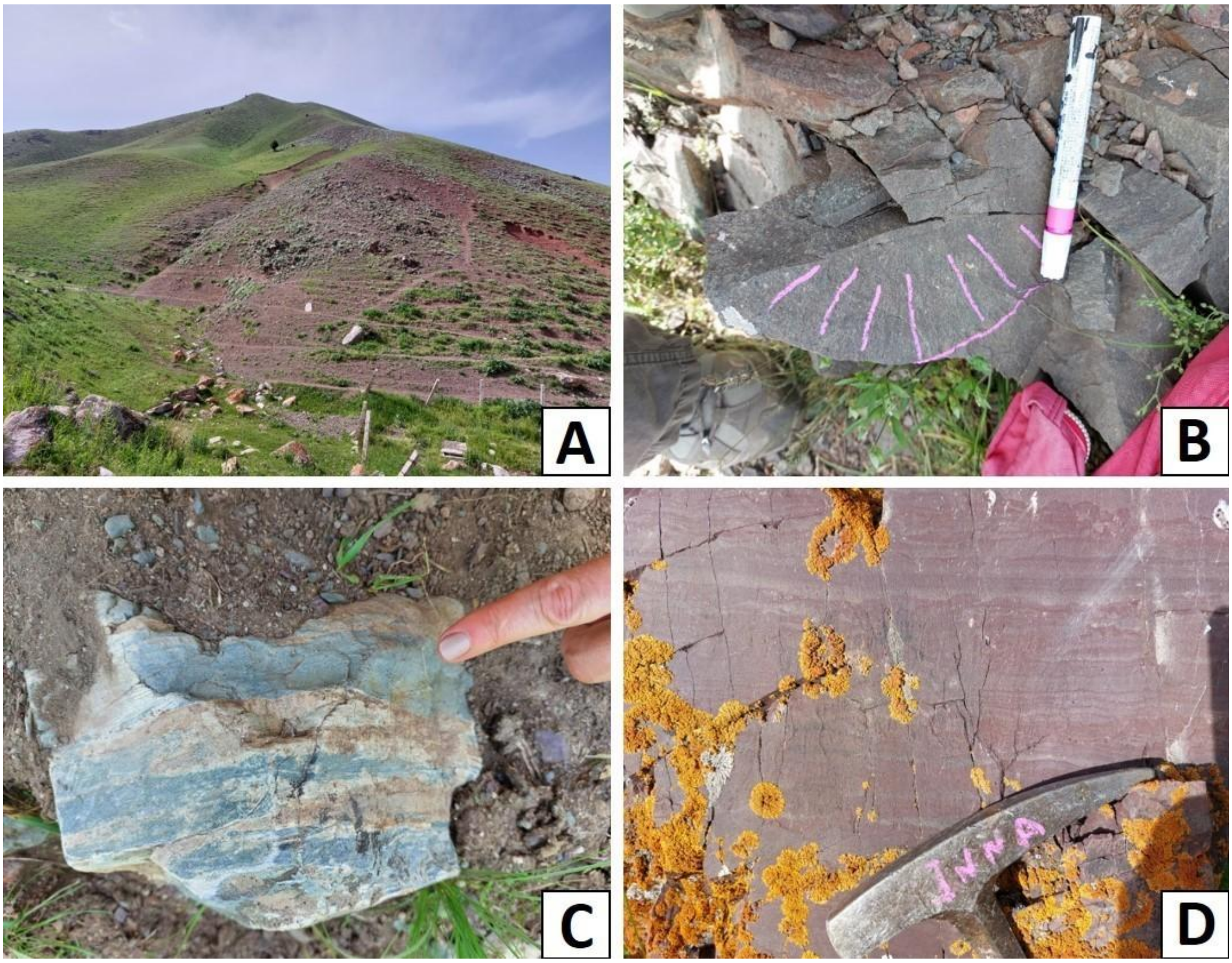


**Fig. 7.** Ala-Archa Section. A, Devonian volcanics; B, pillow-lava, C, greywacke sandstone; D, banded sandstone.

**Stop 2**, **Shamsi section**

The Early Paleozoic volcanic and clastic rocks crop out in a canyon of the Shamsi River 8 km SE of Kalinovka Vil. (Figs. 4, 8). The Shamsi section includes volcanic, subvolcanic and volcanogenic-sedimentary clastic rocks of the middle Ordovician Shargyi Formation and plutonic rocks of the Shargyi Complex. The volcanic association includes almost black to dark-grey aphyric basalts, grey and greenish porphyric basalts and andesibasalts (Fig. 8A, B), in places, as pillow lavas. The phenocrysts in porphyric varieties are clinopyroxene and plagioclase. In other areas of the Kyrgyz Range, the Shargyi Fm. also includes andesidacites, rhyolites, tuffs and tuff-conglomerates (Dzhenchuraeva et al., 2015). The total thickness of the formation is 1600-3900 m. The Shargyi Fm. is intruded by igneous rocks of the Shargyi Complex, which consists of gabbro, diorite, Qu-diorites and granodiorite, which occur as stocks and dikes cutting the volcanogenic rocks of the Shargyi Fm. (Fig. 8C, D). The stocks are often surrounded by hornfels and skarns (marble-like limestones). The magmatic rocks at the contacts often carry secondary epidote.

According to the preliminary geochemical data, the volcanic and plutonic magmatic rocks are diorites and granodiorite (Shargyi Complex) and andesibasalts, andesites, and dacites and their alkaline varieties (Shargyi Fm.) of tholeiitic, calc-alkaline and moderately alkaline series. The data on major elements suggest a single trend of crystallization of the magmas, which produced the rocks of both the Shargyi Complex and Shargyi Fm. The rocks are enriched in LREE ($La_n$ = 23.5-107.7, $La/Yb_n$ =3.9-15.7, $La/Sm_n$ = 2.2-5.7), show Eu minimums (Eu/Eu* = 0.5-0.9), and troughs at

Nb ($Nb/Th_{pm}$ = 0.1-0.3; $Nb/La_{pm}$ = 0.3-0.6) and Ti (Ti/Ti* = 0.13-0.33). Those features are typical of supra-subduction magmatic rocks. The negative values of εNd (from -8.8 to -5.2) and close model ages (1.7-2.0 Ga) indicate a single mantle source containing recycled crustal material. The rocks possibly formed on the middle Ordovician Kentash arc built on a sialic basement, although there are still no precise age data from those.

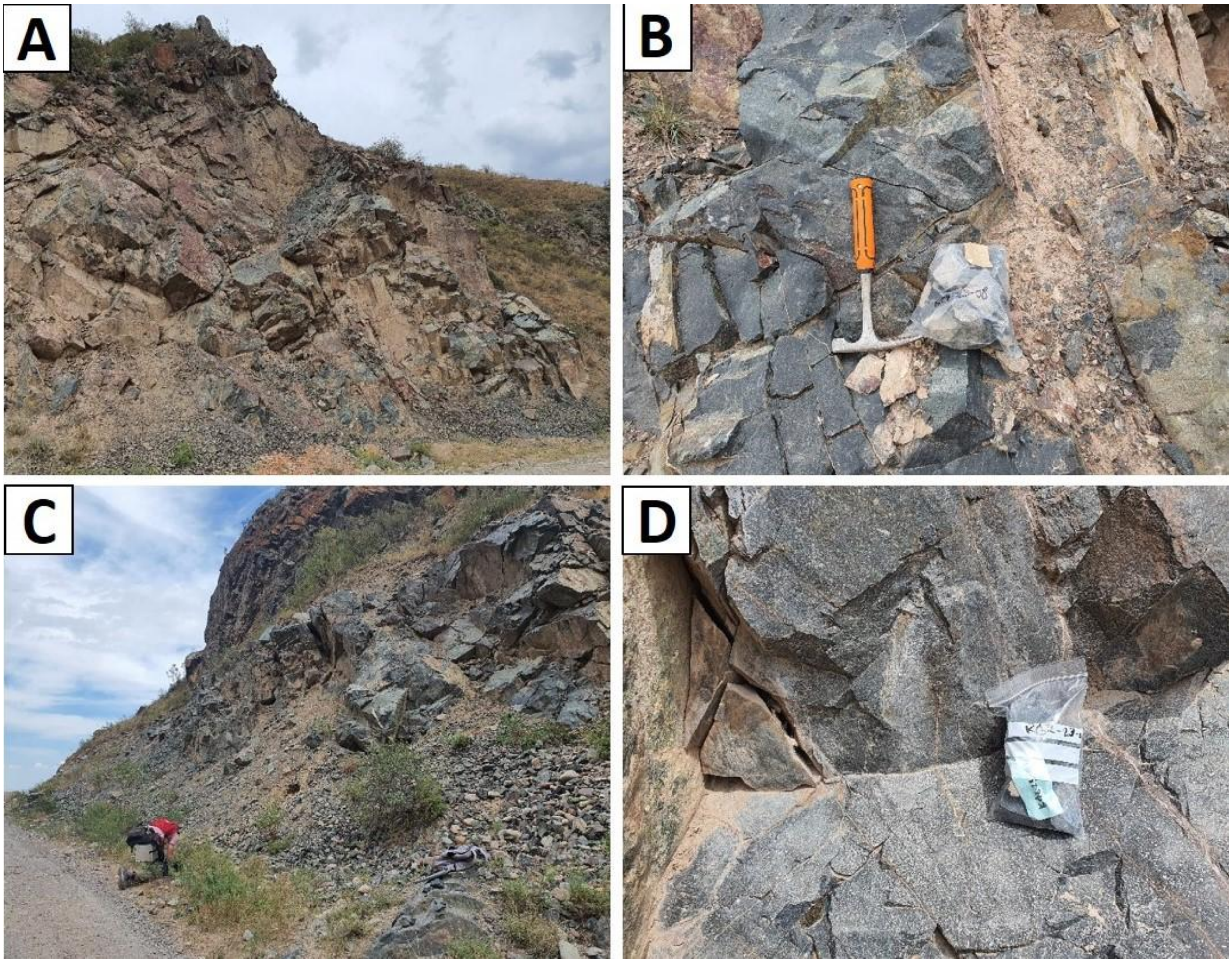


**Fig. 8.** Shamsi section. A, B, an andesibasalt of the Shargyi Fm; C, D, a fine-grained gabbro of the Shargyi Complex.

**Stop 3, Dolon section**

<u>The Dolon clastic section</u> is located along the motor-road running over the Dolon Pass (Figs. 4, 9A). It is dominated by Cambrian-lower Ordovician turbidites, overlain (or obducted?) with a disconformity by a diamictite with huge blocks of ophiolitic material, granite, and sandstone (Fig. 9B). According to Maksumova (2009), the Dolon area includes four main groups of lithologies (Fig. 10).

1) Olistostrome-hosted blocks of limestone of Cambrian to Tremadocian age and Lower Ordovician ($O_1$ar, lower Arenigian, or Floian in the modern subdivision) large- to small-pebbled conglomerates carry clasts of volcanic rocks, serpentinite, tuff, gabbro, cherts, granitoids, exotic cliffs, boulders and limestone. Those tectono-gravity and gravity mixtites show signatures of horizontal displacement and thrusting (Fig. 11A). The conglomerates are replaced by gravelites and sandstone.

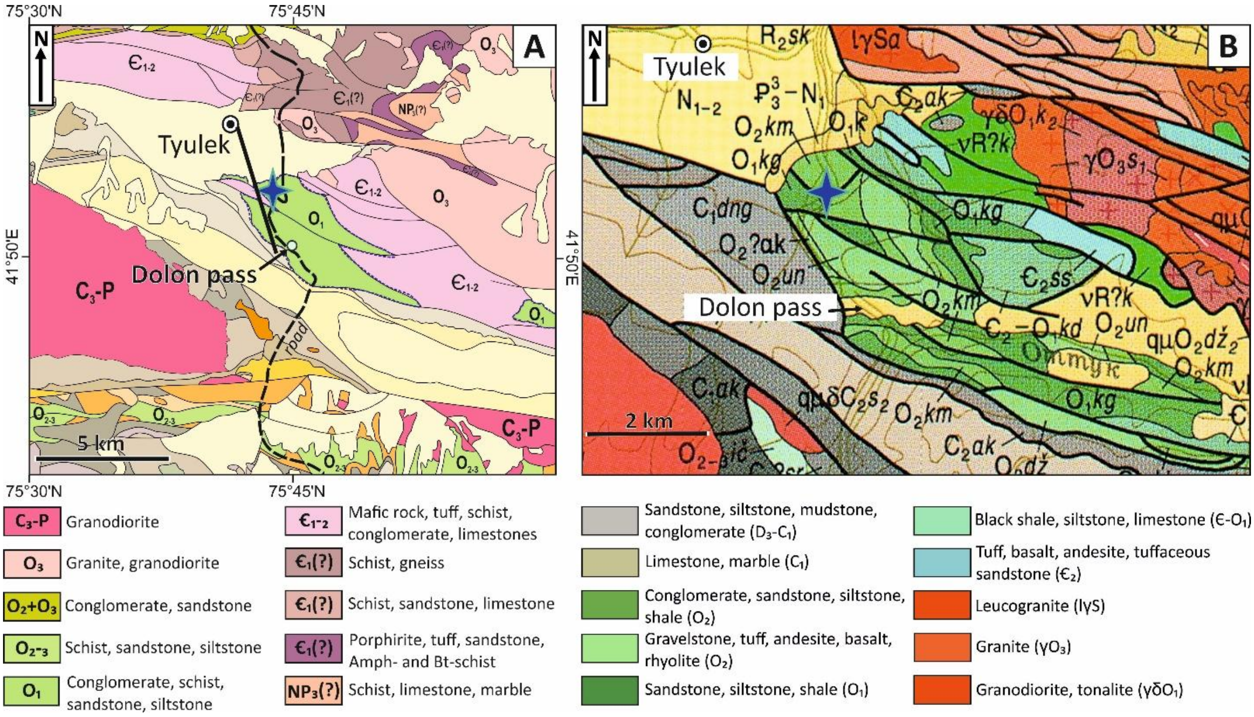



**Fig. 9.** Dolon section. Fragments of a 1/200,000 geological map showing the location (A) and the main units (B) (Geological map of the USSR, Sheet K-43-22, scale 1/200,000).

2) A sequence of south-dipping massive arkosic sandstones of Lower Ordovician age ($O_1ar_{2-3}$, middle-upper Arenigian or Floian). The sequence includes two units. The lower 150-200 m thick unit consists of thin-bedded hemipelagites, black and siliceous shales (Fig. 11B), interbedded with fine-grained sandstones, which host sponge spicules and graptolites. The 570 m thick upper unit represents a flysch of sandstone, siltstone, and mudstone with graptolites sitting over coarse-grained sandstone with interbeds of conglomerates.

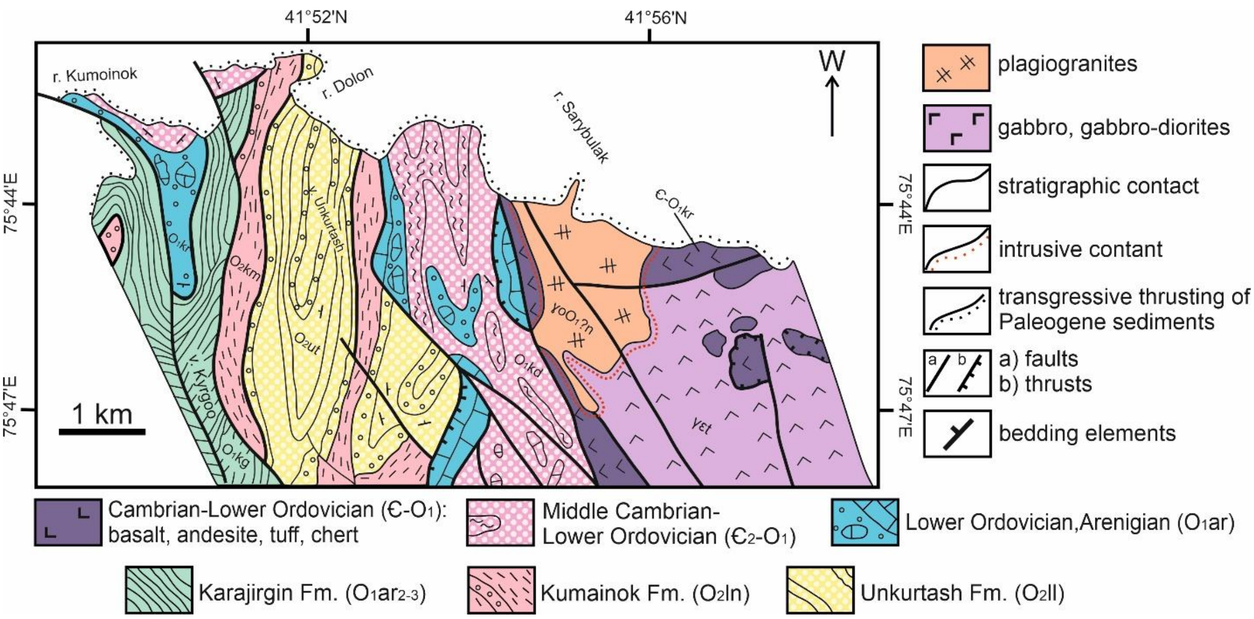



**Fig. 10.** Dolon section. A geological scheme of Maksutova R.A. (Guide-book, 2009).

3) A 400 m thick sequence of sandstones and shales forming turbidite association of middle Ordovician age ($O_2$ln, Llanvirnian or Dapingian) showing a north-dipping cleavage. The sequence also includes two units. The lower 200 m thick unit is a coarse-clastic flysch consisting of conglomerates, gravelstones and sandstones. The conglomerates carry limestone and sandstone

bounders and much smaller pebbles of shale, quartzite, and arkosic sandstone. The upper 125-200 thick unit consists of mudstone and siliceous shale with interbeds of limestone and arkosic sandstone. The siliceous shales host brachiopods, trilobites, crinoids, phyllocarids and graptolites.

4) A 400 m thick flysch of Middle Ordovician age ($O_2$ll, Llandeilian or Darriwilian). The flysch represents a multi-stage intercalation of conglomerate, gravelite, sandstone, siltstone (with graptolites) and mudstone (Fig. 11C). There is a 30 m flow of andesitic porphyrites (Fig. 11D).

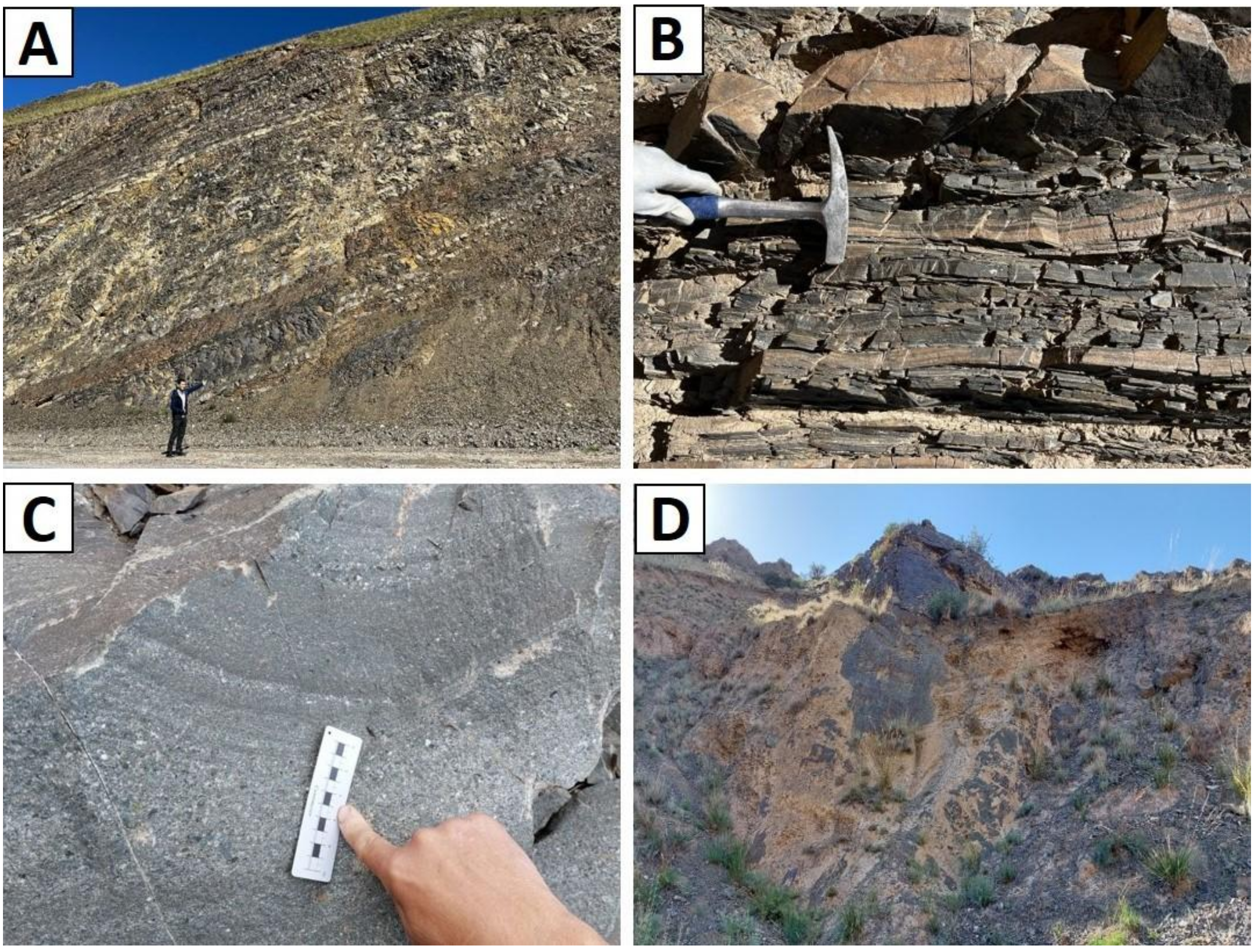


**Fig. 11.** The Dolon section. A, a huge outcrop of faulted turbidites; B, black turbidites; C, graded conglomerates; D, a flow of porphyrite (andesibasalt?).

In the modern stratigraphic framework, the late Cambrian-early Ordovician sedimentary clastic deposits belong to Karajorgin, Kumainok and Unkurtash formations (Fig. 10). The Karajorgin Fm. (Furongian-Tremadoc) consists of tuffaceous-sandstone, siliceous siltstone, and conglomerate. The Kumainok Fm. (Floian-Dapingian) represents a "classical" turbidite of interbedded sandstone and siltstone. The total thickness of both formations is about 1 km (Fig. 11A, B). The clastic formations are unconformably overlain by oceanic rocks (OPS), chert and basalt/gabbro, and plagiogranite. This section represents a series of perfectly exposed turbidite sections with a limited amount, though very important, outcrops of OPS and late Paleozoic (?) volcanic bodies. The turbidites can be studied for reconstructing fossil subduction zones (Safonova et al., 2024). The Unkurtash Fm. includes Floian-Darriwilian clastic rocks (conglomerate-gravelstone-sandstone-siltstone flysch) and magmatic rocks of unclear genesis and age (Fig. 11C, D).

We will observe and study sections of clastic and volcanic rocks located at a distance of ca. 7 km (by road) north of the Dolon pass (Figs. 9). We will focus on early-middle Ordovician turbidites of the Kumainok Fm. exposed along the main motor-road (Fig. 11A, B) and middle Ordovician conglomerates, sandstones, shales and volcanics of the Unkurtash Fm. exposed along the Unkur-Tash river, a left tributary of the Dolon River (conglomerates, sandstones, shales, volcanic rocks; Figs. 10, 11C, D).

**Stop 4, Kyzyl-Ompul Complex**

The Kyzyl-Ompul magmatic complex is represented by late Carboniferous-Permian granitoid intrusions of probably intra-plate origin. The below description of Kyzyl-Ompul intrusions is based on the Explanatory note to the Geological map of the USSR (1961) and our field observations made in 2023 and 2024. The numerous intrusions were emplaced in three phases: 1) syenite, syenitic diorite, monzonite; 2) grano-syenite; 3) alaskite granite.

Phase I (§$C_3$-P). The alkaline granitoids of Phase I, syenites and monzonites, crop out as stocks at the southern slope of the Kyrgyz Range (Figs. 4, 12A). There are four mains groups of lithologies: 1) giant-grained syenite; 2) giant-porphyric syenite; 3) medium- and fine-grained syenite, and 4) syenitic diorite and monzonite. The giant-grained syenites (Fig. 12B) are the earliest and form large stocks. The giant-porphyric syenites form medium and small stocks and dykes intruded into the giant-grained syenites (Fig. 12C). The medium- and fine-grained syenites and the syenitic diorites and monzonites form relatively small bodies intruding the first and second groups of syenites and, probably, represent the latest rocks formed during Phase I. They could be coeval/syngenetic with the granosyenites of Phase II. The giant-grained and giant-porphyric syenites are of special interest. The giant-grained syenites (Fig. 12B) consist of large 3 to 35 cm elongated to isometric idiomorphic crystals of K-Na-feldspar (90-95% of rock volume), anorthoclase and orthoclase. The crystals are “welded” by a middle-grained matrix consisting of 3-5 mm crystals of feldspar (andesine), biotite, clinopyroxene (augite) and hornblende. The minerals of the matrix also occur as intergrowths in the large crystals of K-Na-feldspar. The accessory minerals are apatite, zircon, sphene, fluorite and opaque minerals. The giant-porphyric syenites occur as small to large stocks and dikes inside the giant-grained syenites. These rocks are special for the porphyric structure with 50-60% of feldspar crystals (Fig. 12C). In places, the amount of large crystals decreases to form evenly grained syenites.

Phase II (v§$C_3$-P). The granosyenites are exposed in the Kyzyl-Ompul mountains as stocks and dike-like bodies, which probably are parts of a single intrusive body. Their contacts with Phase I syenites are tectonic. The Phase II granosyenites are greyish-pink, brownish and grey rocks with medium-grained or porphyric structures. The medium-grained varieties have hypidiomorphic structure. The porphyric varieties occur mainly at the marginal parts of the intrusions/stocks and have hypidiomorphic mesostasis. All varieties consist of K-feldspar (~ 50%), plagioclase (20%), quartz (12%), biotite (9-10%) and hornblende (8-9%). The hornblende is a secondary mineral replacing clinopyroxene. The accessory minerals are sphene, apatite, zircon, orthite, rutile and magmatite.

Phase III (vP?). The alaskite granites of Phase III intrude the syenites of Phases I and II and probably represent the youngest granitoids in the study area. They form two separate bodies in the Kyzyl-Ompul Mts. and at the Shyrgyi River mouth. The Phase III pink to meat-red granites are fine- to medium-grained, locally porphyric. They consist of feldspar (40-60%), quartz (40-50%), albite-oligoclase (<5%) and biotite (< 2%). The accessory minerals are apatite, magnetite and zircon.

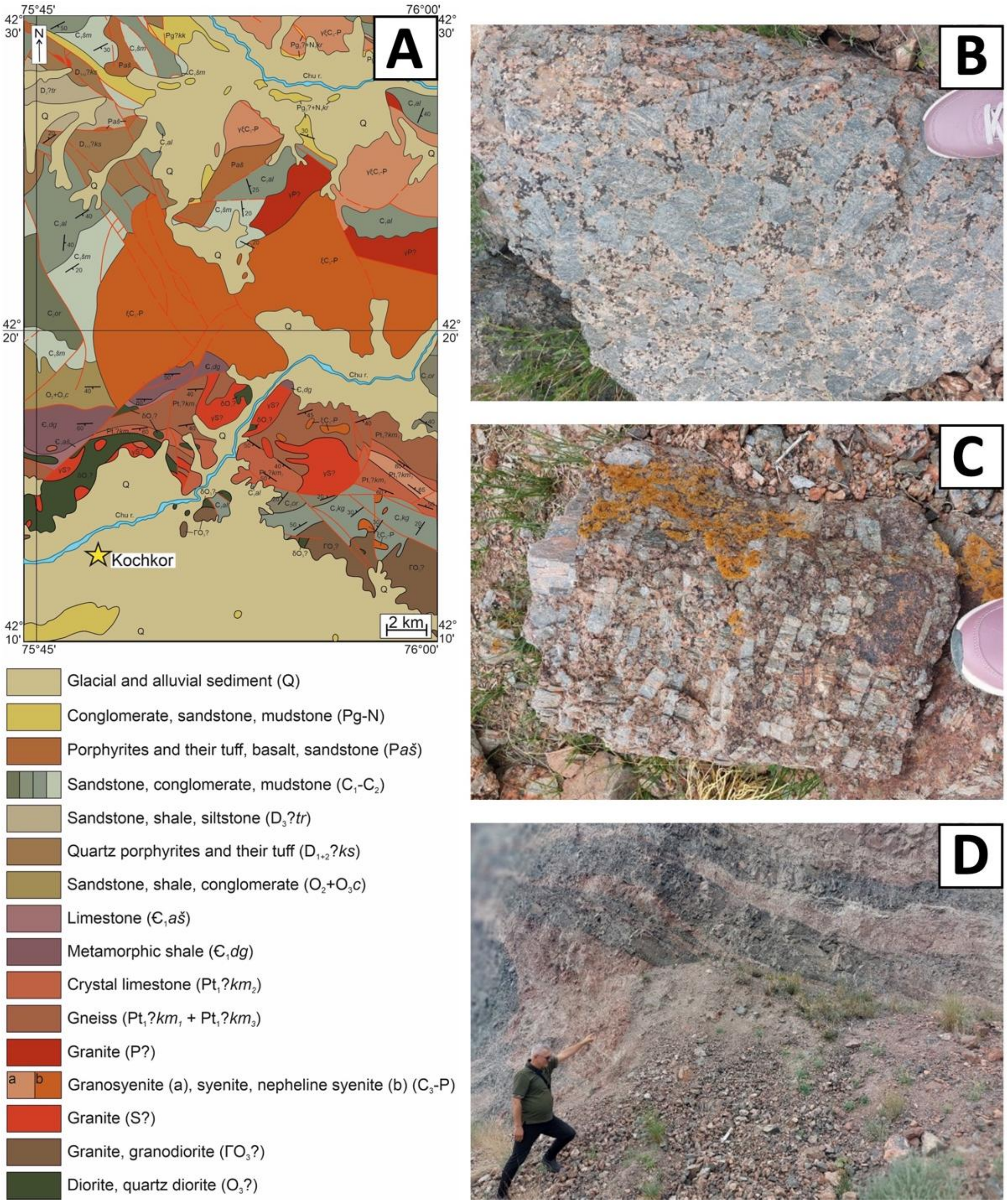



**Fig. 12.** Kyzyl-Ompul Complex of alkaline giant-grained granitoids. A, a fragment of the 1/200,000 geological map (1961); B, giant-grained syenite; C, mafic dikes/sills; D, giant-porphyric syenite.

The intrusions of all three phases have hot contacts with sediments containing late Carboniferous fauna and volcanic rocks of possibly Permian age. No precise isotope ages from the Kyzyl-Ompul granitoids have been obtained so far. The syenites of probably Phase I are cut by dikes and sills of mafic rocks (Fig. 12B): gabbro, microgabbro, dolerite of possibly Permian age, although no robust age constrains are available as well. We will observe probably Phase I syenites and mafic dikes/sills cropping out approximately 20 km north of Kochkor Vil. (Fig. 12A).

**Stop 8, Kumtor Deposit**

The Kumtor gold deposit is located in the western Tien-Shan (Fig. 13) and represents a super-large black shale gold deposit (Pak and Ivleva, 2015). The Kumtor Deposit is one of the largest gold mines in Central Asia that has being explored for gold since 1997. Being located at an altitude of 4000 m, the mine is the second highest in the world after they Yanacocha Deposit in Peru. The deposit is mined by open-pit mining techniques utilizing typical drill, blast and truck/loader or truck/shovel operations. The ore is delivered to the crusher and further to the mill, where gold is extracted using a carbon-in-leach technology. The rated throughput is approximately 16 tons of ore per day. The mine is the largest private sector employer and taxpayer in Kyrgyzstan. The reserves of the deposit were estimated at 717 tons with an average grade of 4.4 g/t. (Nikonorov et al., 2004). Over the past 20 years, reserves and resources of the Kumtor gold field have increased to 1,000 tons (Jenchuraeva et al., 2020). Until now, more than 420 tons of gold have been mined.

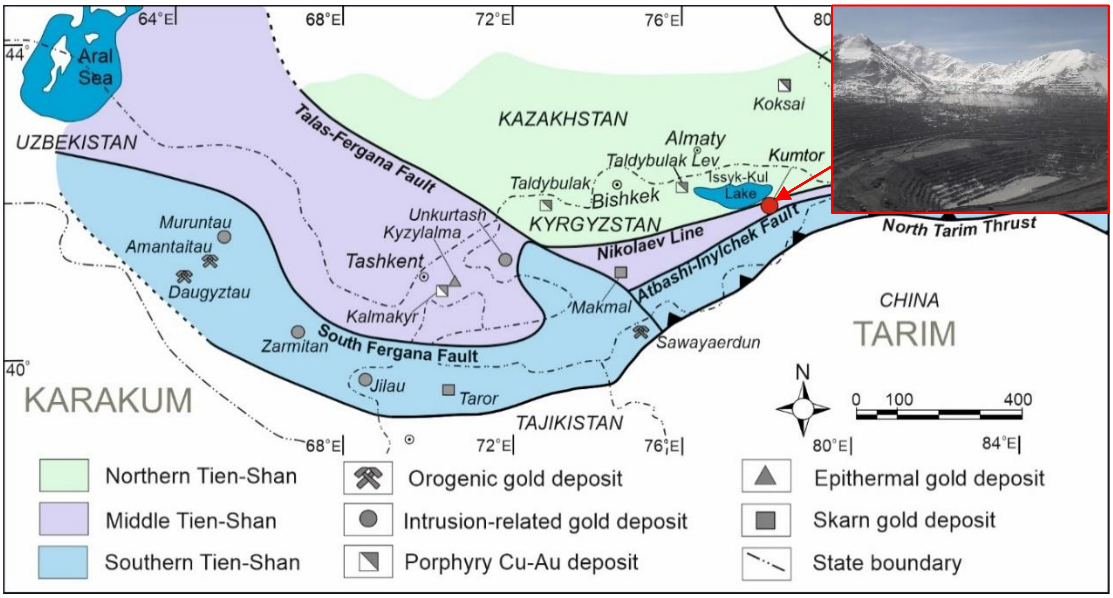



**Fig 13.** Tectonic map of the western Tien Shan showing the location of major gold deposits. Red circle is the location of the Kumtor gold deposit.

The deposit is represented by an ore-bearing zone stretched along the Kumtor thrust fault (Fig. 14). The hanging wall hosts Vendian ore-bearing black shale, while the footwall exposes small blocks of lower Paleozoic limestone, chert and siltstone, and lower Carboniferous limestone. The fault is expressed by a thick (100-250 m) zone of crushing, boudinage and limonitization. The fault arose in the place of an older thrust and was repeatedly reactivated in late Hercynian and Alpine times. This zone consists of a clay matrix hosting fragments of limestone, chert, black shale and sandstone of various ages (Nikonorov et al., 2004) and rare boudins of late Neoproterozoic – early Cambrian rhyolite, trachydolerite and syenite (Konopelko et al., 2014) occur in the alpine tectonic zone that bounds the deposit to the northwest.

Gold mineralization is localized in carbonaceous shale, siltstone, tilloid and carbonate-shale rhythmic packages. The main ore-bearing formations are carbonaceous rocks with disseminated pyrite mineralization. The gold mineralization is accompanied by quartz-K-feldspar, quartz-albite and quartz-carbonate metasomatites (Jenchuraeva et al., 2020), which contain gold-bearing veins of pyrite with gold present as thin veinlets and disseminated small grains. About 90% of all gold is confined to hydrothermal pyrite, the remain part is hosted by quartz, carbonate, feldspar, and scheelite (Shevkunov et al, 2022). Gold in ores is found in native, finely dispersed and telluride forms. Ore-bearing bodies form stockworks and mineralized zones.

The U-Pb zircon age of 293.1 ± 1.7 Ma (Ivleva et al., 2022; Asilbekov, pers. comm.) obtained from a Kumtor granite (emplacement age) is close to the $^{40}Ar/^{39}Ar$ age of 285.4 ± 0.2 Ma obtained from sericite-bearing rocks (gold mineralization age) (Mao et al., 2004), suggesting temporal and possibly genetic relationships between the granite and gold mineralization.

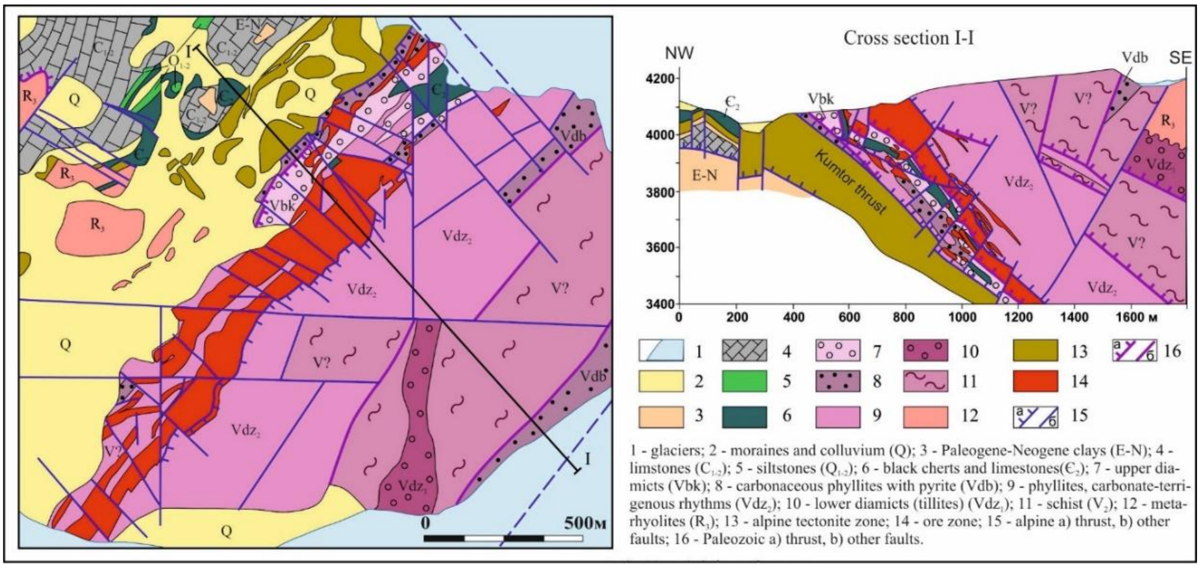



**Fig. 14.** Geological map and cross-section of the Kumtor gold deposit (based on materials from the Kumtor Gold Company).

**Stop 9, Uchkuduk - a Cenozoic intra-plate volcano**

There are numerous Phanerozoic localities of continental intra-plate basalts in the Central Asian Orogenic Belt (CAOB). The intra-plate basalts occur as plateaus and fields of volcanoes of different ages. Among them are Late Cretaceous–Paleocene volcanic fields of the North Tien Shan, which have been studied by many researchers, who identified their intra-plate origin and suggested their relation to mantle plumes based on geological geophysical and geochemical data (e.g., Sobel and Arnaud, 2000; Vinnik et al., 2004; Simonov et al., 2015). The basaltic rocks commonly occur as dikes and stocks intruding Paleozoic rocks (or flows and sills intruding Cretaceous–Paleocene sediments.

The Uchkuduk volcanic field belongs to the Central Asian Meso-Cenozoic province of plume-related intraplate basalts (Simonov et al., 2015). It is located west of Lake Issyk-Kul (Fig. 4). The previous geochronological studies of Meso-Cenozoic intra-plate basaltic complexes showed that the intraplate volcanics of Kyrgyzstan have Late Cretaceous to the Paleocene age. The basaltic stocks and dikes intrude Carboniferous sand-silt deposits and the Paleogene Suluterek Fm., which, in turn, are overlain by the Neogene sediments (Fig. 15). The basalts are dominated by alkaline varieties and are characterized by high $TiO_2$ (2.0-2.7 wt. %). Geochemical data from Uchkuduk basalts support their plume-related origin: they are moderately to strongly enriched in all typical plume-related incompatible elements, such as La, Nb and Ti, i.e. in general they are compositionally similar to continental and oceanic hot spots, such as Cenozoic magmatic complexes of Central Mongolia and Hawaii (e.g., Yarmolyuk et al., 2008; Regelous et al., 2003). The Uchkuduk lavas are characterized by high TiO2 (1.9–2.9 wt.%), LREE ($La/Sm_n$ = 2.3–4.3) and Nb (27–89 ppm) (Simonov et al., 2015). In addition to the enrichment in most incompatible elements, the most prominent feature of the Uchkuduk plume-related basalts is the presence of Nb positive anomalies in the multi-element patterns. The increased $Gd/Yb_n$ ratios (2.6–3.8) is also typical of most plume-related volcanics, are indicative of garnet fractionation and the derivation of parental melts ay depths of 60 km and more. The melt inclusions show that the parental magmatic melts were generated at high temperatures ranging from 1245°C (olivine) to 1110°C (clinopyroxene). Their formation and eruption were triggered by the Tien Shan Plume about 480 km in diameter. The mantle beneath the Tien Shan Plume shows characterized by increased velocities of S-type seismic waves and thinned mantle lithosphere at depths of 130 to 220 km (Vinnik et al., 2004).

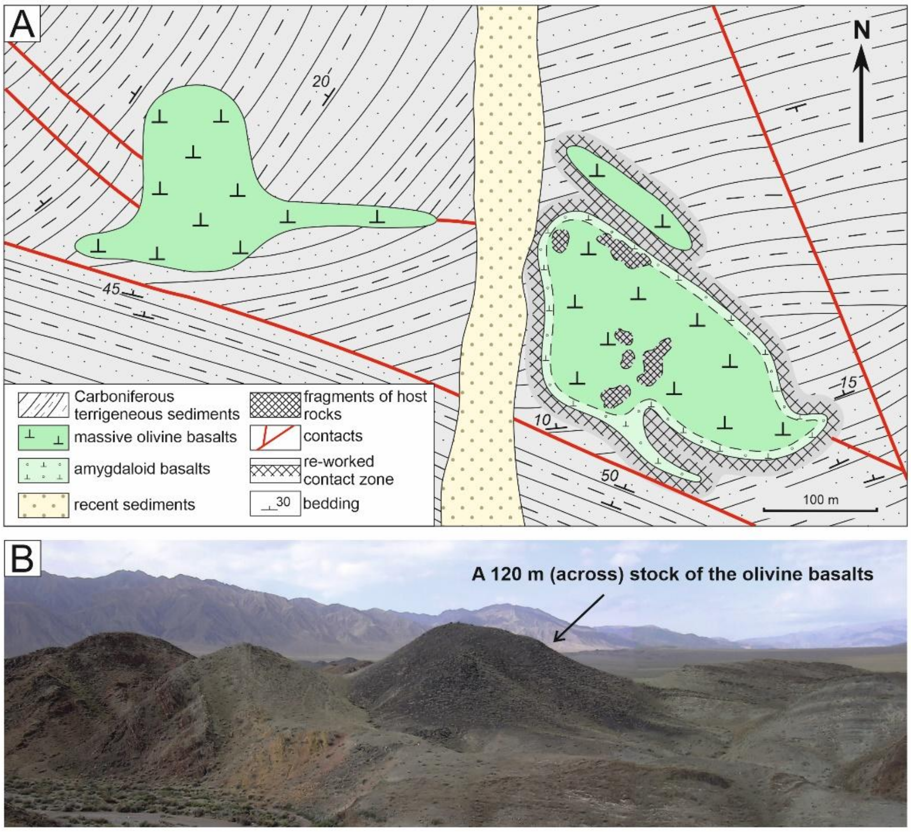



**Fig. 15.** Geological map (A) and a photo (B) of the Uchkuduk volcanic field.

## References

Alexeiev, D.V., Kröner, A., Kovach, V.P., Tretyakov, A.A., Rojas-Agramonte, Y., Degtyarev, K.E., Mikolaichuk, A.V., Wong, J., Kiselev, V.V., 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.

Bakirov, A.B., 1999. Evolution of the Tien-Shan lithosphere. Izvestiya NAN KR, 3-14 (In Russian)

Bakirov, A.B. and Maksumova, R.A., 2001. Geodynamic evolution of the Tien-Shan lithosphere. Russian Geology & Geophysics, 42(10), 1435-1443.

Bakirov, A.B., Korolev, V.G., Kiselev, V.V., 1980. The Earth's crust of the Tien-Shan: composition, structure and evolution. Izvestiya AN Kirgizskoi SSR, 2, 3–13 (In Russian).

Bakirov A.B., Tagiri M., Takasu A., Sakiev K.S., Orozbaev R.T., Bakirov A.A., Togonbaeva A.A., Satybaev M.M., Baslakunov J.U., Monograph of "(U)HP terranes of Tien-Shan", (Eds: Bakirov A.B. & Orozbaev R.T.), Bishkek, Ilim, 2017, 232 pp.

Biske, Y.S., Seltmann, R., 2010. Paleozoic Tian-Shan as a transitional region between the Rheic and Urals-Turkestan oceans. Gondwana Research 17(2-3), 602–613.

Degtyarev, K.E., 2012. Tectonic evolution of the early Paleozoic island arcs and continental crust formation in Caledonides of Kazakhstan. GIN RAS, Transactions 602. GEOS, Moscow 289 p. (in Russian)

Dobretsov, N.L., Berzin, N.A., Buslov, M.M., 1995. Opening and tectonic evolution of the Paleo-Asian Ocean. International Geology Review 37, 335–360.

Djenchuraeva, A.V., Zakharov, I.L., Zhukov, Y.V., Getman, O.F., Maksumova, R.A., Neyevin, A.V., Nogaeva, L.P., Rinenberg, R.E., 2015. Stratified formations of Kyrgyzstan. KRSU, Bishkek, 338 p. (in Russian)

Excursion Guidebook "Tectonic evolution and crustal structure of the Tian Shan belt and related terrains in the Central Asian orogenic belt". Bishkek, 120 p.

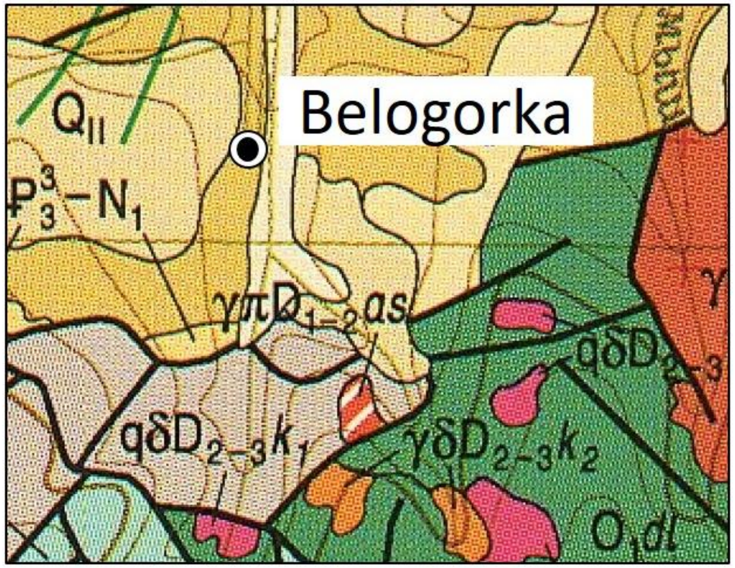
Geological map of the USSR, 1961. North Tien Shan Series. 1/200 000. North Tien Shan Series. Sheet K-43-XXII. Eds: Glasovskiy, A.G, Mozolev, L.N. (in Russian)

Ivleva, E.A., Pak, N.T., Asilbekov, K.A., Skrzypek, E., Hauzenberger, Ch., Orozbaev, R., 2022. Gold

mineralization in connection with Permian magmatism in the eastern part of the Southern and Middle Tien Shan (Kyrgyzstan). Vestnik KRSU 22(4), 180–191.
Jenchuraeva, R., Pak, N., Nikonorov, V., Ivelva E., 2020. Gold deposits of Kyrgyzstan. Ilim, Bishkek, 494 p.
Konopelko, D., Biske, G., Seltmann, R., Petrov, S.V., Lepekhina, E., 2014. Age and petrogenesis of the Neoproterozoic Chon-Ashu alkaline complex, and a new discovery of chalcopyrite mineralization in the eastern Kyrgyz Tien Shan. Ore Geology Reviews 61, 175–191.
Maksumova, R.A., Bakirov, A.B., Sakiev, K.S., 2009. Tectonic zoning of Tien Shan Caledonides. International excursion and workshop “Tectonic evolution and crustal structure of the Tian Shan belt and related terrains in the Central Asian orogenic belt”. Abstract vol, Bishkek, 33–35.
Mao, J., Konopelko, D., Seltmann, R., Lehmann, B., Wen, C., Yitian, W., Eklund, O., Usubaliev, T., 2004. Post-collisional age of the Kumtor gold deposit and timing of Hercynian events in the Tien Shan, Kyrgyzstan. Economic Geology 99(8), 1771–1780.
Nikonorov, V.V., Karaev, Y.B., Borisov, F.I., Tolsky, V.I., Zamaletdinov, T.S., Larina, T.V., Gorbaneva, T.V., 2004. Gold of Kyrgyzstan. In: Geology and Conditions of Localization. NASI Publishing, Bishkek, 271 p.
Orozbaev R. T., Takasu A., Bakirov A.B., Tagiri M. and Sakiev K.S. (2010). Metamorphic history of eclogites and country rock gneisses in the Aktyuz area, North Tien-Shan, Kyrgyzstan: a record from initiation of subduction through to oceanic closure by continent-continent collision. J. Metamor Geol 28, 317-339.
Orozbaev R. T., Hirajima T., Bakirov A.B., Takasu A., Maki K., Yoshida K., Sakiev K.S., Bakirov A.A., Hirata T., Tagiri M., Togonbaeva A.A. (2015). Trace element characteristics of clinozoisite pseudomorphs after lawsonite in talc-garnet-chloritoid schists from the Makbal UHP Complex. Lithos, 226, 98-115.
Pak, N., Ivleva, E., 2016. Rare-earth mineralization in Kyrgyzstan: Location patterns and development prospects. Mining Journal 8, 55-61.
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.
Regelous, M., Hofmann, A.W., Abouchami, W., Galer, S.J.G., 2003. Geochemistry of lavas from the Emperor Seamounts, and the geochemical evolution of Hawaiian magmatism from 85 to 42 Ma. Journal of Petrology 44(1), 113-140.
Safonova, I., Maruyama, S., Kojima, S., Komiya, T., Krivonogov, S., Koshida, K., 2016a. Recognizing OIB and MORB in accretionary complexes: A new approach based on ocean plate stratigraphy, petrology and geochemistry. Gondwana Research 33, 92–114.
Safonova, I., Biske, G., Romer, R.L., Seltmann, R., Simonov, V., Maruyama, S., 2016b. Middle Paleozoic mafic magmatism and ocean plate stratigraphy of the South Tianshan. Gondwana Res. 30, 236–256.
Safonova, I., Savinskiy, I., Perfilova, A., Obut, O., Gurova, A., Krivonogov, S., 2024. A new tectonic model for the Itmurundy Zone, central Kazakhstan: linking ocean plate stratigraphy, timing of accretion and subduction polarity. Geoscience Frontiers 15(4), 101814.
Sengör, A.M.C., Natal'in, B.A., Burtman, V.S., 1993. Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia. Nature 364, 299–307.
Shevkunov, A.G., Guda, A.A., Skorynina, A.A., McKnight, S.W., 2022. Studies of mineral composition of ores of the Kumtor deposit (Central Tien Shan) by GXRD and XRF methods. Mineralogy 8(3), 79-101.
Simonov, V.A., Mikolaichuk, A.V., Safonova, I.Y., Kotlyarov, A.V., Kovyazin, S.V., 2015. Late Paleozoic–Cenozoic intra-plate continental basaltic magmatism of the Tienshan–Junggar region in the SW Central Asian Orogenic Belt. Gondwana Research 27(4), 1646–1666.
Sobel, E.R., Arnaud, N., 2000. Cretaceous–Paleogene basaltic rocks of the Tuyon basin, NW China and the Kyrgyz Tian Shan: the trace of a small plume. Lithos 50(1-3), 191–215.
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).Vinnik, L.P., Reigber, C., Aleshin, I.M., Kosarev, G.L., Kaban, M.K., Oreshin, S.I., Roecker, S.W., 2004. Receiver function tomography of the central Tien Shan. Earth and Planetary Science Letters 225(1-2), 131–146.
Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A., Badarch, G., 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. Journal of the Geological Society of London 164, 31–47.
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.

# Graphical Summary

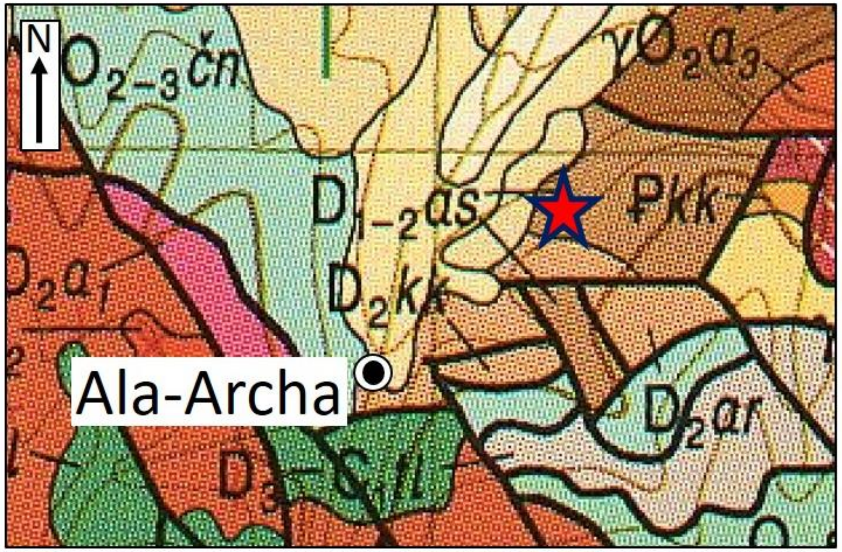
**Sept 8, Stop 1-1, Belogorka site**




- Sandstone, siltstone, mudstone, conglomerate ($D_3$-$C_1$)
- Greywacke, gravelstone, siltstone, shale ($O_{2-3}$)
- Reddish sandstone, siltstone, shale, limestone ($O_1$)
- Granosyenite, granodiorite ($D_{2-3}$)
- Monzodiorite, diorite, gabbrodiorite ($D_{2-3}$)

The outcrops at this site consist of **late Ordovician** conglomerate, sandstone, dolerite, basalt, andesi-basalt, trachyandesite, siliceous mudstone and tuffs, which carry no fauna, but **conformably overlie middle Ordovician** deposits. This volcanogenic –sedimentary package is **intruded** by early **Carboniferous plagiogranite** and Qu-porphyry to form hornfels.

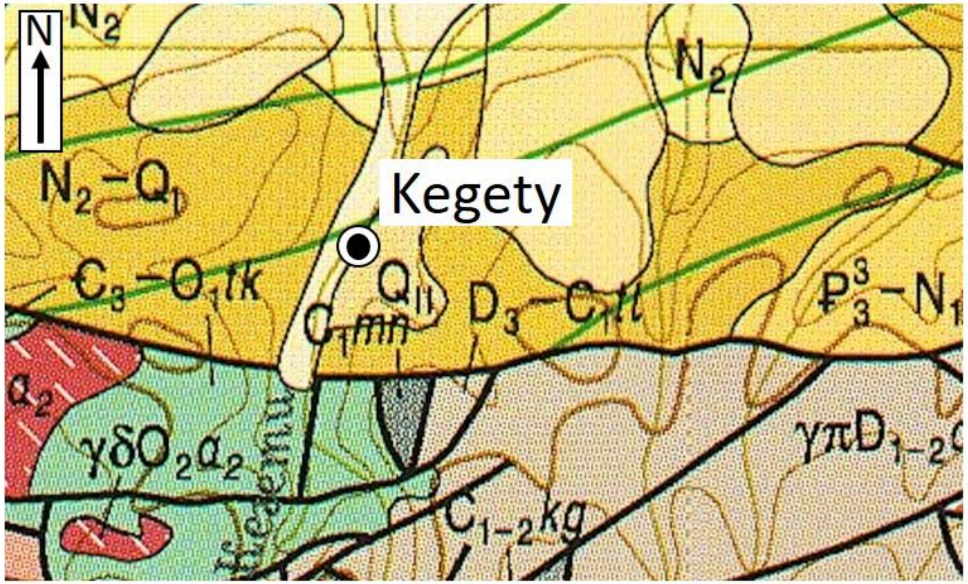
## Sept 8, Stop 1-2, Ala-Archa site



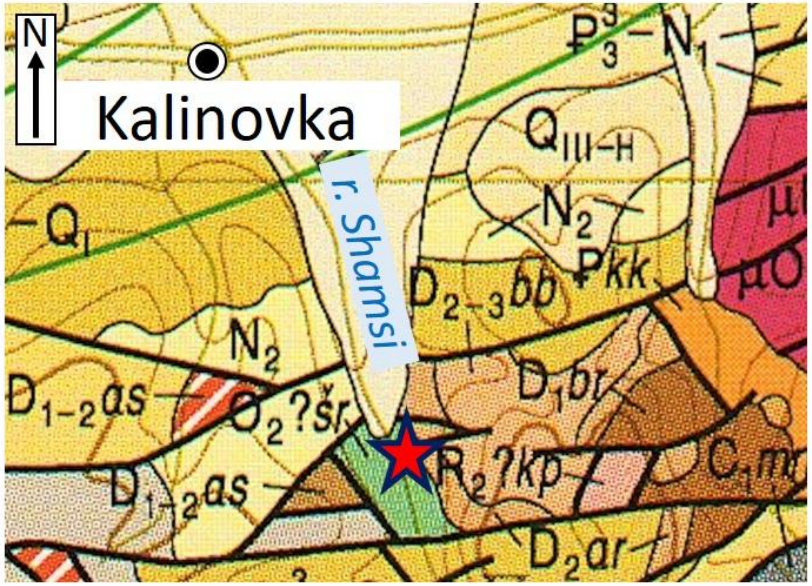

- Sandstone, siltstone, mudstone, conglomerate ($D_3$-$C_1$)
- Basalt, andesibasalt, tuff, tuffaceous sandstone ($D_2$)
- Reddish sandstone, conglomerate ($D_2$)
- Pillow-lava, acidic tuff, trachydacite, tuffaceous sandstone ($D_{1-2}$)
- Greywacke, gravelstone, siltstone, shale ($O_{2-3}$)
- Reddish sandstone, siltstone, shale, limestone ($O_1$)
- Diorite, monzodiorite ($O_2$)

The outcrops are **late Ordovician turbidites** (as blocks) and Devonian lavas. The boundary between these two units is hidden. There are also granitoids, possibly Ordovician.

## Sept 8-9, Kegety Valley, guest house Ak-Bozui




## Sept 9, Stop 3, Shamsi site

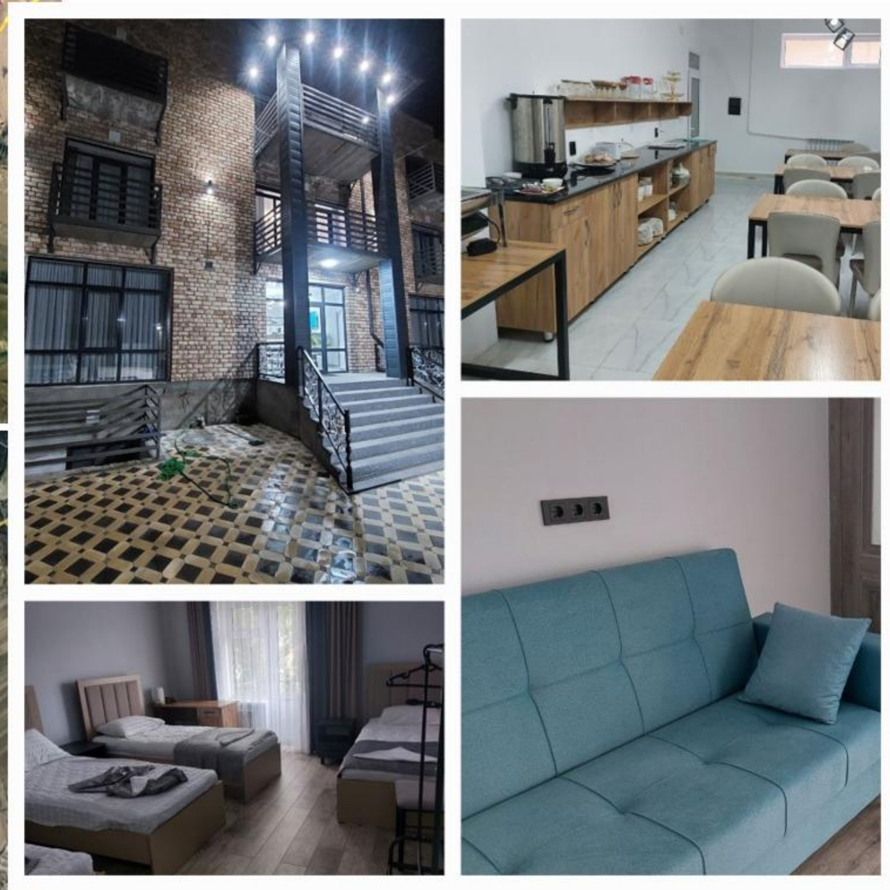



- Sandstone, siltstone, mudstone, conglomerate ($D_3$-$C_1$)
- Gravelstone, sandstone, andesite, dacite ($D_{2-3}$)
- Basalt, andesite, dacite, tuff-sandstone ($D_{1-2}$)
- Volcanic rocks, intermediate-acidic tuff, ignimbrite ($D_1$)
- Basalt, andesite, dacite, rhyolite ($O_2$)

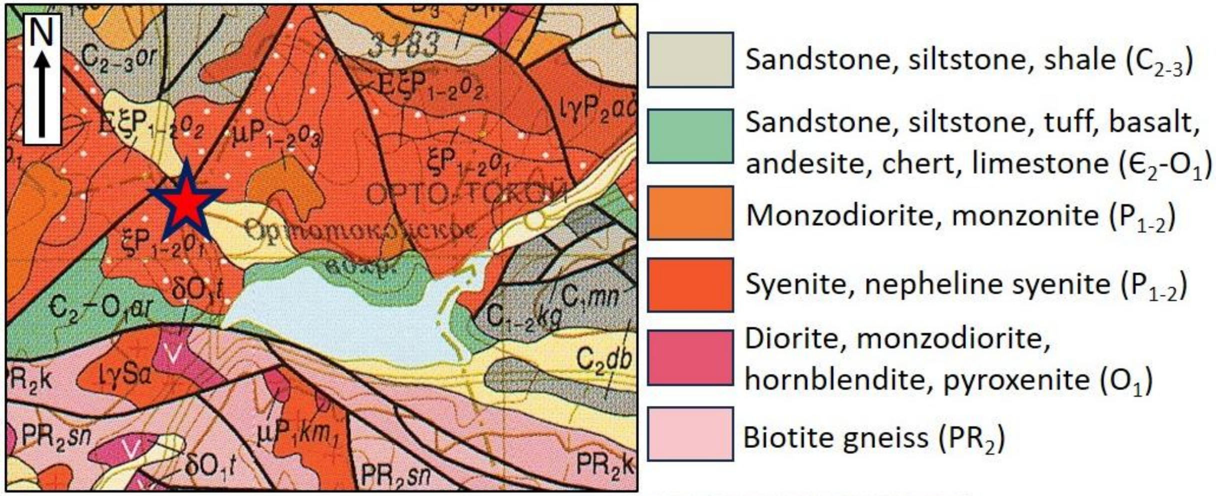

The volcanogenic-sedimentary section is well exposed in a canyon of the Shamsi River 8 km SE of Kalinovka Vil. The **volcanic rocks** are associated with **clastic rocks** of the **middle Ordovician** Shyrgyi Fm. The volcanics are black to dark- grey **aphyric basalts**, grey and greenish **porphyric basalts** and **andesibasalts**, in places, they occur as **pillow-lavas**.

## Sept 9-11, 2 nights, Kochkor Vil., Hotel Bagysh





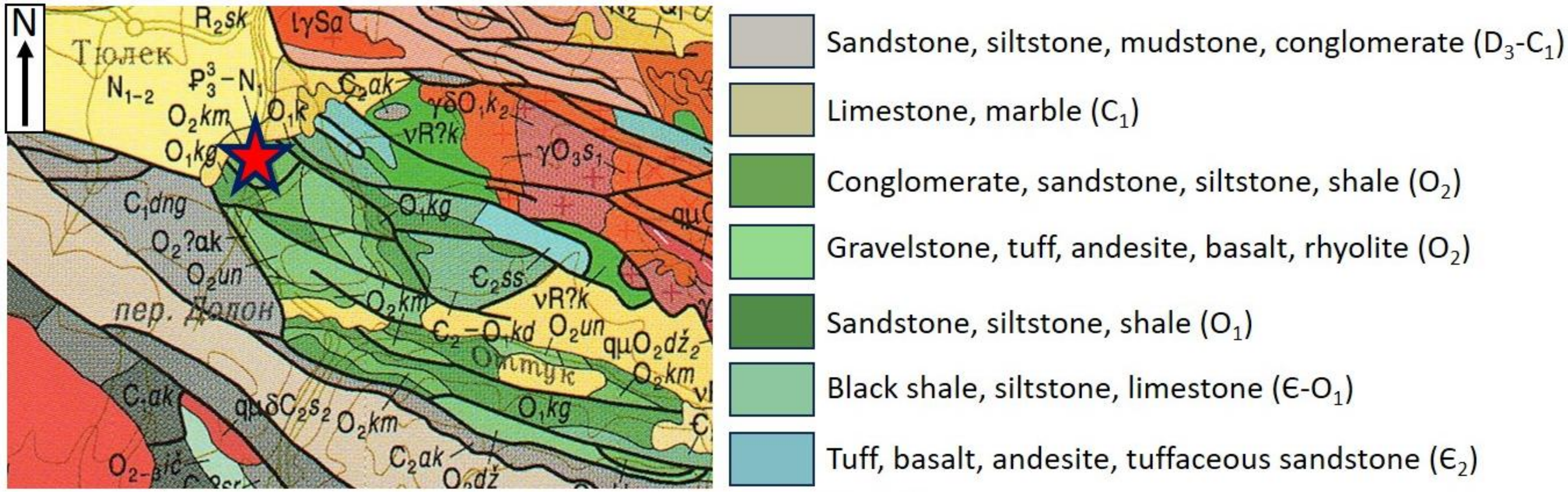
## Sept 10, Stop 4, Kyzyl-Ompul site




The **late Carboniferous(?)-Permian** igneous complex hosts granitoids of **three phases** of magmatism: **syenitic**, **granosyenitic**, **granitic**, possibly, of **intra-plate** origin.

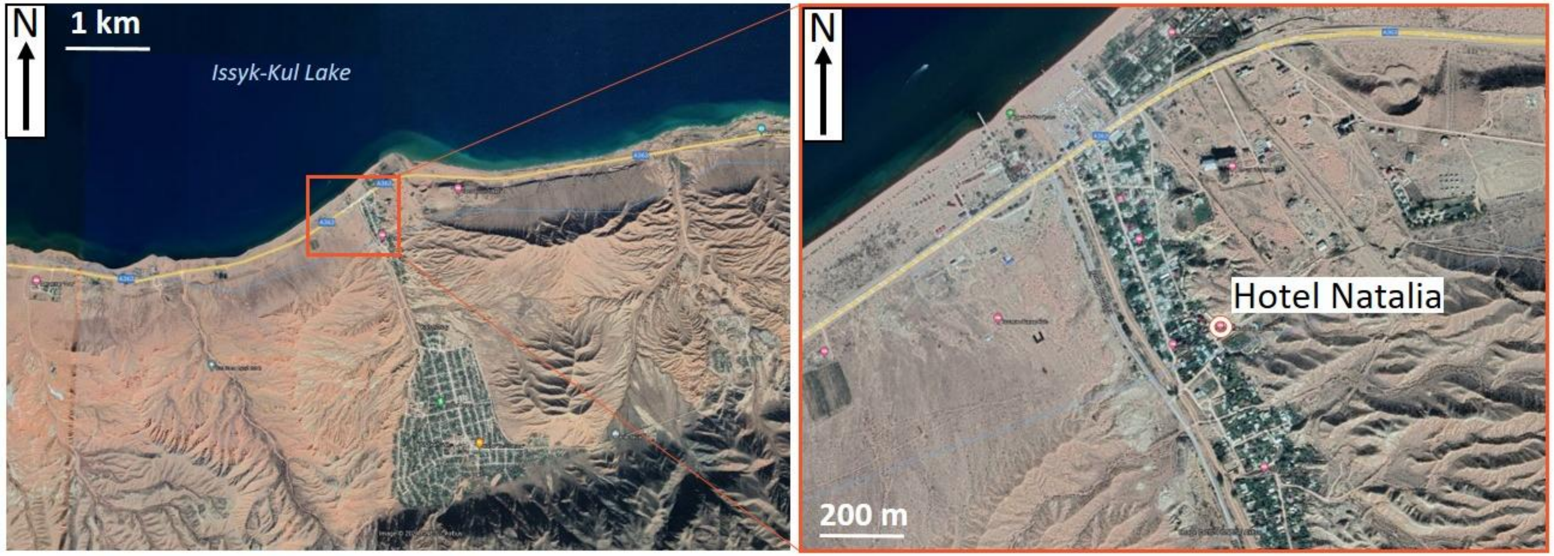
The intrusions of all three phases have **hot contacts** with **sediments** containing **late Carboniferous fauna** and mafic volcanic rocks of possibly Permian age. **No precise isotope ages** from the Kyzyl-Ompul granitoids have been obtained so far.

## Sept 11, Stop 5, Dolon site

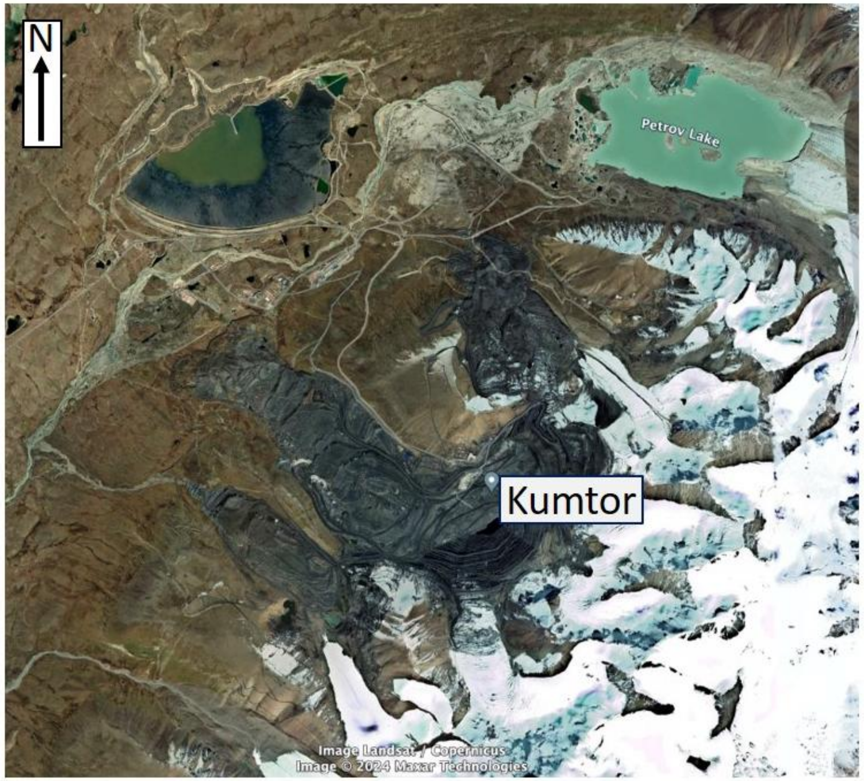



The Dolon section consists of **turbidites** (tuff sandstone, siliceous mudstone, gravel stone, conglomerate) and limestone of the Karadjorgin Fm. of **late Cambrian-early Ordovician age** (microfossils age constraints). The total **thickness** is about **1 km**. The clastic formations are **unconformably overlain** by ocean plate stratigraphy (OPS) rocks: chert, basalt, gabbro and plagiogranite. This section can be studied **for reconstructing** polarities of fossil **subduction zones** and **magmatic arcs**.

# Sept 11-13, 2 nights, Kadzhi-Say Vil., Hotel Natalia




## Sept 12, Stop 8, Kumtor gold deposit mine




The **U-Pb age of zircon** from Kumtor **granite** is **293.1 ± 1.7 Ma** (*Ivleva et al., 2022*) and the **$^{40}Ar/^{39}Ar$ age of sericite rocks** is **285.4 ± 0.2 Ma** obtained on (the **age of gold mineralization**; *Mao et al., 2004*), suggesting a **link between** the **intrusion of granite** and **gold mineralization**.

The Kumtor gold deposit is located in the eastern Northern Tien-Shan. It is the **largest** black shale **gold deposit** of **Central Asia** and **second top in the world**.

The mine is located at an **elevation** of **4000 m** and has been being explored since 1997.

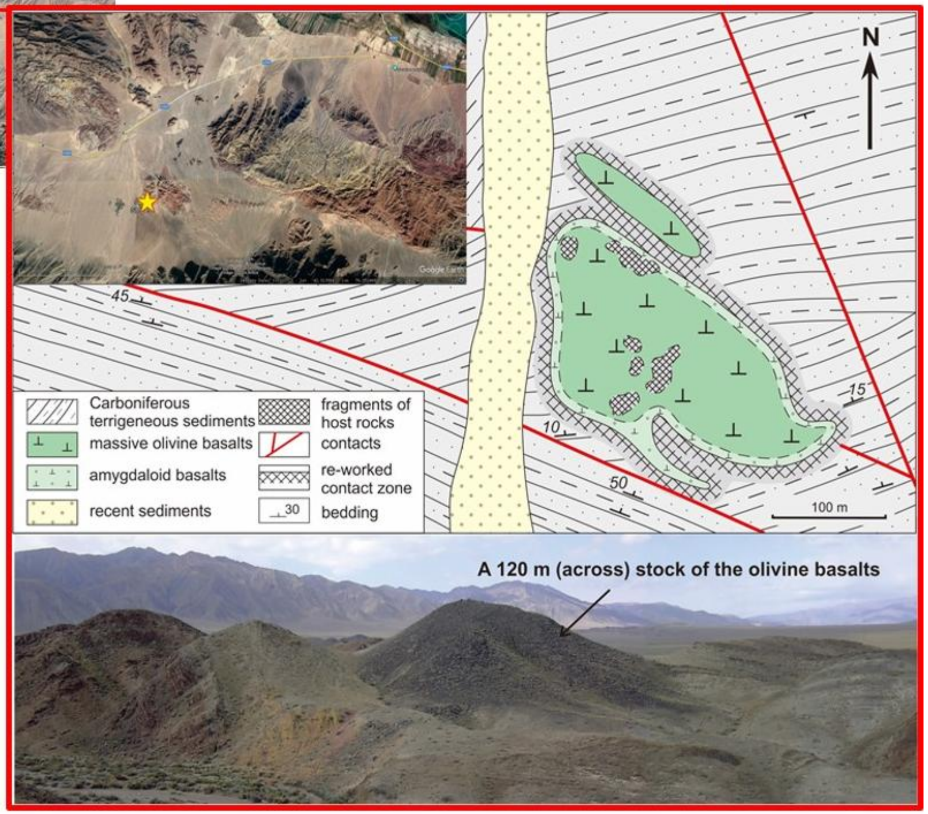
The reserves are ca. **1000 tons** with an average grade of **4.4 g/t**, of which more than 420 tons of gold have been already mined.

The hanging wall consist of **Vendian** ore-bearing **black shales** and the footwall hosts small blocks of **lower Palaeozoic limestone**, **chert** and **siltstone**, and **lower Carboniferous limestone**.

Gold **mineralization** is **linked with carbonaceous shales** and **siltstones** and hosted by hydrothermal pyrite, quartz, carbonates, feldspar, and scheelite in quartz-K-feldspar, quartz- albite and quartz-carbonate metasomatites (*Jenchuraeva et al., 2020*).

## Sept 13, Stop 9, Uchkuduk volcano


The Uchkuduk volcanic field belongs to the Central Asian Meso-Cenozoic province of **plume-related intraplate basalts** (*Simonov et al., 2015*).




**Late Cretaceous - Paleocene age**

The basalts are dominated by **alkaline** varieties and are characterized by **high** $\mathbf{TiO_2}$ (2.0-2.7 wt.%).

They are compositionally **similar** to **continental** and **oceanic hot spots**, such as **Cenozoic** magmatic complexes of **Central Mongolia** and **Hawaii**.

Their **formation** and eruption were **triggered** by the **Tianshan Plume** about 480 km in diameter.