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The structural positions of the ophiolite complex in the Earth crust of the western Tien-Shan

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Abstract. The westernmost parts of the Tien Shan region are located between two areas of crustal suturing, formed by the closure of the Turkestan Ocean, and probably the closure of a second ocean, the Gissar Ocean. Regional correlation of these sutures, however, has been problematic due to the lack of geological and geophysical data, as well as conflicting interpretations within the literature of various geological bodies. We summarize the information about Paleozoic ophiolites of westernmost parts of the Tien Shan for the international geoscientific audience from the literature and our own unpublished data. We focus on the best-known examples of Southern Tien Shan ophiolites which are remnants of Paleo-Asian Ocean, aligned in two main belts in Uzbekistan. Ophiolites reveal a wide age spectrum ranging from the Ordovician to the Devonian on the northern slope of Southern Tien Shan, and the Early Carboniferous on the southern slope. Considering all data on these ophiolites as well as regional considerations lets us conclude that a single ocean located subduction of the Turkestan Ocean basin under the northern Karakum-Tadjik terrane caused back-arc continental rifting in the Gissar region in Early Carboniferous resulted in the formation of a small basin with oceanic crust. By late Carboniferous/early Permian times, both oceanic basins were subducted.

1. Introduction

The South Tien Shan, separated from the Middle Tien Shan by the South Tien Shan Suture (Turkestan Suture; [1-3]), is a Late Palaeozoic-age, fold-and-thrust belt formed during the closure of the Turkestan Ocean (Central Tien Shan Ocean; [4-6]). On the territory of Uzbekistan, the ocean is established according to the suture traced from Bukantau and Northern Nuratau, along the northern foothills of the Turkestan-Alai structures up to the Baubashata mountains. After the Talas-Fergana fault, the ophiolite belt extends to Kokshaal and further along the Tarim and North China microcontinent to Mongolia [1].

The southern (present-day coordinates) passive margin of the Turkestan Ocean, exposed today in the Gissar Segment, was built up on continental basement of apparent Neo-Mesoproterozoic age [7]. This basin was established in mid-Carboniferous times [8] following a period of continental rifting and related magmatism in the Tournaisian and Visean [9], and was related to the fragmentation of the Karakum-Tajik-Alai microcontinent into two separate components namely: the Karakum-Tajik fragment and the Alai fragment. Konopelko et al. [7] have suggested that this microcontinent, which formed the southern passive margin of the Turkestan Ocean shows evidence of extension in Early Carboniferous times. This extension resulted in the formation of the short-lived Gissar Ocean, separated from the Turkestan Ocean by the Gissar microcontinent (part of the Alai microcontinent). By late Carboniferous/early Permian times, both the Turkestan Ocean [6] and the Gissar Ocean [7] were closed.

However, whether suture zones of diverse ages represent the closure of a pre-existing “older” oceanic basin or, alternatively, represent marginal basins which opened behind an older subduction complex and subsequently closed, is rarely considered. Regardless of controversy about tectonic environment of formation and emplacement, ophiolites approximate the former locations of ocean basins and convergent margins, and are key paleo-plate tectonic indicators. Paleozoic ophiolites and the associated rift assemblages attest to a complicated history of ocean basins separated by microcontinents, involving rift-drift, seafloor spreading and supra-subduction zone oceanic crust generation [10, 11]. The purpose of this paper is to present a summary of the existing data about ophiolites of Uzbekistan and a tectonic synthesis of the western part of the Tien Shan.

2. Structural positions of Palaeozoic ophiolites of westernmost parts of the Tien Shan

Ophiolites of Uzbekistan reflect a complex, mostly Paleozoic assembly of westernmost parts of the Tien Shan and provide insight into suturing and terrane-accretion processes. Once a suite of rocks is identified as ophiolitic it is important to determine its initial tectonic setting to aid in tectonic and plate reconstructions. We summarize the information about Paleozoic ophiolites of westernmost parts of the Tien Shan for the international geoscientific audience from the literature and our unpublished data.

The present-day geographic distribution of the main ophiolite massifs in the Southern Tien Shan identifies three separate belts: the northern belt running from the Sultan - Uvais to South Fergana, the southern running from the Kuldjuktau to Karatyube and third one in South Gissar (Figure 1). The Talas-Fergana fault divides the Tian Shan into western and eastern parts and the Ural-Tyanshan strike-slip fault divides the Ural and Tian Shan parts. The available geophysical data indicate that northern belt stretches in a northwest direction through Sultan-Uvais Mountain towards Mugodzhar to the South Ural Mountains. The Sultan-Uvais oceanic sections supposed as a link between the Turkestan and Ural paleobasins [12,13]. The central strip of ultramafic formations of the Sultan- Uvais Mountains stretches across the entire ridge from northwest to southeast for almost 50 km with an average width of 2-2.5 km. The main mass of Sultanuwais serpentinites is located in the form of two bands. The first band is traced in the northern part of the ridge and lies among the main effusive rocks of the Djamansai Formation (D_1), the second band is located somewhat south of the first, forming interformational lenses along the contact of terrigenous-sedimentary rocks of the Koksai and sedimentary-effusive rocks of the Djamansai Formation. A number of small serpentinite bodies are also known among the ancient (S_1) metamorphosed terrigenous rocks. Ultramafic rocks are represented by serpentinites with minor dunites, peridotites, and pyroxenites. Serpentinites and products of their alteration (listvenite, talcite, pyroxenite, rodingite, talc-carbonate, actinolite, tremolite rocks, gabbro and gabbro-amphibolite, as well as plagiogranites developed in its eastern part [14,15]. The zone of outcrops of ophiolite complexes of the Sultan-Uvais Ridge to the surface has a considerable length and finds its expression in high positive magnetic field anomalies [16].

The Bukantau ophiolite complex combines ultramafic-mafic and plagiogranite bodies in the form of small tectonic lenses, tracing the zones of the South Bukantau and Boztau-Okjetpes deep faults. The complex is dominated by ultramafics, gabbros are of subordinate importance, plagiogranites are very rare [15]. Ultramafic rocks are completely altered, represented by serpentinites, phlogopite-serpentine, tremolite-actinolite-chlorite and talc-carbonate rocks (often with Cr-spinels, listvenites, and birbirites). Gabbros are transformed into gabbro-amphibolites; they, together with granites, are intensely cataclastic and mylonitized. Judging by the paragenesis of the newly formed minerals of gabbroids (bluish-green hornblende, actinolite, chlorite, albite, and albite-oligoclase), the metamorphism of the rocks occurred under conditions of greenschist and low steps of the amphibolite facies. The outcrops of rocks of the Bukantau complex are spatially separated, their age relationships are unclear, and their chemistry has not been sufficiently studied.

The mafic-ultramafic formations of the Northern Tamdytau are divided into two formational complexes: the Tamdy gabbro-peridotite and the Jamankyngyr gabbro-plagiogranite complexes [17, 18, 19]. They are confined to the zone of the Muruntau-Nurata deep fault and are located in its feathering structures at the contact of the Silurian and Riphean formations. The Tamdy complex includes most of the outcrops of ultramafic and mafic rocks of the region. It includes the Teskuduk-Chengeldy massif and the Uchkuduk-Tyumenbay ophiolite band. The first is composed of peridotites, pyroxenites, gabbros, and serpentinites. The Uchkuduk-Tyumenbay strip is located to the south and can be traced at a distance of more than 10 km. It is dominated by serpentinites with relics of peridotites (wehrlites). They are located among the Riphean, Cambrian and Ordovician formations, represented by amphibolites, chlorite-sericite-quartz schists, gneisses, sandstones and siltstones. The following sequence of occurrence of individual members of the ophiolite association is noted: the lower part of ophiolites is represented by serpentinites, altered wehrlites, clinopyroxenites, dunites, websterites, which gradually transform into gabbroids (total thickness 100-120 m); middle part (200 m) - ferrogabbro, leucogabbro, up to tonalites; upper part - plagiogranites. Ultramafic-mafic bodies are located among sandy-shale, siliceous and effusive rocks of the Kyngyr (S_2) and Balpantau (S_2-D_1) formations. Fragments of these rocks are found in the Carboniferous deposits.

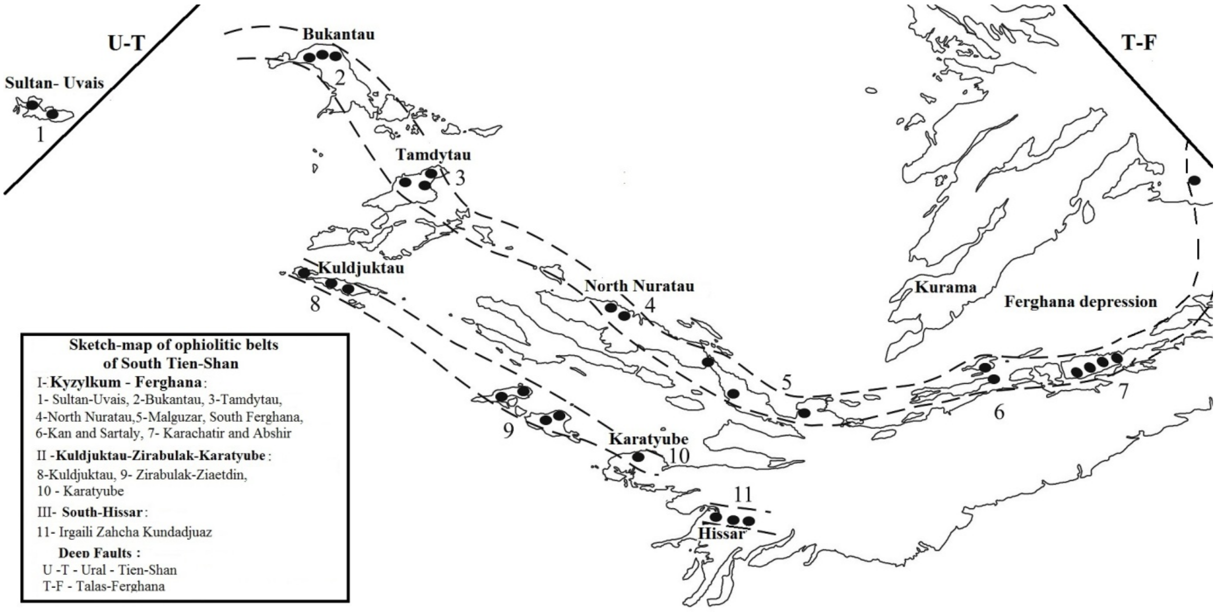

Figure1. Sketch map of ophiolitic belts of South Tien-Shan

Serpentinites and gabbroids of the North Nurata gabbro-peridotite complex occur among sandy-shale deposits of the Lower Silurian in the zone of contact with undivided metamorphic strata, as well as with spilite-diabases of the Lower Carboniferous [15]. They are marked in the form of small lenticular bodies with a total outcrops area of no more than 5 km. These bodies are located spatially in the form of a strip, which includes the following areas from northwest to southeast: Djadyr, Sentyab, Yangikishlak, Emchisay and Karakiyasay. In the Djadyr area, the rocks of the complex are represented by serpentinite bodies 1.5 x 0.3 km in size. In the Sentyab area, mafic and ultramafic rocks compose a number of lenticular bodies. They are represented by serpentinite, altered pyroxenite and gabbro. Vein and lenticular bodies of serpentinites and listvenites are developed in the Yangikishlak area. The largest outcrops of serpentinites (100 x 300-600 m) are exposed on the right slope of the Tanga-say.

Ophiolites of South Fergana are confined to the zone of the deep fault and extend in the latitudinal direction for a distance of over 150 km, forming two subparallel discontinuous stripes spaced 20-25 km [1, 2]. The first - Kan located in the zone of low foothills of the Alai, starts from the valley of the river Isfara and includes the Isfara and Uchkurgan bodies of serpentinites and the Kan massif, further to the east it passes into the Karachatyr strip. The second - Sartaly, located to the south, in the zone of high foothills of the Alai, starts from the valley of the river Sokh and through Sartaly, stretches to the east to the Abshir and Kirghizata strips. Alpine-type ultramafic rocks (mainly serpentinites) compose the Kan massif (26 x 0.2-1.0 km) in the northern foothills of the ridge Katran-Too and represent a large zone of serpentinite melange. The host rocks are greenstone metavolcanics and gabbro-amphibolites of the Kan Formation. The ophiolite belt of South Fergana Fergana on the meridian of Osh turns abruptly to the northwest, and then, after a loop-like bend in the Baubashata mountains (Fergana sigmoid), is cut off by the Talas-Fergana strike-slip [1, 2, 9]. The results of the study showed that the rocks of the ophiolite association are everywhere in tectonic relationships with sedimentary strata [8, 20, 21]. One of their stripes in the form of a giant curved arc can be traced along the eastern border of the Fergana depression. Throughout its entire length, the rocks of the ultramafic-mafic-gabbro complex are associated with metashists of the Maylisu Formation (an analogue of the Kan Formation). In some areas of this arc, serpentinite melange of two types is developed: polymictic melange, which, in addition to hyperbasites and gabbroids, contains blocks of Riphean and Silurian shales and Lower Carboniferous limestones, and monomictic melange, consisting of rocks of the ultramafic-gabbro complex [22]. An undisturbed section of the ophiolite association is exposed along the river Akjol in the core of a large anticlinal structure. The visible base of the section is composed of rocks of the ultramafic-gabbro complex associated with the Upper Riphean metaschists. The total thickness of the strata is more than 2000 m. According to the definition of leucogabbro, an absolute Early Silurian U-Pb age of 440 ± 6 Ma was obtained [23]. Noteworthy is the similarity of the shape of the outcrops of the Baubashata ophiolites with the ophiolite strip of the Sultan-Uvais ridge.

Ultramafic-mafic rocks of Zeravshan–Eastern–Alay belt of Hercynides outcrops now in southern Kyzylkum's mountains (Kuldjuktau, Zirabulak - Ziaetdin and Karatyube mountains) and stretch forward to the east in Zeravshan and Gissar Mountains, Karategin and up to East Alay where it is lost under overthrusts of the Alpine Pamir (1, 8, 24). In general, the tectonic environment for the origin of these ophiolites is not well understood and data on their geochemical signature are scarce. The Beltau gabbro-peridotite massif is located at the western end of the Kuldjuktau ridge and is located among dolomitized, marbleized limestones, dolomites and siliceous-carbonate rocks of the Upper Silurian and Middle Devonian. The massif has a two-phase structure: the first phase is peridotite (serpentinized plagioclase-bearing lherzolites), the second is gabbroids (troctolites, olivine gabbro, gabbronorites, gabbro-pyroxenites, titanium-augite and hornblende gabbros, leucogabbro and anorthosites, and their derivatives [25].

The Kutchi massif is located on the northern slopes of the Zirabulak mountains and is located among siliceous-mica schists, quartzites and greenstone rocks of the Silurian (S_1). The massif is composed of apogarzburgite serpentinites.

Ultramafic bodies of the Karatyube Mountains are located on the northern slopes, in the exocontact part of a large Karatyube granitoid massif. The rocks are located among the metamorphosed sandy-shale deposits of the Silurian (S_1). Ultramafic rocks form small (up to several hundred meters) lenticular bodies composed of serpentinized peridotites.

The South Gissar ultramafic-mafic belt runs along the southern slopes of the Gissar ridge for 150 km and is characterized by small lenticular bodies of serpentinites and gabbroids located in the South Gissar fault zone among the volcanic-sedimentary strata C_{1-2}. The largest of them are Kundadjuaz (Tupolang river basin, 0.7 km^2), Zakhcha (Yakkabag mountains - 0.2 km^2) and Irgailik (Almaly-Irgailik - 0.5 km^2). The bodies have a lenticular shape, their contacts with the surrounding Lower Carboniferous limestone-sandy-shale and volcanogenic rocks are tectonic. By composition, they are classified as gabbro-peridotite, peridotite-pyroxenite, and gabbro-plagiogranite formations. The Kundadjuaz massif is located in the southwestern wing of the Machetli anticline of the southwestern spurs of the Gissar ridge. From the northeast are located carbonate-sandy-shale deposits C_1, from the southwest the massif contacts with effusive-sedimentary stratum C_2, which includes conglomerates, tuffs, lavas, andesitic and diabase porphyrites. A stock-like gabbro body is exposed in the southwestern contact of serpentinites. The predominant part of the massif is composed of serpentinites, somewhat less gabbro-diabase, representing the next phase of intrusion. To the northeast there is a large Machetli granitoid massif, apophyses of which cut through gabbro and serpentinites. In terms of chemical composition, serpentinites are close to harzburgites and lherzolites [15].

The age of the ophiolite associations varies along the strike of the Southern Tian Shan. Ophiolite plagiogranites have an absolute age according to the U-Pb method of Late Cambrian zircon in the Sultan-Uvais area (c. 505 Ma) and Early Silurian c. 438 Ma in the west of Tamdytau, respectively [9]. In Nuratau, the determination of ophiolite metagabbros gave a U-Pb zircon age of 448 Ma [26]. In the south of the Sartala allochthon of Fergana and in the northern part of the Fergana ridge, ophiolite gabbros and basalts are overlain by cherts of the Early Ordovician and Silurian [2]. In the Mailisu area - at the most eastern outcrop of the ophiolites of the Southern Tian Shan up to the Talas-Fergana fault - according to the definition of leucogabbro, an absolute Early Silurian U-Pb age of 440 ± 6 Ma was obtained [23]. The Devonian U-Pb zircon age of 422 Ma was obtained for gabbro beyond the Talas-Fergana fault in Atbashi and Djanjir [27]. In general, when moving from west to east, a regular change of ophiolite formations by more young ones is revealed.

3. Discussion and implications

A review of the geodynamic evolution of the Turkestan and Gissar Oceans is beyond the scope of this paper and would require a number of complementary geological data, most of which are currently unconstrained. However, the data presented in this paper allow a reconstruction of the tectono-magmatic evolution that affected the westernmost parts of the Tien Shan region. In the Turkestan suture, the ophiolites contain MORB-like rocks and range in age from Cambrian to Carboniferous (ca. 509–350 Ma), suggesting major and long-lived oceanic basin [1,2,5, 9, 26]. It is generally accepted that the South Tien Shan Orogen resulted from the closure of the Turkestan (also called the South Tien Shan) Ocean followed by collision between the Karakum- Tajik and the Kazakh–Kyrgyz continents during the Late Paleozoic. In terms of its geodynamic position, our study area is located between the two main sedimentary – structural zones formed by a) the closure, in Late Carboniferous times, of the Turkestan Ocean [1,6,8], and b) the Gissar Ocean which closed in Carboniferous-Permian times [7,8]. As noted above, the Southern Tien Shan microcontinent was located between these two areas of crustal suturing. As a result, however, of the limited databases (both geological and geophysical) as well as the conflicting interpretations within the literature, it is difficult to: (1) correlate these two sutures laterally; (2) establish any form of definitive timing and kinematics for their tectonic evolution; and, (3) reconstruct the geodynamic evolution of the Southern Tien Shan region. Available age data for ophiolites and subduction-related volcanic rocks [2, 26] indicate the partial closure with the formation of an island arc in the northern part of the Turkestan Ocean [21] and possibly the formation of an active margin in the south [28], starting in the Ordovician and continuing into the Silurian.

Although there is broad agreement with regard to the existence of a subduction zone separating the Zeravshan-Eastern Alai region from the Karakum-Tajik microcontinent, there are differences of opinion in terms about how many oceans were involved in Palaeozoic geodynamic events, of their position and polarity [1, 8, 29,30]. These differences reflect interpretational variations of the geological and structural environments and the local, often limited, availability of data. Our study suggests more complex scenario than previously depicted for the tectono-magmatic evolution of the southern (present-day coordinates) passive margin of the Turkestan Ocean and provide new constraints for the definition of its possible evolution.

Thick Carboniferous-age volcanic piles unconformably overlie the Palaeozoic-age formations in the southern part of the Gissar range, extending for c. 150 km from the Baysun region of Uzbekistan to central Tajikistan and covering both sides of the inferred Gissar Suture. The oldest volcanics (Tournaisian-Visean) are present in Uzbekistan, and represent a rifting environment at a supra-subduction setting above a S-facing active plate margin [7]. A second volcanic formation (Bashkirian-Moscovian) indicate that magmas with transitional ocean ridge-supra- subduction signatures continued to form in the south Gissar range until this time. Analysis of the granitoids from the region would also suggest a supra-subduction setting as well as signatures typical for a continental arc environment [9]. The origin of the Gissar Suture, however, is unclear with a variety of possible interpretations suggested, including an oceanic or a rifted /marginal basin, or backarc rifting with subsequent partial breakup [1,8, 29,30]. A reconstruction for the Carboniferous would suggest that rifting in the Gissar region resulted in the formation of a small basin with oceanic crust subducting to the N as evidenced by the rift affinities of magmatic rocks found in the region [7] and by the evidence from the voluminous Andean-type supra-subduction Gissar Batholith located to the N.

Many authors [e.g., 1, 7, 29] suggest the existence of two separate oceanic basins, the Turkestan and Gissar Oceans. Other authors [e.g., 30 and references therein] suggest the existence of third - Zerafshan oceanic basin originally located between the Zeravshan region and the Karakum-Tajik microcontinent. Considering the position of ophiolites, it can be noted that to the north from South Gissar is located another one, Zeravshan–South Gissar belt of Hercynides. It outcrops now in southern Kyzylkum's mountains (Kuldjuktau, Zirabulak - Ziaetdin mountains) is stretch forward to the east in Gissar Mountains, Karategin and up to East Alay where it is lost under overthrusts of the Alpine Pamir [1; 8, 24]. We suggest that opening of the marginal basin designated by ophiolites that formed at the end of the Early Carboniferous at the boundaries of the Karakum–Tajik continents (southern Gissar, northern Pamirs) could not have been significant and explain the occurrence remnants of the oceanic lithosphere formed during the Silurian in Kuldjuktau, Zirabulak - Ziaetdin and Karatyube mountains. Since the Carboniferous, there has been a change in the geodynamic regime in the southern part of Turkestan Ocean. Subduction of its crust began under the Afghan-Tajik microcontinent, which eventually led to the emergence of the Gissar-Khiva magmatic arc, stretching for thousands of kilometers from the Gissar ridge in the east to the Sultan Uvais meridian in the west. The combination of counter motion movements of the Kazakh-Kyrgyz and Karakum-Tajik continents with the subduction of the crust of the Turkestan oceanic basin under them predetermined the formation of the fold-nappe structure of the Southern Tien Shan, and the emergence of volcano-plutonic belts superimposed on the edges of the Kazakh-Kyrgyz and Karakum-Tajik continents. Despite evidence that the Kuldjuktau, Zirabulak - Ziaetdin and Karatyube mountains formed a subduction-accretionary orogen in the Silurian, it appears that actual ocean closure was delayed until the Carboniferous.

4. Conclusion

We are at early stages of understanding the Paleozoic ophiolites of Uzbekistan and what they tell us about the evolution of the Turkestan and Gissar Oceans. Considering all data on these ophiolites as well as regional considerations lets us conclude that: (1) Ophiolites reveal a wide age spectrum ranging from the Ordovician to the Devonian on the northern slope of Southern Tien Shan, and the Silurian and Early Carboniferous on the southern slope; (2) A single ocean located between Kazakh–Kyrgyz and the Karakum-Tajik continents existed from Late Cambrian to Late Carboniferous; (3) Subduction beneath the Kazakh-Kyrgyz continent proceeded from Silurian through to Devonian times with partial closure with the formation of an island arc in the northern part of the Turkestan Ocean and the formation of an active margin in the south followed by a dormant phase through to the early Carboniferous; 4) Southward subduction of the Turkestan ocean basin under the northern Karakum-Tadjik terrane in Early Carboniferous caused back-arc continental rifting in the Gissar region resulted in the formation of a small basin with oceanic crust; 4) By late Carboniferous/early Permian times, both basins were subducted.

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