Nappes of the southern Tien Shan

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[1] The southern Tien Shan is a folded area with widespread Paleozoic nappes. The ensembles of nappes distributed in Uzbekistan, Tajikistan, Kyrgyzstan, and China are described, and their structural similarity and distinctions in different parts of the area are shown. Nappes of the southern Tien Shan occur on a passive margin of the Paleozoic Alay-Tarim continent. The lower nappes are composed of the passive margin rocks; the upper, of the Paleozoic Turkestan oceanic crust rocks and of rocks of an accretionary prism that occurred nearby the Paleozoic Kazakh–Kyrgyz microcontinent margin. The accretionary prism was formed during a long-term interval. In the Moscovian after the closure of the Turkestan oceanic basin and during the collision of the Alay-Tarim and Kazakh–Kyrgyz terranes the accretionary prism rocks were overthrusted onto the Alay-Tarim continental margin. The oceanic crust subduction was followed by the Late Carboniferous and Early Permian subduction of the Alay-Tarim continental crust beneath the Kazakh–Kyrgyz terrane. At that time a transverse shortening of the Alay-Tarim continental slope resulted in a tectonic decoupling of sediments and formation of the southern Tien Shan lower nappes.
INDEX TERMS: 1209 Geodesy and Gravity: Tectonic deformation; 1212 Geodesy and Gravity: Earth's interior: composition and state; 1213 Geodesy and Gravity: Earth's interior: dynamics; *KEYWORDS:* Nappe, accretionary prism, Tien Shan, Turkestan oceanic basin.

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Introduction

[2] The Tien Shan is a Paleozoic folded area. The southern Tien Shan is composed of rocks of the Paleozoic Alay-Tarim continent (Figures 1 and 2) that is separated by the Turkestan oceanic basin suture from Paleozoic rocks of the so-called Kyrgyz or Kazakh–Kyrgyz microcontinent [*Burtman,* 1997, 2006a, 2006b]. In the Late Paleozoic, oceanic crust rocks of the Turkestan basin and sediments that accumulated at its margins were overthrusted onto the Alay-Tarim continent and nowadays form nappe ensembles in the southern Tien Shan. These nappes are the greatest Paleozoic nappes known in Asia.

[3] By the early 1960s thrust faults that separated different facies of synchronous sediments were described in the Alay and Turkestan ranges, southern Tien Shan, on limbs of large synclines [*Porshnyakov,* 1960, 1962]. Studies of thrust faults in that and other southern Tien Shan regions suggest that they represent fragments of a multilayered Late Paleozoic nappe ensemble that covered a vast territory [*Burtman,* 1968, 1970; *Burtman and Klishevich,* 1971]. Nappes from different southern Tien Shan regions were described in books by *Biske* [1996], *Biske et al.* [1982, 1985], *Burtman* [1973, 1976, 2006a], *Mukhin et al.* [1991], and in many papers. Russian book by *Burtman* [2006a] and this paper discuss the nappe distribution throughout the southern Tien Shan.

[4] **Methods.** Nappe ensembles consist of several or numerous allochthonous thrust sheets separated by overthrust faults. They are described in successive units overlying each other in the composite geologic section. The structural units differ in composition of sediments that accumulated in various geotectonic environments, namely, on shelf, continental slope, in accretionary prism, and others. A unit is composed of rocks of an initial mono- or polyfacies zone.

[5] Geologic sections of the area include ten or more allochthonous thrust sheets. In multilayered tectonic ensembles the sheets formed by rocks of similar composition and genesis are repeated several times in the geologic section.

[6] In the proposed model of southern Tien Shan nappes we distinguish primary and secondary overthrust faults. Primary overthrust faults separate tectonic sheets composed of rocks that were formed in different, mainly adjacent tectonic environments, for instance, on shelf and continental slope. Primary overthrust faults represent unit boundaries. Secondary overthrust faults twin the sets of tectonic sheets in the geologic section. They complicate the nappe ensemble structure and internal structure of the units. Tectonic sheets

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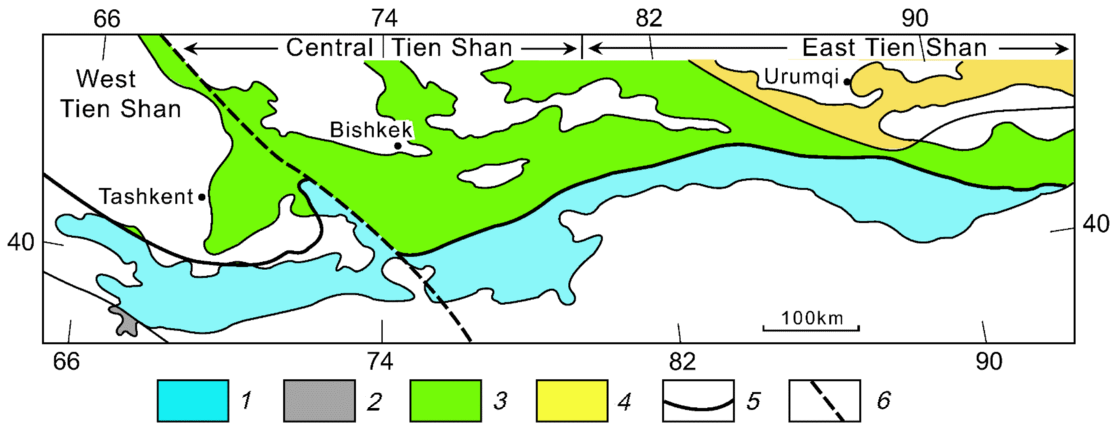


Figure 1. Tien Shan major geologic provinces. 1–2 – South Turkestan domain composed of the Paleozoic Alay-Tarim continent rocks (2 – Gissar tectonic zone); 3–4 – North Turkestan domain: 3 – rocks of the Kazakh-Kyrgyz composite microcontinent formed in the Ordovician-Silurian from coupling of the Early Paleozoic sialic blocks, 4 – rocks of the Late Paleozoic Bogdashan volcanic island arc; 5 – Turkestan oceanic suture; 6 – Talas-Fergana strike-slip fault.

composed of rocks of the same origin and age are referred to a single unit independently of their position in geologic sections that are commonly deformed by secondary overthrust faults. The reconstructed position of units, which they occupied prior to overthrusting, appears as a natural succession of facies zones on continental margins and in oceanic basins.

[7] Rocks of the structural units comprise tectonic sheets, windows, and sheet fragments of different origin: tectonic slices, klippes, tectonic mélange blocks, and olistoplaques and olistoliths in olistostromes. Position of these fragments is commonly a debated topic. On describing a complicated nappe structure in the Tien Shan the generalized term "oreade" is convenient for designation of unit parts and fragments independently of their position and mode of setting apart (oreades are nymphs of mountains and rocks in ancient Greek myths).

[8] It is appropriate to begin the discussion of southern Tien Shan nappes from the western Tien Shan where they are better studied.

Western Tien Shan

[9] The Northern Fergana, Southern Fergana, and Alay nappe ensembles formed in the Carboniferous and Early Permian, occur in the western Tien Shan. Every nappe ensemble and its neoautochthons occupy an area that is described below as a tectonic zone that is named as a certain nappe ensemble (Figure 3). The Gissar tectonic zone where nappes are insignificant or absent, also occurs in the western Tien Shan. Tectonic zones are separated by Late Permian thrust faults and strike-slip faults.

Northern Fergana Zone

[10] The Northern Fergana tectonic zone includes the Baubashata mountain group and the Atoinak Range. The zone is bounded by the following Late Permian faults: Talas-Fergana strike-slip fault on the northeast, Karaunkur strike-slip fault on the south, Atoinak strike-slip thrust fault on the north, and Chat (West Karasu) thrust fault on the west (Figure 4).

[11] The geologic section begins with the Baubashata unit that is overlain by the Ontamchi, Kerey, and Shaydan units (Figure 5). Stratigraphic sections in the Northern Fergana zone were described by *Biske and Porshnyakov* [1974], *Burtman* [2006a], *Burtman and Klishevich* [1971].

[12] **Baubashata.** The Baubashata unit is exposed in cores of antiform folds. Its basal part is composed of 2000-m-thick sequence bearing Silurian faunal remains. The sequence is characterized by tectonic relationships between polymictic and quartz sandstones and clayey shales bearing Llandovery, Wenlock, and Ludlow graptolites. The sequence includes basalts, andesites, volcanic tuffs and breccias as well. In the upper part of the sequence shales alternate with the limestone that contains Ludlow–Pridoli brachiopods, corals, and trilobites (Karaunkur Formation).

[13] The discussed sequence is unconformably, with tectonic contact overlain by the Late Silurian and Devonian carbonate and volcanogenic rocks. The stratigraphic section begins with the 1500-m-thick limestone bearing Late Ludlow, Pridoli and Early Devonian corals and brachiopods. Volcanogenic rocks (Bossogotash and other formations, up to 2000 m thick) wedge in the Devonian limestones along their extension. In the lower part of the formation volcanites are of contrasting composition and include dacite, rhyolite, and basalt. The upper part of the formation is composed of subalkalic andesite-basalt and basalt. The limestones occurring among volcanites yield remains of the

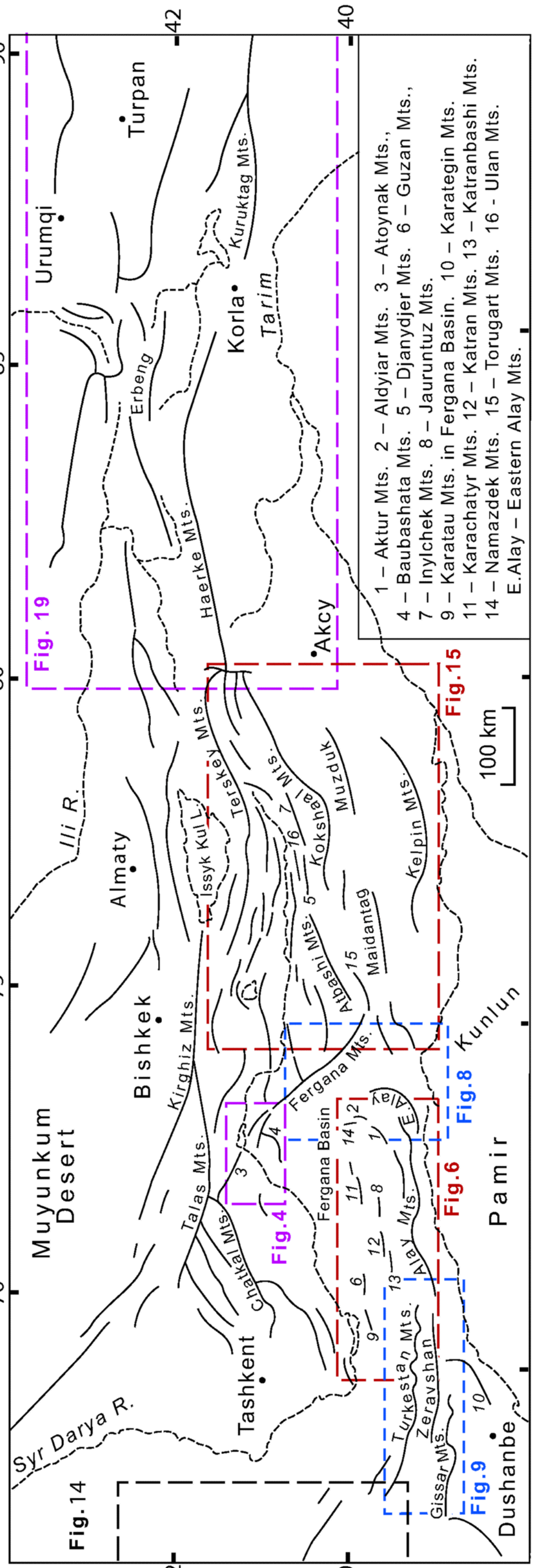


Figure 2. The Tien Shan orography. Solid lines denote mountain ranges; dashed lines, rivers and lakes.

Early Devonian, Eifelian, and Givetian organisms. Beds of volcanic rocks disappear upward from the base, whereas accumulation of 3000-m-thick carbonate sediments bearing corals, brachiopods, goniatites and foraminifers, continued up to the Early Bashkirian. The upper part of the stratigraphic section is composed of conglomerates with limestone pebble and blocks and coarse flysch bearing Bashkirian foraminifers (Konurtyube Formation, 400 m thick). The erosion that preceded the conglomerate accumulation reached in places the Visean rocks.

[14] **Ontamchi.** Sediments of the Ontamchi unit were mostly accumulated in deep-water conditions. Clayey, clayey siliceous and silty shales bearing Late Llandovery and Wenlock graptolites are exposed at the base of the visible stratigraphic section. Among the shales sandstone and conglomerate beds as well as dacite and basalt flows occur. Petrochemical properties of the lavas indicate their island arc origin [*Biske,* 1996]. The Upper Silurian section is composed of clayey and clayey siliceous shales and polymictic sandstones alternating with reef limestones bearing Ludlow and Pridoli corals and brachiopods and with basalts, andesites, and tuffs (Kyzkurgan, Seresu, Turasu, and other formations, 1500 m thick). The Lower Devonian is represented by tuffs and shales with tentaculitids; the Eifelian, by basalts, andesites, tuff-breccias, and tuffs interbedded with limestone bearing brachiopods and corals (Airytash Formation, 500 m thick).

[15] Upward from the base siliceous siltstone and bedded limestone with conodonts and radiolarians (Chichar and other formations) are recorded. This sequence is 100 m to 300 m thick and corresponds to the Givetian–Serpukhovian interval. Its is unconformably overlain by the 300-m-thick Late Serpukhovian-Early Bashkirian conglomerates, sandstones, clayey shales, cherts and siliceous limestones bearing foraminifers. The sequence contains olistostromes with the Visean limestone olistoliths.

[16] Rocks of the Ontamchi unit compose thrust sheets and slices. The stratigraphic succession of rocks described above cannot be observed in an uninterrupted section. The rocks are in tectonic interrelationships and are partly transformed into mixtite with Silurian shales as a matrix.

[17] **Kerey.** The Kerey unit is formed by weakly metamorphosed spheroidal basalts and picrites that are up to 2000 m thick in the Alashtau oreade (Figure 4, *1*). Lavas alternate with chert beds and tectonic lenses of serpentinized ultrabasite. Volcanogenic rocks are of Early–Middle Devonian age. They are overlain by the Givetian-Serpukhovian deep-water siliceous carbonate sediments.

[18] **Shaydan.** The basal part of the Shaydan unit is formed by a thrust sheet composed of gabbro and ultrabasite rocks. The lower part of the sheet is formed by serpentinized harzburgite and dunite along with serpentine mélange bearing blocks of basic volcanites, metamorphic schists, and gabbroids. Pb-Pb zircon age from dunite derived by a thermoion emission method, is 532±12 Ma old. These rocks are overlain by alternated wehrlites and lherzolites that are replaced upwards by pyroxenite and flaser gabbro grading into gabbro amphibolite. U-Pb and Pb-Pb zircon ages from gabbro

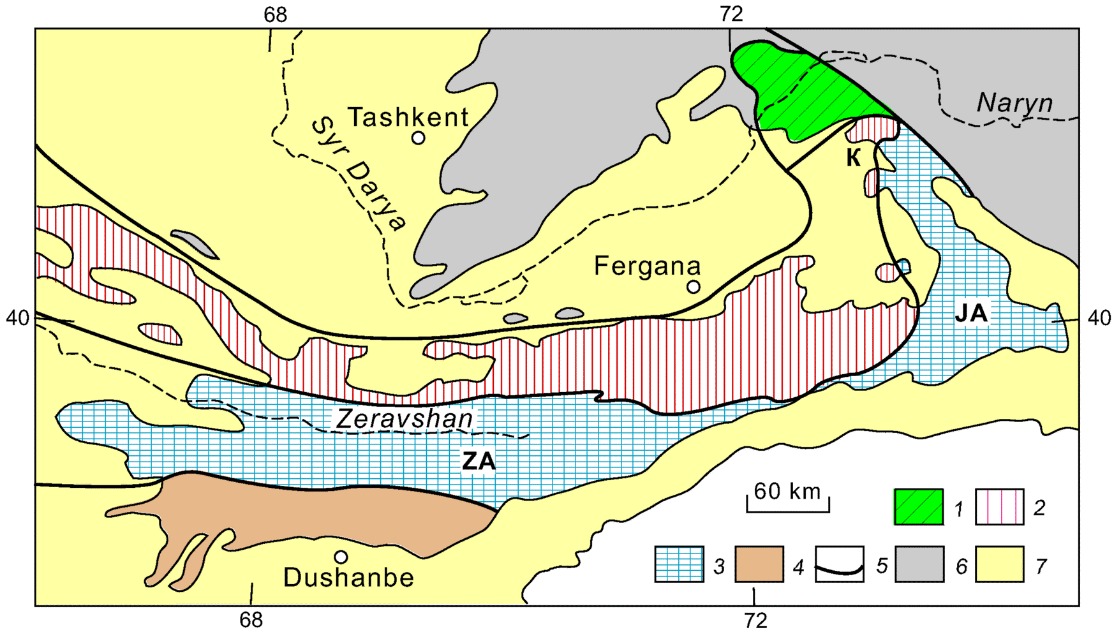


Figure 3. Tectonic zones of the South Turkestan domain in the western Tien Shan. 1–4 – South Turkestan domain; zones: 1 – Northern Fergana, 2 – Southern Fergana (K – Karaunkur region, 3 – Alay (ZA – Zeravshan-Alay region, JA – Yassy-Alay region), 4 – Gissar; 5 – Tectonic zone boundaries; 6 – North Turkestan domain; 7 – Mesozoic and Cenozoic sediments.

were estimated in the interval of 395–475 Ma. The upper part of the section is composed of a complex of parallel diabase and gabbro diabase dikes. According to petrochemical properties, the dike rocks are intermediate between komatiite and oceanic tholeiite [*Hristov et al.,* 1986; *Komarevtsev et al,* 1987; *Kurenkov et al.,* 2002].

[19] The 2500-m-thick gabbro ultrabasite complex is overlain by a 1500-m-thick thrust sheet that is mostly composed of volcanogenic rocks metamorphosed to greenschists including glaucophane schists (Maylisu and Akdzhol formations). Petrochemical properties of metamorphic rocks correspond to oceanic tholeiite basalts. Chert beds among metamorphic schists contain conodonts of likely Silurian age. The metamorphosed rocks are overlain by clastic and siliceous carbonate sediments bearing conodonts of all Devonian epochs and Visean–Serpukhovian foraminifers and goniatites. Volcanogenic rocks of the oceanic crust in the Shaydan unit were metamorphosed not later than the Early Devonian.

[20] **Neoautochthon.** Neoautochthon rocks occur in synform folds formed at later stages of deformation.

[21] Neoautochthon-1 overlaps the Serpukhovian rocks of the Shaydan unit and transgressively overlies the lower beds of the unit. Neoautochthon-1 is composed of conglomerate, sandstone, and limestone beds bearing Early Moscovian foraminifers and brachiopods (Chaak and other formations, 1000 m thick).

[22] Neoautochthon-2 transgressively overlies the Shaydan, Kerey, and Ontamchi units and Neoautochthon-1. The section begins with conglomerate, sandstone, and limestone members bearing Late Moscovian brachiopods and foraminifers (Suoktyube Formation, 1500 m thick). Upward from the base they are replaced by a sequence mainly composed of proximal terrigenous flysch with limestone beds (Bekechal, Turduk, and other formations, 3000 m thick). Foraminifers and brachiopods from this sequence are of Late Moscovian, Kasimovian, Gzhelian, Asselian, and Sakmarian age.

[23] Neoautochthon-3 unconformably overlaps the eroded Shaydan, Kerey, Ontamchi, and Baubashata units and Neoautochthon-2. It is represented by continental sediments bearing Late Permian flora (Kelematy and Karasu formations, 2000 m thick).

Southern Fergana Zone

[24] The Southern Fergana tectonic zone occupies northern slopes and foothills of the Turkestan and Alay ranges and the Karaunkur region of the Fergana Range (Figures 4, 6 and 7). The zone is bounded by Late Permian faults, namely, by the Karaunkur strike-slip fault on the north and by the Uzgen-Sanzar thrust fault on the south and on the east.

[25] Nappes of the lower storeys are formed by rocks that were accumulated on shelf and continental slope of the Alay-Tarim terrane (Isfayram and Abshir units); nappes of the upper storeys, by oceanic crust rocks (Taldyk and Shankol units). The Kan unit holds a peculiar place among them likely representing a fragment of the Turkestan oceanic basin's suture. The Karaunkur region also includes the Toguzbulak unit that contains sediments probably accumulated and metamorphosed in an accretionary prism.

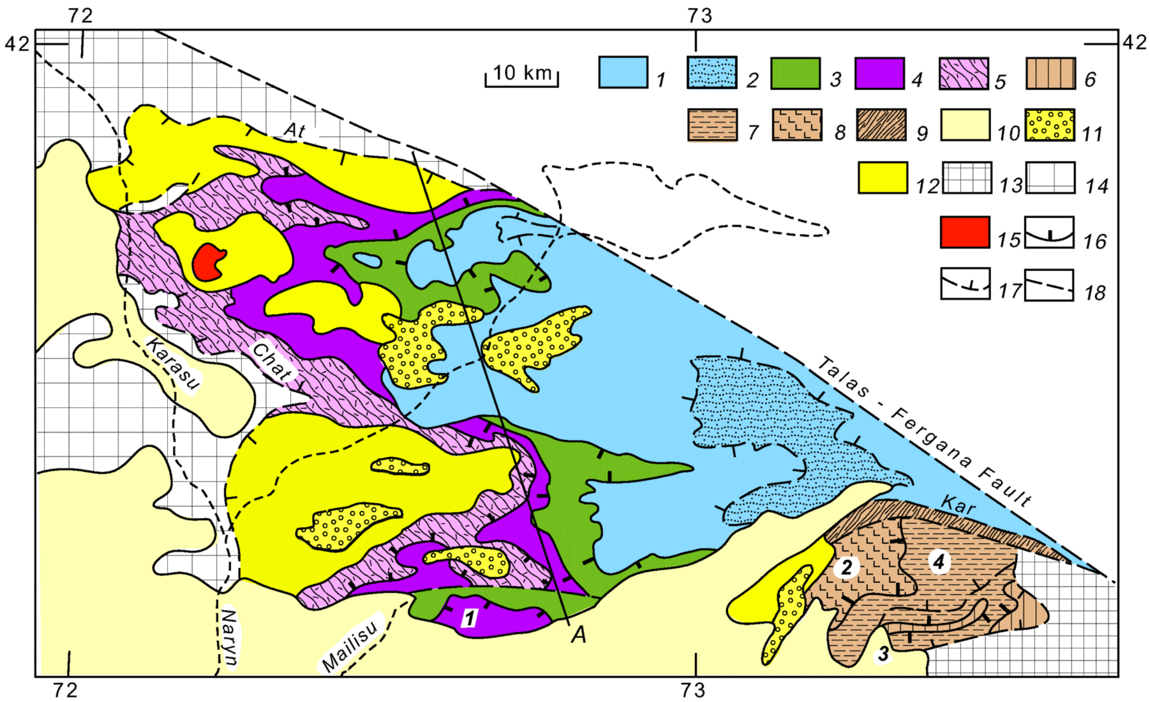


Figure 4. Northern Fergana tectonic zone and Karaunkur region of the Southern Fergana tectonic zone. 1–5 – Northern Fergana zone, structural units: 1–2 – Baubashata (1 – Devonian and Carboniferous, 2 – Silurian), 3 – Ontamchi, 4 – Kerey, 5 – Shaydan; 6–9 – Karaunkur region of the Southern Fergana zone, structural units: 6 – Isfayram, 7 – Abshir, 8 – Taldyk, 9 – Toguzbulak; 10 – Cenozoic and Mesozoic; 11 – Neoautochthon-3; 12 – Neoautochthon-2 and Neoautochthon-1; 13 – Alay tectonic zone; 14 – North Turkestan domain; 15 – Late Paleozoic granites; 16 – Primary overthrust faults of deformation stages D-2, D-3, D-4; 17 – Secondary overthrust faults and thrust faults; 18 – Other faults. A – line of geologic section (Figure 5). *Oreades: 1* – Alashtau, *2* – Djindy, *3* – Kapka, *4* – Kuroves. *Faults of deformation stage D-6: At* – Atoinak thrust-strike-slip fault, *Kar* – Karaunkur strike-slip fault, *Chat* – Chat thrust fault.

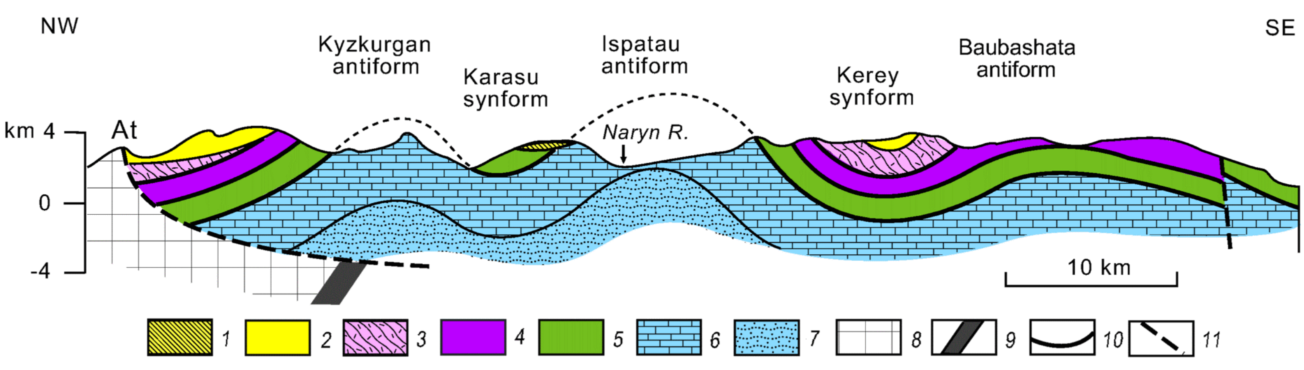


Figure 5. Structural units of the Northern Fergana tectonic zone in the geologic section along line A in Figure 4. 1 – Neoautochthon-3; 2 – Neoautochthon-2 and Neoautochthon-1; 3–7 – Units of the Northern Fergana zone: 3 – Shaydan, 4 – Kerey, 5 – Ontamchi, 6–7 – Baubashata (6 – Devonian and Carboniferous, 7 – Silurian); 8 – North Turkestan domain, 9 – Turkestan oceanic suture; 10 – Primary overthrust faults; 11 – Late Permian and younger faults (At – Atoinak fault). Synforms and antiforms – folds F_5.

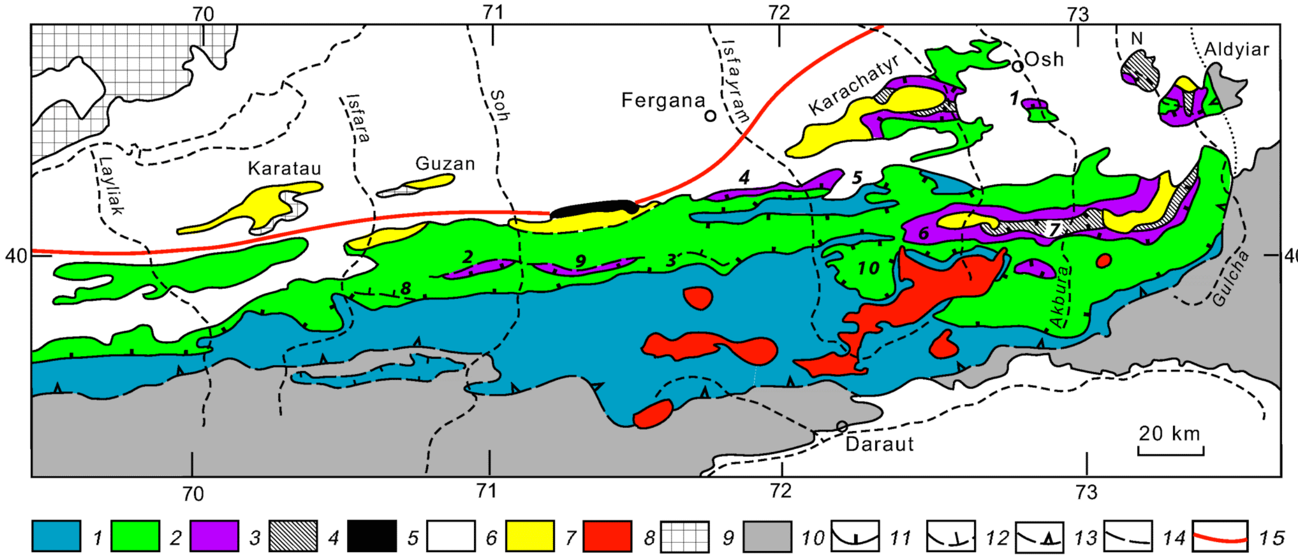


Figure 6. Southern Fergana tectonic zone. 1–5 – Units of the Southern Fergana zone: 1 – Isfayram, 2 – Abshir, 3 – Taldyk, 4 – Shankol, 5 – Kan; 6 – Cenozoic and Mesozoic; 7 – Neoautochthon-2 and Neoautochthon-1; 8 – Late Paleozoic intrusions; 9 – North Turkestan domain; 10 – Alay tectonic zone; 11 – Primary overthrust faults of deformation stages D-2, D-3, D-4; 12 – Secondary overthrust faults; 13 – Uzgen-Sanzar thrust fault; 14 – Other faults; 15 – Position of the Turkestan oceanic basin suture beneath Cenozoic sedimentary cover. N – Namazdek Mts. *Oreades: 1* – Akbura, *2* – Batken, *3* – Hamzabad, *4* – Hodjagoir, *5* – Kauzan, *6* – Kirgizata, *7* – Kumbel, *8* – Kyk, *9* – Sarytal, *10* – Tegermach.

[26] Stratigraphic sections representing units of the Southern Fergana tectonic zone were described by *Biske* [1996], *Burtman* [1976, 1984, 2006a], *Burtman and Klishevich* [1971], and *Porshnyakov* [1973].

[27] **Isfayram.** The Isfayram unit is composed of a thick shallow-water carbonate sequence and of pelagic sediments that underlie and overlie the carbonate rocks.

[28] In the Alay and Turkestan Ranges the basal part of the visible stratigraphic section is formed by clayey and siliceous shales and sandstones bearing Llandovery, Wenlock, and Ludlow graptolites. Basalt and tuff beds occur as well. The shales and overlying limestones contact along a tectonic boundary owing to different physical properties of the rocks on their deformation.

[29] Base of the carbonate sequence occurs at various

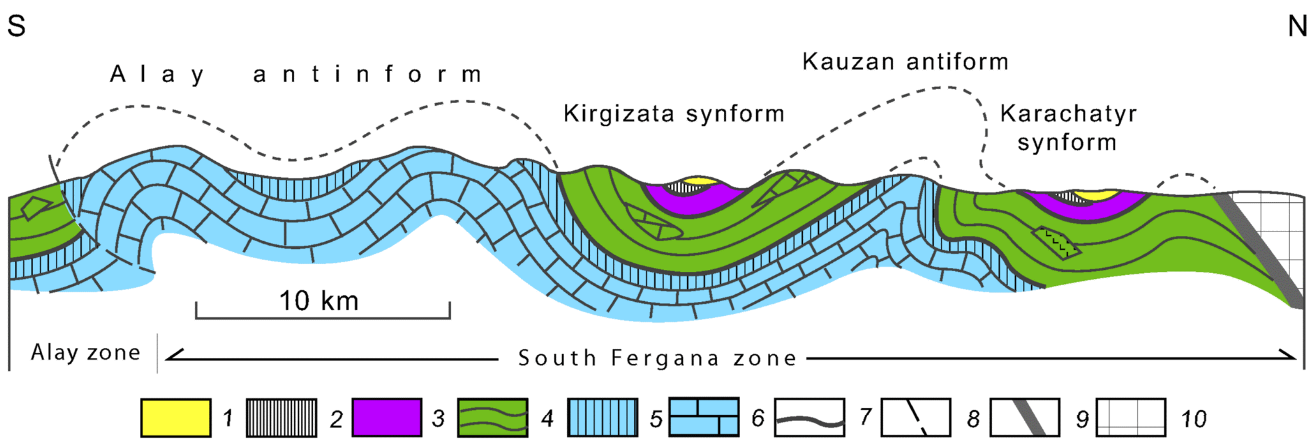


Figure 7. Units of the Southern Fergana tectonic zone in a schematic geologic section across the Alay Range. 1 – Neoautochthon-2; 2–6 – Units: 2 – Shankol, 3 – Taldyk, 4 – Abshir and Tar, 5–6 – Isfayram and Chekantash (5 – Upper Carboniferous flysch, olistostromes and conglomerates, 6 – Devonian-Upper Carboniferous carbonate rocks); 7 – Primary overthrust faults; 8 – Uzgen-Sanzar fault; 9 – Turkestan oceanic suture; 10 – North Turkestan domain. Synforms and antiforms – folds F_5. Granitoid intrusions are not shown.

levels from the Ludlow to Middle Devonian in different sections. In the northern sections it is commonly older. The carbonate sequence is 2000 m to 4000 m thick and is rich in fossil macro- and microfauna. Relation of thicknesses of the Devonian and Carboniferous parts, as well as the structure and composition of carbonate rocks differ in certain sections; various section types were distinguished [*Porshnyakov,* 1973]. The Alay type of stratigraphic section corresponds to an internal area of carbonate accumulation; the Yauruntuz and Aktur types are formed by rocks accumulated in external parts of the area.

[30] The carbonate sequence is mainly composed of shallow organogenic and organoclastic rocks. The upper Silurian part of the section contains quartz sandstone beds; the Early Devonian includes chert, alkalic basalt, and tuff layers. In the Sokh-Isfayram interfluve the Givetian carbonate coral-bearing rocks include a 500-m-thick lens of alkalic lavas and acidic and basic tuff. In the Serpukhovian–Early Moscovian relatively deeper conditions provided accumulation of clayey and clastic bedded limestone with chert layers. In these sediments (Gaz and other formations, 50 m to 500 m thick) a hiatus at the Bashkirian base is commonly recorded; Serpukhovian limestones are occasionally missing in the section. The top of the carbonate sequence rises southward within the Lower Moscovian Substage.

[31] The Lower Moscovian limestone is overlain by a flysch and olistostrome sequence of variable structure and thickness (Tolubay, Malyaran, and other formations, 50–1000 m thick). Its lower part is composed of finely rhythmic calcareous sandy clayey flysch. Upward from the base the flysch becomes coarser and conglomerate and olistostrome beds are recorded. The largest olistoplaques reach hundreds of meters. Large blocks and olistoplaques are composed of shallow authigenic limestone. The form and trains of olistoliths indicate that they entered the basin from the south (in modern system of coordinates). The olistostrome section demonstrates a reversed stratigraphic succession of authigenic limestone olistoplaques, which corresponds to consecutive destruction of the limestone massif; the Early Moscovian olistoplaques occur at the base and are followed by the Early Carboniferous, Devonian, and Late Silurian, respectively. The olistoliths and conglomerate pebble include cherts and pelagic limestone. The upper part of the sequence contains blocks bearing fragments of condensed siliceous carbonate section of the overlying Abshir unit. The youngest foraminifers from olistoliths are of Early Moscovian age, whereas flysch sediments yield the Early and Late Moscovian foraminifers. The Early Moscovian time was characterized by the authigenic clastic material accumulation, in the Late Moscovian it was supplemented with pelagic rock fragments from the overlying Abshir nappe.

[32] In the Alay Range on the south of the discussed tectonic zone the Early Moscovian flysch is conformably overlain by conglomerate sequence with siliceous shale, siltstone, and sandstone beds bearing fragments of the Moscovian-Kasimovian foraminifers and Late Carboniferous plants (Surmetash Formation, 2000 m thick). Pebble and boulders in the conglomerate are of siliceous and carbonate composition.

[33] In the Karaunkur region of the Fergana Range the Isfayram rocks are exposed in tectonic windows (Figure 4). The carbonate sequence is about 2000 m thick there. The lower part of the section contains Wenlock and Late Silurian corals and brachiopods; the higher beds, Devonian and Early Carboniferous forms; and sediments nearby the top, Serpukhovian foraminifers. The limestones are overlain by 300-m-thick conglomerate and sandstone member that includes wildflysch beds bearing limestone blocks. Clastic limestone beds yield probably redeposited Bashkirian foraminifers.

[34] Sediments of the Alay type are autochthonous on the most part of the described tectonic zone. Near a margin of the Southern Fergana zone they were overthrusted onto the rocks of the adjacent tectonic zone. Carbonate and siliceous sediments in sections of the Yauruntuz and Aktur types, which were accumulated on the outer shelf, compose olistoplaques in the tectonized olistostrome of the Abshir unit and klippes of secondary nappes and thrust faults.

[35] **Abshir.** Accumulation area of the Abshir unit included a part of outer shelf and extended continental slope and foot of the Alay-Tarim passive margin. Stratigraphic sections of the unit are mainly composed of pelagic sediments.

[36] On northern slopes of the Alay and Turkestan Ranges the clayey carbonaceous shales with phthanite strata are recorded at the base of the Abshir nappe thrust sheets. The shales upward from the base and along the strike grade into a distal terrigenous flysch with olistostrome beds (Syuget, Pulgon, and other formations). The shales and flysch yield Llandovery, Wenlock, and Ludlow graptolites. In places the sequence includes Pridoli sediments. Quartz sandstones were recorded in the Wenlock part of the section. Stratigraphic succession of Silurian sediments is disrupted, which makes difficult a real estimation of their thickness. It is evaluated for each stage at several hundred meters. Some sections include volcanogenic rocks. A calcareous alkalic volcanite sequence is distributed in the Alay Range. It is represented by basalts, dacites, rhyolites, and their tuffs (Karatyube Formation, 600 m thick) bearing shale beds with Late Llandovery-Wenlock graptolites.

[37] Sections of several types, namely, carbonate, carbonate siliceous, siliceous, and volcanogenic siliceous, are distinguished in the Pridoli, Devonian, and Lower Carboniferous sediments. Most of sections are condensed and include sediments of low thickness, which were accumulated during a long-term time interval.

[38] ***Carbonate type*** (Kokbeles) is known from tectonic slices and olistoplaques. The 100-m-thick Pragian-Eifelian sequence of conglomerates, sandstones, and limestones is overlain by a 200–400-m-thick dolomite and limestone member corresponding to the Givetian–Moscovian. In other sections the condensed Givetian-Moscovian carbonate rocks overlie the thicker Late Silurian–Early Devonian limestones. Carbonate type of the Abshir unit section is transitional to sections of the Isfayram unit.

[39] ***Carbonate siliceous type*** (Shakhimardan) is composed of carbonate flysch and siliceous rocks. The Alay Range in the Hamzabad oreade (Figure 6, *3*) is characterized

by flysch with clastic limestone strata bearing Pridoli and Lochkovian graptolites, corals, and brachiopods (Krukkel Formation, 500 m thick). Flysch is overlain by rhythmically alternated bioclastic limestones and cherts with clayey shale beds in the lower part of the section (Talbulak and other formations, 1000 m thick). Graptolites, brachiopods, tentaculutids, ammonoids, and corals indicate the Lochkovian to Givetian age of the sequence. The higher part of the section is formed by the relatively thin (100 m to 500 m) Upper Devonian and Lower Carboniferous limestones.

[40] In the eastern part of the Turkestan Range, in the Kyk oreade section (Figure 6, *8*) several conodont zones of the Emsian, Eifelian, Givetian, Famennian, Tournaisian, and Serpukhovian are absent, likely owing to stratigraphic hiatuses. The upper part of the limestone contains Early Bashkirian conodonts. The section of the discussed type is crowned by the Late Bashkirian or Early Moscovian conglomerates, sandstones, and clayey shales.

[41] ***Volcanogenic siliceous type*** (Okzhatpes) is characteristic of the Dzhindy oreade in the Karaunkur region (Figure 4, *2*). The oreade is composed of several tectonic slices. Their basal part is represented by the Lower Devonian cherts, lavas, and basic and intermediate tuffs with coral- and brachiopod-bearing limestone beds. This sequence is overlain by limestone with Givetian corals and cherts and limestones bearing Serpukhovian and Bashkirian foraminifers. The upper part of the section is composed of proximal terrigenous flysch with olistostrome and conglomerate strata that contain limestone fragments with Bashkirian foraminifers.

[42] ***Siliceous type*** (Shalan) of section is the most widespread. It is composed of variegated radiolarite, spongolite, phthanite, and limestone members, with siliceous clayey shale and turbidite beds (Tomasha, Bidana, Talbulak, and other formations). According to conodont and foraminifer records, the base of the sequence is dated in various sections as the Lochkovian, Pragian, or Emsian, and the top corresponds to the Serpukhovian or Early Bashkirian. In some sections hiatuses were recorded. Siliceous rocks strongly prevail in the Devonain and Tournaisian; proportion of the pelagic limestone increases upward from the base. The total thickness of the sequence ranges from 40 m to 400 m.

[43] Upper part of the Shalan-type section is formed by a thick flysch and olistostrome sequence. The limestone beds in the coarse flysch yield Serpukhovian–Bashkirian and Early Moscovian foraminifers. The oldest fossil fauna in the olistoliths is of Cambrian age and the youngest, of Early Moscovian age.

[44] ***Abshir mixtite.*** A considerable part of the Abshir unit was changed into mixtite with a matrix of intensely deformed Silurian shales. The widespread mixtite contains larger and smaller authigenic blocks of Silurian, Devonian, and Carboniferous rocks derived from the siliceous, volcanogenic siliceous, and other types of sections of the Abshir unit.

[45] Another kind of mixtite includes blocks of authigenic and allothigenic origin. Silurian graptolite shales and blocks of Shalan rocks are mixed in it with fragments of the olistostrome formed in the Late Carboniferous prior to and during the nappe formation. Allothigenic blocks are composed by (a) limestone bearing a shallow-water Late Silurian, Devonian, and Early Carboniferous fauna from the Isfayram unit; (b) andesite, trachyandesite, andesite-dacite, and their tuffs of authigenic origin or derived from the Isfayram unit; (c) ophiolite fragments, namely, basalt and tuffs from the Taldyk unit, gabbro-pyroxenite cumulates from the Taldyk or Shankol units, and apobasite metamorphic greenschists from the Shankol unit.

[46] Among the Abshir mixtite large and gigantic olistoplaques are recorded. Part of them are authigenic, formed by siliceous rocks of the Shalan section. Others, of hundred meters in size, are composed of the Taldyk basalts. A great block of volcanogenic rocks, likely a tectonically transported gigantic olistoplaque, occurs in Karachatyr Mountains among the Abshir mixtite (Figure 6). The block is formed by rhyolite, dacite, basalt, tuffs, and by an olistostrome with volcanomictic cement and Cambrian limestone olistoliths (Dedebulak Formation, 500 m thick). According to petrochemical properties, the volcanogenic rocks correspond to island arc volcanites [*Vanina,* 1988].

[47] Most of gigantic olistoplaques are composed of an outer shelf carbonate sediments derived from the Isfayram unit and Kokbeles-type section of the Abshir unit. The limestones have tectonic contacts with the Abshir mixtite. They compose the Katran, Yauruntuz, Aktur, Katranbashi (Figure 2), and other large mountain chains. The limestones are overthrusted onto the Abshir mixtite and are overlain by it. These limestone massifs, several kilometers thick and tens of kilometers long, probably are gigantic olistoplaques. During the overthrusting and subsequent deformations the olistoplaques' base was a surface along which the massifs were squeezed out. The process resulted in formation of secondary overthrust and thrust faults observed nowadays at boundaries of the limestone massifs.

[48] Mixtites were formed mainly owing to gravitational processes initiated or intensified by the Alay-Tarim continent and Kazakh–Kyrgyz microcontinent collision that began in the Moscovian. The flysch and olistostrome sequence was accumulated in the Bashkirian and Moscovian on the gentle and extended Alay-Tarim continental slope. During the collision of the Alay-Tarim and Kazakh–Kyrgyz terranes the width of the Abshir facies zone decreased and the grade of continental slope rose. This resulted in gravitational intermixing of the accumulated sediments. In the Moscovian fragments of shallow limestone and ophiolites entered the mixtite from the Alay-Tarim continent (from the south in modern system of coordinates) and from the set of ophiolitic nappes that overthrusted from the opposite side, respectively. Subsequently the gravitational mixtite was overlain by ophiolitic nappes and underwent a tectonic processing. Its matrix was fragmented and secondary overthrust and thrust faults together with drag folds were formed. Finally the gravitational mixtite was transformed to tectonite.

[49] **Taldyk.** The Taldyk unit is composed of weakly metamorphosed ophiolites and overlying pelagic sediments. The Taldyk unit rocks overlie the Abshir unit and compose blocks in the Abshir mixtite.

[50] The Sarytal oreade (Figure 6, *9*) represents an allochthonous body located in a synform fold. The lower 500 m of the allochthon are formed by dunite, harzburgite, pyroxenite, cumulative gabbro–norite rocks and ophicalcite breccias. Pb-Pb zircon age from pyroxenites obtained by a thermoion emission method, is 1330±12 Ma old [*Komarevtsev et al.,* 1987]. These members are overlain by volcanogenic sedimentary rocks beginning with 25-m-thick hematite cherts bearing Early Ordovician conodonts. Among them are conglomerate lenses with gabbride pebble. Contact of these rocks with the underlying ophicalcite breccia is complicated by a thick ultrabasite–basite sill but is retained in places beneath the sill. The cherts are overlain by 150-m-thick spheroidal amygdaloidal olivine basalts and picrites with chert layers bearing Early–Middle Ordovician radiolarians and conodonts. Further above are 500-m-thick pillow tholeiitic basalts with beds of hyaloclastite, sandstone, and cherts bearing Llandovery graptolites and Late Silurian–Early Devonian radiolarians.

[51] The Batken oreade (Figure 6, *2*) is a deformed allochthonous thrust sheet. Its basal portion is composed of 150-m-thick olivine basalts overlain by pillow–pipe tholeiitic basalts with chert, hyaloclastite, and volcanomictic sandstone beds. Blocks of siliceous and carbonate rocks found among the lavas contain Silurian graptolites, Early–Middle Devonian foraminifers, and Late Devonian conodonts.

[52] The Kyrgyzata oreade (Figure 6, *6*) is composed of several thrust sheets crumpled in a synform fold (Figure 7). This allochthon is 90 km long and up to 20 km wide; the number of thrust sheets and slices vary in its different parts. On the west the basal part of the unit is formed by a thrust sheet (0.5 km to 7 km) composed of gabbro and ultrabasite rocks that are mostly transformed into a serpentinite mélange. The ultrabasites are overlain by a 200-m-thick mélange formed by basalt, ultrabasite, chert, and limestone blocks.

[53] Volcanic rocks and reef limestones are recorded further upward from the base. Secondary overthrust faults separate the section into several tectonic slices with a total thickness of 1000 m. Extrusive rocks are represented by pillow and pipe basalts. The Early–Middle Devonian and Tournaisian conodonts were found in limestone and chert beds among basalts and clastites.

[54] A higher stratigraphic position in the Kyrgyzata oreade section is occupied by a thick thrust sheet which base is composed of the 100-m-thick tuff sandstone and tuff siliceous rocks bearing Silurian radiolarians and Devonian conodonts. They are overlain by a 1000-m-thick basalt hyaloclastite of the Yash Formation which is in turn covered by pipe–pillow lavas of the 1000-m-thick Aravan Formation including basalts, picrites, and komatiites with limestone lenses bearing Emsian conodonts and Middle Devonian radiolarians. Volcanogenic rocks are cut by sills and swarms of picrite and basalt dikes, part of which refer to a dike-into-dike type. The lavas are overlain by a 500-m-thick sequence of variegated siliceous shales with tuff, sandstone, and limestone beds. The Middle Devonian radiolarians and Early Carboniferous foraminifers were encountered at the base and in the middle part of the sequence, respectively.

[55] The Hodjagoir oreade (Figure 6, *4*) consists of thetwo allochthonous thrust sheets. The lower, 1000-m-thick sheet is composed in its basal and middle parts of phthanite and hyaloclastite with reef limestone bearing Devonian conodonts. These rocks are overlain by a 100-m-thick tuff sandstone and red jasper member bearing Givetian, Frasnian, and Tournaisian conodonts and, in the upper part, Serpukhovian goniatites.

[56] The section of the upper thrust sheet begins with a phthanite and siliceous siltstone member that contains Llandovery and Lochkovian–Pragian conodonts. It is overlain by 600-m-thick hyaloclastites and 1500-m-thick pillow–pipe tholeiitic basalts with gabbro, gabbro–diabase, and diabase dikes and thick gabbro–peridotite sills. The volcanites are covered with 100-m-thick siliceous shales and tuffs bearing Middle-Late Devonian radiolarians and Late Devonian–Early Carboniferous ammonoids and goniatites.

[57] The Akbura oreade (Figure 6, *1*) section consists of basalts interbedded with cherts, tuffites, and limestones bearing Middle Devonian corals. They are overlain by a 180-m-thick variegated chert member containing Givetian and Late Devonian radiolarians. Above is a 50-m-thick member of breccia, sandstone, limestone, and cherts with the Visean foraminifers.

[58] The Kuroves oreade (Figure 4, *3*) is located in the Fergana Range. The lower part of its visible section is composed of clayey shales with the Late Llandow graptolites, Wenlock and Ludlow coral-bearing limestones, and sandstones and clayey shales bearing Ludlovian graptolites. Upward from the base lies a 1500-m-thick member of basalts, picrites, and tuffs interbedded with cherts and limestones containing the Early–Middle Devonian corals. The upper part of the section is formed by variegated cherts and terrigenous flysch of the 2000-m-thick Teleksay and Kirkichin formations. Scarce foraminifers define the age of the sequence as the Early Carboniferous. The rocks form several tectonic slices that include serpentinized ultrabasite lenses.

[59] Klippes and olistoliths composed of the Taldyk unit rocks are also known in other areas of the Southern Fergana tectonic zone.

[60] In the Alay Range the basalts that are the oldest in the Western Tien Shan fragments of rocks likely derived from the Turkestan oceanic crust, are recorded. The tectonic slice includes basalts interlayered with phthanites, sandstones and limestones yielding Toyonian (Early Cambrian) archaeocyathids and brachiopods. In another exposure basalt fragments form a breccia with carbonate and carbonate tuff cement. The breccia beds alternate with a limestone bearing Tommotian (Early Cambrian) archaeocyathids. These rocks, about 300 m thick, compose a block in the mixtite with a matrix formed by Silurian shales of the Abshir unit.

[61] ***Origin of the rocks and conditions of sediment formation.*** The rocks of the layered, dike and volcanogenic complexes of the Taldyk unit belong to the tholeiitic petrochemical series. The lower part of the visible section is composed of serpentinized harzburgite, peridotite, dunite, and lherzolite. The layered complex that represents an alternation of gabbro and peridotite, is characteristic of a marginal subduction-related basin or of island arc [*Abakumova and Nenakhov,* 1988].

[62] The dikes are composed of basalt, picrite, and gabbro. Picrite dikes are attributed to the early generation, gabbro-diabase and basalts to the later one. The dike swarms and sills are irregularly distributed among lavas, part of dikes is of a dike-into-dike structure. This dike complex demonstrates a dispersed type of spreading characteristic of the oceanic bottom beyond a mid-oceanic ridge and of marginal basins. Petrochemical and geochemical properties of dikes from the Kyrgyzata ophiolithes indicate that they were formed in a mid-oceanic ridge or on oceanic islands [*Kurenkov et al.,* 2002].

[63] The lavas consist of picrite, tholeiitic and subalkalic basalt, and hyaloclastite. Discrimination of tholeiitic basalts in various diagrams shows that according to petrochemical and geochemical properties they are close to volcanites from mid- oceanic ridges and to intraplate oceanic basalts [*Abakumova and Nenakhov,* 1988].

[64] Basalts of the Sarytal oreade were erupted from the Early Ordovician to Early Devonian with great interruptions; in the Akbura, Kyrgyzata, Kuroves, and Hodjagoir oreades eruptions occurred in the Early–Middle Devonian; in the Batken oreade, in the Late Devonian.

[65] In the Sarytal oreade section the volcanite composition changes from low-Ti picrites and olivine basalts at the base to tholeiites in the mid-section and subalkalic high-K and high-Ti basalts and tuffs at the top. The rare-earth element spectrum in the Ordovician low-Ti lavas is characteristic of marginal sea spreading zones. The graywacke sandstones lying among the volcanites in the upper part of the section contain andesite–basalt, andesite, and dacite fragments suggesting the occurrence of a volcanic arc. Geochemical peculiarities of the graywackes indicate that the clastic material was produced by an oceanic island arc [*German and Budyanskii,* 1990]. The presence of Early Ordovician silicites at the base of the basalts and their stratigraphic contact with the underlying ophiolitoclastic breccia in the Sarytal section testifies the oceanic crust spreading beyond a mid-oceanic ridge in the Early Ordovician [*Kurenkov et al.,* 2002]. The spreading likely occurred in the basin separated by a volcanic island arc, which rocks later were a source of the graywacke material.

[66] Consequently, the Taldyk unit includes fragments of the Turkestan oceanic crust, namely, ultrabasites and cumulative gabbroids, and of basalts and the overlying pelagic sediments. The Ordovician lavas of the Sarytal unit were erupted onto oceanic bottom in a marginal basin separated by an oceanic island arc. Other allochthonous sheets contain Devonian lavas that were erupted in a mid-oceanic ridge and outside it. Among peculiarities of ophiolitic sections in the discussed area are a fragmentary dike stratum and occurrence of thick basaltic hyaloclastites erupted at a relatively small depth.

[67] The condensed sediments overlying the lavas are composed of siliceous rocks and tuffaceous clastites bearing pelagic faunal remains. These pelagic sediments were accumulated in the Givetian–Serpukhovian interval. Reef limestones occurring among the lavas were likely formed on oceanic islands.

[68] **Shankol.** The Shankol unit is composed of greenschists, glaucophane schists, amphibolites and the overlying weakly metamorphosed sediments. Primary composition of metamorphic rocks was represented by basic lavas, tuffs, sandstones, and pelites. Tectonic serpentinite lenses in places occur at the base of the unit.

[69] A high-baric metamorphism occurred at the earlier stage; subsequently diaphthoresis in the accretionary prism produced a greenschist formation [*Bakirov and Sakiev,* 1999]. The Rb-Sr age of the rock metamorphism is 475±49 Ma old. The Pb-Pb zircon age from metabasites derived by a thermoion emission method, is 935±60 Ma old [*Duk,* 1995].

[70] The Kumbel oreade (Figure 6, *7*) is a deformed thrust sheet over 1000 m thick, lying in the Kyrgyzata synform fold on the Taldyk rocks. The sheet is composed of schists that are unconformably overlain by nonmetamorphosed proximal carbonate terrigenous flysch bearing Late Silurian corals, brachiopods, and graptolites (Kaindy Formation, 150 m thick).

[71] In the Namazdek Mountains (Figure 2) metamorphic schists are overlain by conglomerates with schist boulders. Conglomerates alternate with sandstone, siltstone, and limestone beds yielding Early Devonian corals. Nearby the schists in the Aldyyar Mountains a conglomerate sequence with metamorphic schist pebble is exposed. The conglomerates are interlayered with sandstones, siltstones, and limestones bearing Late Silurian corals, brachiopods, and graptolites.

[72] **Kan.** The Kan unit is formed by serpentinite mélange exposed at the foothills of the Alay Range in a stripe 25 km long and up to 4 km wide (Figure 5). The mélange is composed of serpentinites that contain numerous blocks and boulders of ophiolitic rocks (pyroxenite, ophicalcite, gabbroids, basalts, and cherts), rocks metamorphosed to greenschists and glaucophane schists, as well as boulders of weakly metamorphosed clastic, siliceous, and carbonate sediments. Basalts, basalt tuffs, gabbro, cherts, and pelites are recorded among metamorphic rocks. The largest blocks are over 1000 m in size. The Early–Middle Devonian and Famennian conodonts were encountered in metamorphosed cherts that occur among metabasites.

[73] Initial relationships between the Kan and other units are not retained. They are separated by a neoautochthon, young fault, and young sediments. North of the Kan unit the Paleozoic Kazakh–Kyrgyz microcontinent rocks are located. The structure and position of the Kan serpentinite mélange make it possible to consider it as the Shankol nappe root zone which marks the position of the Turkestan oceanic basin suture. West and east of the Kan mélange area the Turkestan oceanic suture is hidden beneath younger sediments.

[74] **Toguzbulak.** This unit situated in the Karaunkur region (Figure 4) is formed by terrigenous sediments irregularly metamorphosed to phyllites and greenschists that contain beds of cherts, quartz sandstones, and marble (Toguzbulak Formation, 1500 m thick). Serpentinized ultrabasite lenses occur among the schists. Contrary to the Shankol metamorphic section, volcanic rocks were not recorded in the Toguzbulak unit. Age of the rocks is

unknown and primary tectonic contacts of the unit with other ones are not retained. It is quite probable that the Toguzbulak unit represents rocks of the Kazakh–Kyrgyz continental rise, which were metamorphosed in the Devonian or Carboniferous on formation of accretionary prism near the microcontinent margin.

[75] **Neoautochthon.** The neoautochthon sediments transgressively overlie the nappe ensemble of the discussed tectonic zone.

[76] ***Neoautochthon-1.*** The Kan serpentinite mélange is overlain with stratigraphic contact by serpentinite sandstones and other ophiolitoclastic rocks (gravelstone, conglomerate, and breccia) with olistostromes. The olistoplaques and olistoliths in olistostrome and the blocks in sedimentary breccias are composed of schists, cherts, and limestones. The olistoliths and blocks contain Devonian and Early Carboniferous foraminifers, conodonts, and corals. The Serpukhovian conodonts, goniatites, and foraminifers were identified in the serpentinite sandstones and chert beds. This clastite and olistostrome sequence is over 500 m thick. It was accumulated in accretionary prism on a continental rise or in oceanic trench. Upward from the base these rocks grade into carbonate flysch with beds of olistostromes, conglomerates, and limestones bearing Serpukhovian, Bashkirian, and Early Moscovian foraminifers, goniatites, and conodonts (Shuran, Karatanga, and other formations, 2000 m thick).

[77] Thus the Kan oceanic crust rocks were transformed to mélange and in the Early Carboniferous were overlain by the Neoautochthon-1 sediments that were deposited on the continental rise up to the Early Moscovian.

[78] The section of that kind is known in the Karachatyr Mountains (Koksarai Formation, Kalmakbulak, 1000 m thick) where Neoautochthon-1 overlies rocks of the Shankol unit. The basal part of the section is composed of serpentinite and limestone conglomerates and breccias with schist fragments. Further upwards they are followed by a carbonate terrigenous flysch bearing foraminifers and ammonoids of the Visean (likely redeposited) to Early Moscovian age.

[79] ***Neoautochthon-2.*** In the Alay Range Neoautochthon-2 unconformably overlies the Shankol, Taldyk, and Abshir units. The lower part of the section consists of conglomerate with pebble of underlying rocks. Upward from the base it grades into terrigenous flysch with limestone strata bearing Late Moscovian–Kasimovian, and in the upper part, Gzhelian-Asselian foraminifers (Aldykin, Muyankol, and other formations, 2500 m thick).

[80] At the northern foothills of the Alay Range Neoautochthon-2 unconformably onlaps onto Neoautochthon-1 that overlies the Kan unit. Here the basal part of Neoautochthon-2 is formed by thick conglomerate that contains pebble of basalts, tuffs, schists, sandstones, and limestones. Further upwards conglomerate beds alternate with sandstone, siltstone, argillite, and limestone yielding Late Moscovian-Kasimovian foraminifers (Kunyakul, Shunkmazar, and Uchbulak formations, 3000 m thick).

[81] In the Karachatyr Mountains Neoautochthon-2 unconformably overlies rocks of the Shankol and Taldyk units and Neoautochthon-1. The lower portion of the section is composed of proximal carbonate terrigenous flysch bearing Late Moscovian–Early Kasimovian foraminifers (Akterek and Dzhilginsay formations, 2000 m thick). The overlying flysch sediments include wildflysch beds with olistoliths of authigenic limestones. The conglomerate strata commonly contain pebble of granites and extrusive acidic and intermediate rocks transported from the Kazakh–Kyrgyz microcontinent which margin was a place of intense volcanism in the Moscovian and Kasimovian. The derived foraminifer fauna estimates the age of the sequence from the Upper Kasimovian to Sakmarian (Uchbulak, Dastar, Kerkidon, and Dangibulak formations, 3000 m thick). Along with foraminifers the sediments yield numerous remains of shallow benthic fauna, namely, corals, bryozoans, mollusks, and trilobites. The upper part of the section is mainly composed of organogenic limestones.

[82] Consequently, the Neoautochthon-2 sediments overlie the Abshir nappe, Shankol and Taldyk ophiolitic nappes, and the root zone of ophiolitic allochthons (Kan unit). North of this suture, in the Fergana Karatau and Guzan Mountains (Figure 2) Neoautochthon-2 onlaps onto the Kazakh–Kyrgyz microcontinent rocks.

[83] ***Neoautochthon-3.*** Continental sediments bearing Permian and Triassic flora and Early Permian foraminifers in conglomerate pebble (Tuleikan, Madygen, and other formations) unconformably overlie all units and Neoautochthon-2.

Alay Zone

[84] The Alay tectonic zone is separated from the Southern Fergana zone by the Uzgen-Sanzar thrust fault of Permian age. The Alay zone includes the southern part of the Fergana Range, the East Alay, Karategin, Zeravshan ranges, and part of the Alay, Turkestan, and Gissar ranges. Being wide in the western and eastern parts, the zone is narrowed between the 72° and 73° meridians and is overlain by younger sediments and by the overthrusted in the Cenozoic Pamirs. The narrowed area separates the Alay zone into two regions, Yassy-Alay on the east and Zeravshan-Alay on the west (Figures 3, 8, and 9).

[85] Geological section of the Alay zone is formed by thrust sheets and slices divided by primary and secondary overthrust faults and thrust faults. A great territory of the Alay tectonic zone is occupied by rocks of the Tar unit. The zone includes the Chekantash, Sugut, and Dzhirgatal units.

[86] Various stratigraphic sections of the Alay zone were discussed by *Biske* [1996], *Burtman* [1968, 1976, 2006a], *Porshnyakov* [1973], and *Yagovkin* [1974].

[87] **Chekantash.** The Chekantash unit is the lowest in the geological section of the zone. In the Yassy-Alay region it can be seen in tectonic windows, namely, in the Kipchalma oreade, Fergana Range (Figure 8, *8*) and in the Kulgedzhele oreade, East Alay Range (Figure 8, *10*). Rocks of the unit most likely occupy the same position in the Birguzy, Chekantash, and Uchat oreades (Figure 8, *4, 5,*

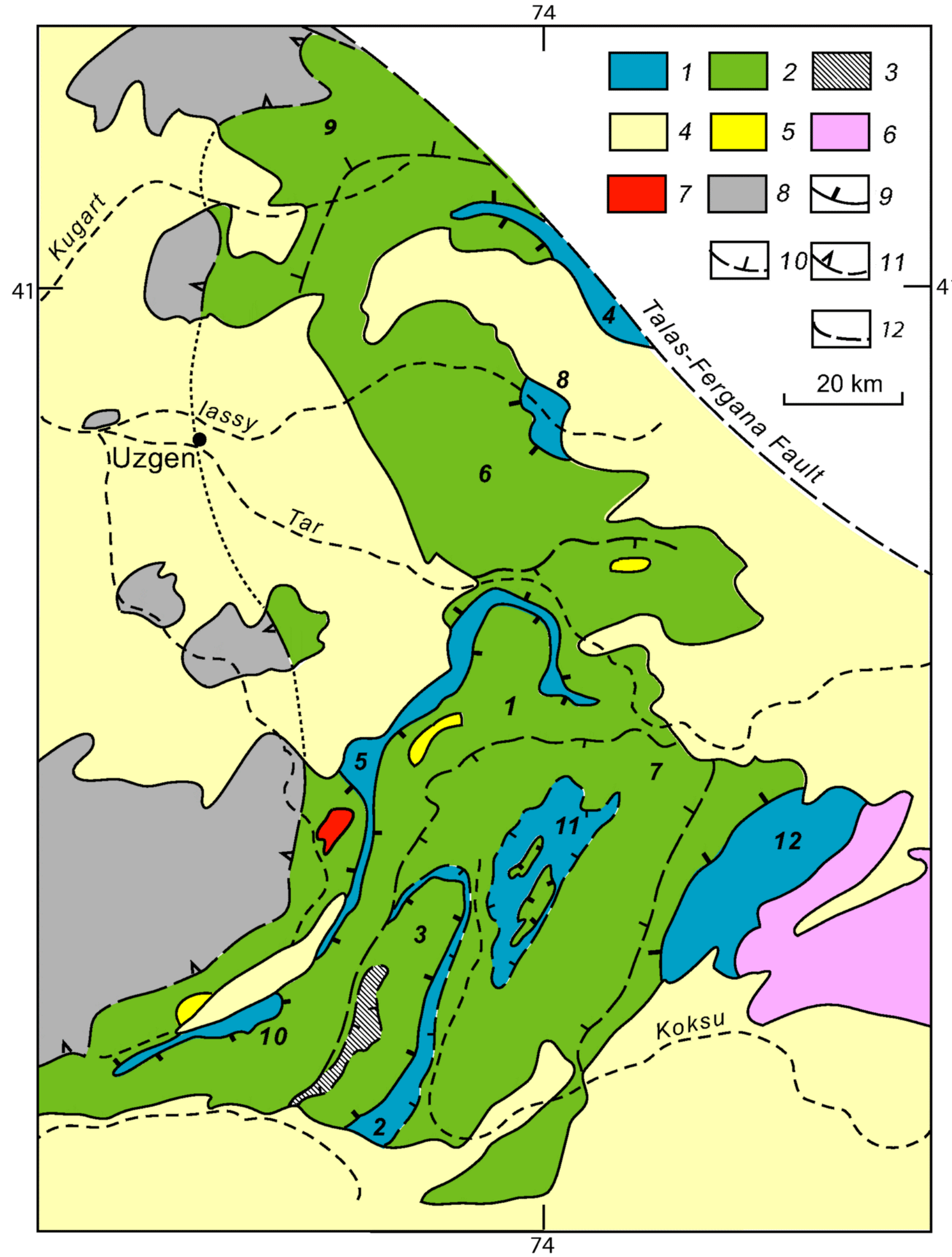


Figure 8. Yassy-Alay region in the Alay tectonic zone. 1–3 – Alay zone, units: 1 – Chekantash, 2 – Tar, 3 – Sugut; 4 – Cenozoic and Mesozoic; 5 – Neoautochthon-3; 6 – Suluterek massif of metamorphic rocks; 7 – Late Paleozoic intrusions; 8 – Southern Fergana tectonic zone; 9 – Primary overthrust faults of deformation stage D-4; 10 – Secondary overthrust faults; 11 – Uzgen-Sanzar thrust fault; 12 – Other faults. *Oreades:* *1* – Akbogus, *2* – Archaltur, *3* – Belauli, *4* – Burguzy, *5* – Chekantash, *6* – Iassy, *7* – Irkesh, *8* – Kipchalma, *9* – Kugart, *10* – Kulgedjele, *11* – Tereksu, *12* – Uchat.

and 12). Allochthonous bodies composed of rocks of this unit also occur among the sediments of the overlying Tar unit as thrust sheets limited by secondary overthrust faults, and in olistoplaques.

[88] In the East Alay Range the lower part of the visible section is formed by 2000-m-thick carbonate rocks with abundant coral and mollusk fauna of the Ludlow, Pridolin, and all Devonian series. The Tournaisian and Visean are represented by a 300-m-thick limestone member bearing foraminifers, brachiopods, and corals. These rocks are overlain by a limestone sequence with chert, argillite, and sandstone beds, accumulated from the Serpukhovian to Late Moscovian as evidenced from foraminifer fauna (Dogdul, Dongurama, and other formations, 1000 m thick). It is

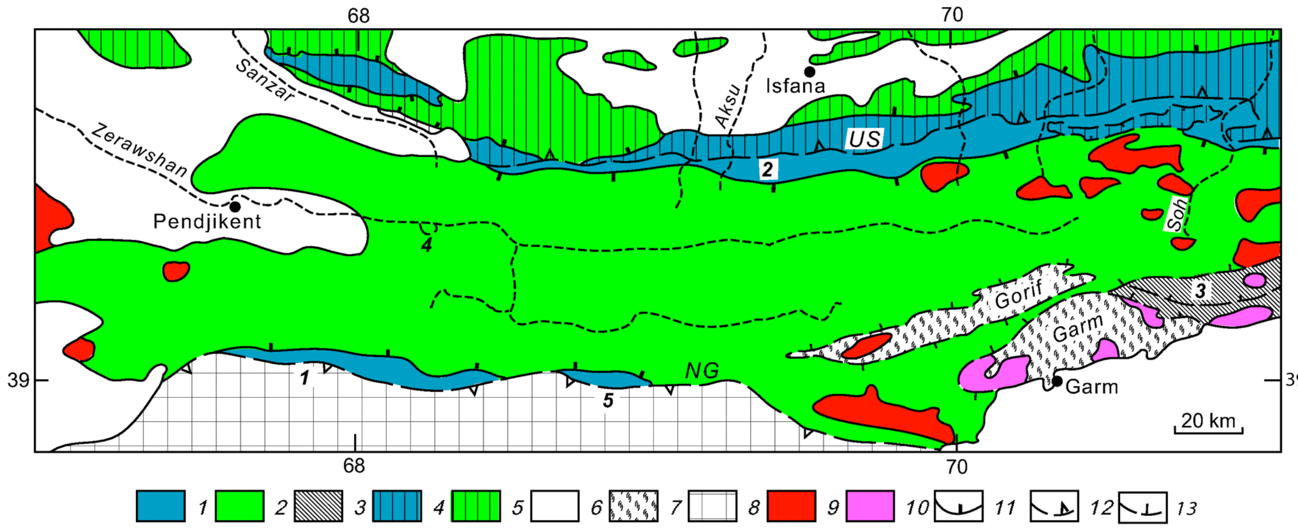


Figure 9. Zeravshan-Alay region of the Alay tectonic zone and western Southern Fergana zone. 1–3 – Alay zone, units: 1 – Chekantash, 2 – Tar, 3 – Dzhirgatal; 4–5 – Southern Fergana zone, units: 4 – Isfayram, 5 – Abshir; 6 – Cenozoic and Mesozoic; 7 – Ancient massifs (Garm, Gorif); 8 – Gissar tectonic zone; 9 – Late Paleozoic intrusive rocks; 10 – Devonian diorites and granodiorites; 11 – Primary overthrust faults of deformation stage D-4; 12 – Secondary overthrust faults and thrust faults separating tectonic zones (*US* – Uzgen-Sanzar fault, *NG* – North Gissar fault); 13 – Other overthrust faults and thrust faults. *Oreades: 1* – Dukdon, *2* – Kurganak, *3* – Pizan, *4* – Urmetan, *5* – Ziddy.

conformably overlain by sandstones, siltstones, and argillites with conglomerate and clastic limestone strata yielding Late Carboniferous foraminifers (Kashkasu and Tuyuk formations, 1000 m thick).

[89] The Kipchalma and Birguzy oreades in the Fergana Range represent a series of thrust sheets formed by terrigenous and carbonate rocks with the Late Silurian and Devonian corals and tentaculites. The Uchat oreade includes the Middle Paleozoic carbonate rocks and the overlying carbonate terrigenous sediments bearing Late Carbonoferous and Asselian foraminifers.

[90] In the Zeravshan-Alay region the Chekantash rocks are exposed in tectonic windows and compose olistoliths and olistoplaques in the Upper Paleozoic sediments referred to the Tar unit.

[91] In the Dukdon and Ziddy tectonic windows (Figure 9, *1 and 5*) the Chekantash unit is overthrusted by the Tar rocks from the north and is thrusted by rocks of the Gissar tectonic zone from the south. The Llandovery to Moscovian sediments of the Dukdon oreade are represented by 3000-m-thick limestones and dolomites yielding abundant coral, brachiopod and foraminifer fauna. Carbonate rocks of the Silurian, Middle Devonian, Visean, and Moscovian sections contain strata of terrigenous sediments; that of the Lower Devonian, Serpukhovian, and Bashkirian include chert beds and lenses. A carbonate terrigenous flysch sequence with basal conglomerates (Darakhtisur and other formations, 1000 m thick) onlaps the carbonate rocks. The polymictic basal conglomerates contain pebble and boulders of Carbonaceous limestone with the youngest fauna of Late Moscovian age. Moscovian foraminifers were found in the flysch sediments as well. This stratigraphic section is complicated by secondary overthrust faults and thrust faults; part of carbonate rocks is of para-autochthonous and allochthonous character.

[92] The Kurganak tectonic window (Figure 9, *2*) is specular in reference to the Dukdon window. Its southern boundary is the overthrust fault at the base of the Tar nappe; the northern, the Karavshin fault that is the western link of the Uzgen-Sanzar thrust fault which separates the Southern Fergana and Alay tectonic zones. An over 3000-m-thick limestone and dolomite sequence is exposed in the Kurganak oreade. The enclosed corals, mollusks, and foraminifers indicate that the sequence corresponds to the whole Devonian, Lower Carboniferous, Bashkirian, Lower Moscovian, and part of the Upper Moscovian. In the Early Devonian part of the section carbonate rocks alternate with terrigenous sediments; in the Middle Devonian and Serpukhovian–Bashkirian parts, with chert beds. Different Devonian and Carboniferous beds are unconformably overlain by a 3000-m-thick conglomerate and coarse flysch sequence with numerous strata of wildflysch and olistostromes. The limestone pebble and boulders bear the Early and Late Carboniferous foraminifers. It is likely in this sequence in the Sokh River basin that the Gzhelian foraminifer specimen was encountered in the conglomerate cement and the Early Permian foraminifers were identified from the limestone beds.

[93] **Tar.** In the Yassy-Alay region the basal part of the visible stratigraphic section of the Yassy oreade (Figure 8,

6) in the Fergana Range is composed of 400-m-thick clayey shales with beds of quartz sandstones, siltstones, and limestones bearing Pridoli corals and brachiopods. They are overlain by distal terrigenous flysch (Yassy and Dzhartyube formations, 3000 m thick). The sandstones and lenses of clastic limestone contain redeposited Devonian corals, tentaculitids, and plant remains. The flysch is overlain by a thin condensed sequence (Kendysu and Dzhurektash formations, from 20 m to 300 m thick) of red and green cherts, clayey shales and bedded limestones bearing foraminifers and conodonts of Late Devonian to earliest Gzhelian age. It is conformably overlain by a proximal, two- and three-component, largely rhythmical flysch composed of sandstone, siltstone, and argillites and enclosing strata of fluxoturbidites and olistostromes (Turgaityube, Mazardon, Mamat, and other formations, 3000 m thick). The calcareous sandstone and clastic limestone beds yield Gzhelian, Asselian, and Early Sakmarian foraminifers.

[94] The Akbogus oreade (Figure 8, *1*) occupies the East Alay Range, Gulchi River valley, and, partly, the southern slope of the Alay Range. The lower part of the oreade section is represented by siliceous and clayey shales with Early and Late Silurian graptolites (Burusundy and Tekelik formations, 1000 m thick). The upper part of the section is formed by carbonate terrigenous flysch (Azvan and other formations, 500 m thick) bearing Lower and Middle Devonian corals, tentaculitids, foraminifers, conodonts, and graptolites. In the Belauli and Irkesh oreades (Figure 8, *3 and 7*) the basalts, andesites, and tuffs are included among Silurian and Early Devonian sedimentary rocks in the Archabulak, Karavankul, and Ailyama formations.

[95] In the Akbogus oreade the Devonian flysch is conformably overlain by a sequence of variegated cherts (radiolarites and phthanites), argillites, siliceous siltstones, and siliceous and clastic limestones (Kalmakasu and other formations, 20 m to 300 m thick). The sequence represents a great stratigraphic interval. In the East Alay Range it yields the Famennian, Visean, Serpukhovian, Bashkirian, and Moscovian ammonoids and foraminifers. In the Alay Range nearby the Daraut Village and in the Sokh River basin the similar sequence contains the Givetian, Frasnian, Tournaisian, Visean, Serpukhovian, Bashkirian, and Early Moscovian conodonts. These condensed sediments are conformably overlain by a terrigenous and carbonate terrigenous flysch sequence bearing Moscovian, Kasimovian, and Gzhelian foraminifers (Akbogus, Demeney, and Oital formations, 2000 m thick).

[96] The Late Carboniferous flysch reaches maximum thickness of 3500 m in the Kugart oreade (Figure 8, *9*) in the Fergana Range. It is represented there by coarse flysch with wildflysch strata containing limestone and basalt boulders.

[97] The Yassy and Akbogus oreades are analogous in structural position and had similar geotectonic depositional environments. They differ in a time span needed for accumulation of the condensed pelagic sediments. The conodont studies in the Yassy oreade showed that these conditions occurred from the Late Devonian to Gzhelian. In the Akbogus oreade the condensed sediments are similar in composition and appearance but were accumulated in a shorter interval from the Givetian or Late Devonian to the Early Moscovian. This indicates that in the Late Moscovian–Gzhelian the deep basin in the western Tien Shan was retained only in the Yassy oreade area.

[98] In the Zeravshan-Alay region (Figure 9) the Tar unit also consists of thrust sheets and slices [*Leonov,* 1979; *Rogozhin,* 2004]. Clayey, carbonaceous clayey, and siliceous shales, sandstones, tuffstones, and siltstones bearing Early Silurian and Ludlow graptolites, are widespread in the Turkestan Range and on the northern slope of the Zeravshan Range (Turkestan, Lyangar, and other formations). Most part of the sequence is composed of a distal flysch. It contains basalt, trachybasalt, and andesite sheet bodies. Terrigenous carbonate sediments of the same age are known in the Zeravshan Range. Section of that type is formed by quartz sandstones, clayey shales, clayey limestones, and dolomites with corals and brachiopods (Zinakh, Shing, and other formations, 1000 m thick).

[99] The area of Silurian zonal thermal metamorphism occurs in the axial part of the Turkestan Range. Eight metamorphic zones, from greenschists to sillimanite garnet gneisses, were distinguished in the 15×120 km stripe. This metamorphism is likely of Silurian age as the isograds cut the Wenlock rocks and the fragments of schists similar to those of the discussed metamorphic zone were recorded in the Upper Silurian sediments. The obtained K-Ar ages of the metamorphic rocks do not contradict this inference [*Bakirov,* 1978].

[100] The Pridoli and Early Devonian are known in the siliceous terrigenous, carbonate siliceous, and reef facies. Siliceous terrigenous sediments bearing graptolites occur on the northern slope of the Zeravshan Range. Radiolarites, phthanites, jaspers, and clayey siliceous siltstones yielding Lochkovian, Pragian, and Emsian conodonts occur in the range as well (part of the Akbasay Formation). On the northern slope of the Gissar Range and in the western part of the Zeravshan Range reef limestones with chert beds are recorded (Kupruk, Khavzak, Shut, and other formations, 2000 m thick). They contain Ludlow, Pridoli, and Early Devonian conodonts and shallow faunal remains.

[101] The Middle and Late Devonian, Early Carboniferous, Bashkirian, and, partially, Moscovian are represented in the Zeravshan Range by siliceous and carbonate condensed sections.

[102] The siliceous type of section is composed of jasper, siliceous clayey shales, and siliceous acidic tuffites bearing conodonts of all the Middle and Late Devonian ages. The sediments are several tens (part of the Akbasay Formation) to several hundreds (Vashan and other formations) meters thick.

[103] The carbonate type of section is known in the Urmetan oreade (Figure 9, *4*) in the Zeravshan River valley. The layer-by-layer study of conodonts from the 300-m-thick limestone showed the presence in the section of all Devonian stages excluding the Givetian, all Lower Carboniferous stages, the Bashkirian, and Lower Moscovian.

[104] The Late Carboniferous–Early Permian is represented by a flysch olistostrome sequence (Obizard and other formations, 1000 m thick) that crowns the section of the Tar unit in the discussed region. The conglomer-

ate and olistostrome beds with large limestone olistoplaques and olistoliths are recorded among the terrigenous flysch. The olistoplaques, olistoliths, and limestone pebble yield the Late Silurian, Early and Middle Devonian, Visean, and Serpukhovian corals, brachiopods, and foraminifers. Carbonate rocks of the Chekantash unit were the source of clastic material for the olistostrome. The conglomerate pebble mainly consists of siliceous rocks derived from the underlying sequence, as well as of sandstone, limestone, and granite. The conglomerate and sandstone cement bears the Late Carboniferous foraminifers.

[105] In the east of the region the olistostrome was studied north of the Daraut Village. Olistoplaques are 300 m thick and several kilometers long there. Olistoliths and olistoplaques are composed of (a) limestone and dolomite similar to the Chekantash rocks and bearing Devonian, Early Carboniferous, Bashkirian, and Moscovian foraminifers; (b) condensed pelagic siliceous carbonate sediments with Devonian and Carboniferous conodonts; (c) sandstones and argillites with the Silurian and Early Devonian graptolites. West of the Daraut Village the olistostrome sequence underwent a strong tectonic processing. Along with the above-mentioned rocks the mixtite contains serpentinite boulders and olistoplaques of: (d) tholeiitic basalts geochemically similar to rocks of a mid-oceanic ridge; and (e) basalts with petrochemical properties of oceanic island arc rocks [*Nenakhov et al.,* 1992; *Pai,* 1991]. The possible source of boulders of extrusive rocks was the Taldyk unit. A lot of mixtite boulders are composed of Lower Paleozoic sediments and of sandstone and conglomerate yielding Asselian foraminifers.

[106] Part of rocks in this region underwent a dynamothermal metamorphism at 300–400°C and at a pressure of 5–10 kbar (Yagnob type of section). These rocks are distributed in the Zeravshan Range and, to a smaller extent, in the Gissar and Karategin Ranges. A gradual transition was recorded between metamorphic and non-metamorphosed Paleozoic rocks. The lower part of the Yagnob type of section is composed of a metamorphosed quartz and quartz arkose siltstone, sandstone, and gravelstone sequence bearing beds of rocks of likely volcanic and volcanogenic sedimentary origin (Yagnob and other formations, 3000 m thick). Most part of the rocks is metamorphosed in greenschist facies. In the upper part of the sequence the metamorphization decreases and the sediments contain Ashgillian and Early Silurian corals. Among these rocks sills and dikes of metamorphosed basalts, andesites, and dacites occur. Andesites and dacites are of high-alkalic composition. The Devonian and Carboniferous rocks and Late Paleozoic flysch also underwent a greenschist metamorphism, which indicates its Permian age.

[107] The Tar unit as a whole is mainly composed of pelagic sediments. In the Silurian the turbidites with a considerable role of distal facies were accumulated and volcanic centers occurred in the region. In the Silurian and Early Devonian bioherms appeared on the margin of the facies zone and, probably, on volcanic mountains. In the Late Silurian, Devonian, and Early Carboniferous most part of the territory was a place of slow accumulation of deep-water sediments including common radiolarites. In the Late Carboniferous the formation of turbidites, including distal and proximal facies, fluxoturbidites, and olistostromes, resumed.

[108] **Sugut.** The Sugut unit is located in the East Alay Range (Figure 8) and is composed of metamorphic rocks (Sugut and Suuktor formations, 2500 m thick). The lower part of the section is formed by metamorphosed sandstones, pelites, cherts, basalts, and tuffaceous rocks along with metamorphosed andesite basalts, andesites, and liparites. Petrochemical properties of metavolcanites correspond to those of island arc extrusive rocks [*Shvanov,* 1983]. The up to 100-m-thick tectonic lenses of brecciated and serpentinized dunites are recorded in the section. The upper part of the section is composed of metamorphosed sedimentary rocks that contain Silurian–Middle Devonian corals and foraminifers. The rocks are irregularly metamorphosed from the phyllite to epidote-amphibolite facies with prevailing greenschists.

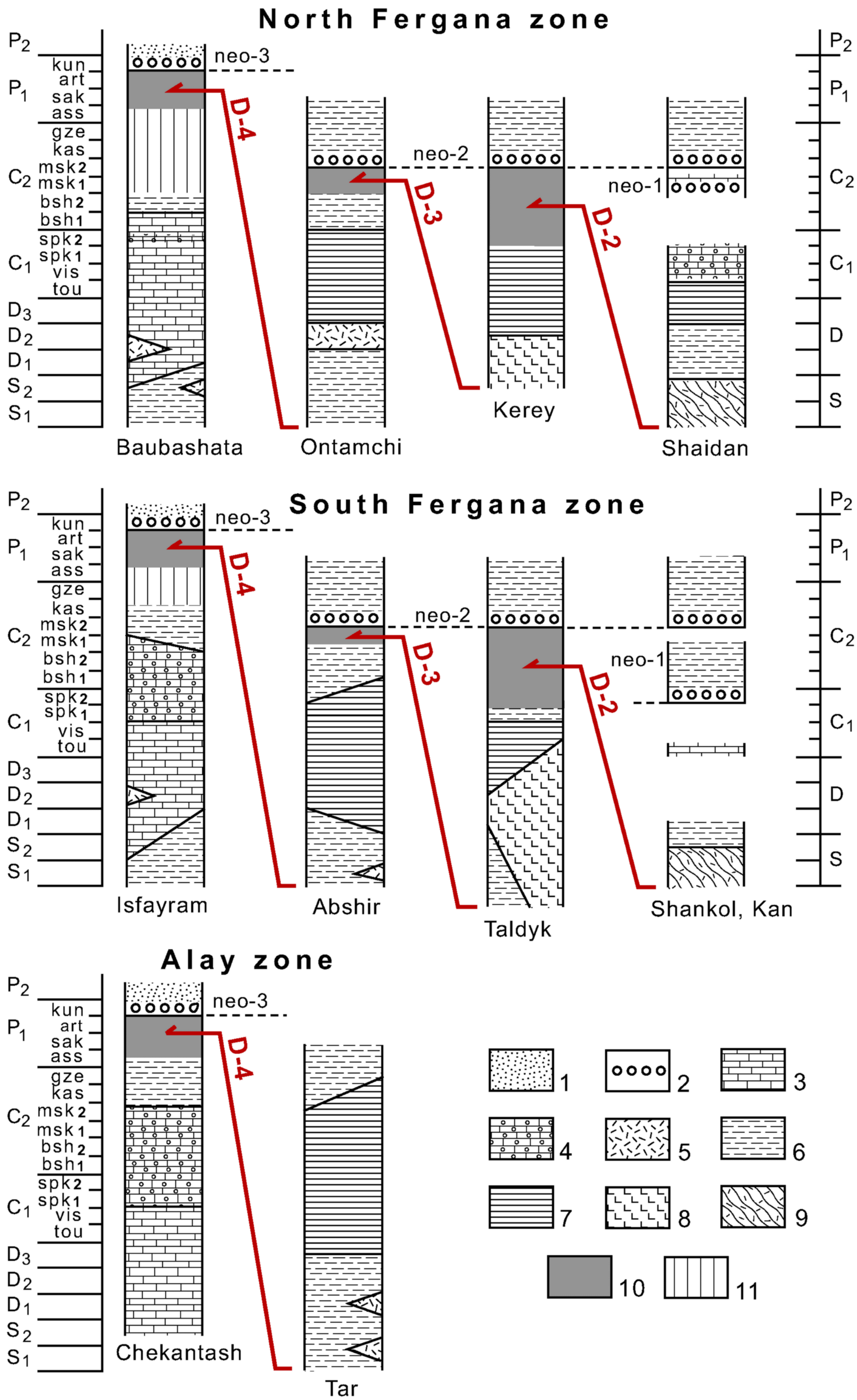
[109] The rocks of the Sugut unit occur in a trough and on a synform flank. They onlap onto a flysch sequence (Terek Formation) of the Tar unit that bears the Carboniferous floral remains. The Sugut unit occupies the uppermost position in the geologic section of the Alay tectonic zone.

[110] Accumulation of the Sugut sediments occurred in a volcanic island arc or on continental slope that underwent volcanic eruptions. This complex gained its modern appearance owing to tectonic decoupling and metamorphism, likely, in the accretionary prism nearby the Kazakh–Kyrgyz microcontinent margin.

[111] **Dzhirgatal.** This unit is located in the eastern part of the Karategin Range and consists of two tectonic sheets 10 and 5 km thick, respectively (Pizan and Khait oreades). The sheets are formed by polymictic and arkose carbonaceous sandstones, siltstones, and argillites that underwent zonal metamorphism from the biotite to sillimanite zone, and are nowadays represented by schists and gneisses (Khait, Chubai, Karagushkhon, and other formations).

[112] Metamorphosed pelites prevail in the Pizan oreade (Figure 9, *3*). Less metamorphosed rocks contain Early and Late Silurian graptolites; limestone beds in the upper part of the section, the Early Devonian and Eifelian crinoids. The Khait oreade is mainly composed of metasandstones. Marble bearing Late Silurian–Early Devonian corals and crinoids is recorded in the upper part of the section. The attribution of beds with fossil fauna to the stratigraphic section of metamorphic rocks has been questioned and their age was suggested to be older. The Dzhirgatal rocks were metamorphosed prior to the intrusion of diorites with Pb-Pb age of 368–395 Ma [*Melnichuk,* 1989].

[113] **Neoautochthon.** The neoautochthon sediments unconformably overlie the Tar rocks and are represented by a conglomerate and sandstone sequence bearing Early Permian, evidently redeposited, foraminifers (Toktash and Karasuran formations, 1000 m thick). The sediments are not widely distributed. They likely correspond to Neoautochthon 3 in the Southern Fergana tectonic zone. In the southern Zeravshan-Alay region in the Fan Mountains, the Late Carboniferous and still older rocks of the Tar


North Fergana zone
South Fergana zone
Alay zone
P2
P1
C2
C1
D3
D2
D1
S2
S1
D
S
kun
art
sak
ass
gze
kas
msk2
msk1
bsh2
bsh1
spk2
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tou
neo-3
neo-2
neo-1
D-4
D-3
D-2
Baubashata
Ontamchi
Kerey
Shaidan
Isfayram
Abshir
Taldyk
Shankol, Kan
Chekantash
Tar
1
2
3
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10
11

Table 1. Structural units of the southern Tien Shan

Structural storey	Kyzylkum	Western Tien Shan			Central Tien Shan	
		Alay zone	South Fergana zone	North Fergana zone	Atbashi-Inylchek zone	Kokshaal zone
IV b	–	Dzhirgatal	Toguzbulak	–	Balykty	–
IV a	Tamdy	Sugut	Shankol	Shaydan	Atbashi	–
III	Kulkuduk	–	Taldyk	Kerey	Keltubek	–
II	Bukan	Tar	Abshir	Ontamchi	Chatyrkul	Maidantag
I	Murun	Chekantash	Isfayram	Baubashata	Kokkiya	Muzduk

Note: Structural storeys I and II are formed by rocks of the Alay-Tarim paleocontinent passive margin; storey III, by rocks of the Turkestan paleoocean crust and oceanic island arcs; storey IV, by sediments of the accretionary prism made up nearby the Kazakh-Kyrgyz paleocontinent active margin of the oceanic crust (substorey IVa) and continental slope and rise (substorey IVb) rocks.

unit are unconformably overlain by a barren sequence of trachytes, phonolites, and other alkalic lavas, of tufflavas and tuffs with conglomerate, sandstone, and limestone beds (Kaznok Formation, 1500 m thick). These sediments are likely of Permian age.

Correlation of Units

[114] Geologic sections in the Northern Fergana and Southern Fergana zones are of similar four-storeyed structure (Figure 10 and Table 1). The lower (I) structural storey is formed by the Baubashata and Isfayram units that mostly consist of shallow carbonate sediments. The II structural storey is occupied by the Ontamchi and Abshir units, which sections are mainly composed of turbidites and deep-water siliceous sediments. The III storey is formed by the Kerey and Taldyk units made up of weakly metamorphosed oceanic volcanites. The IV storey is represented by nappes of the rocks that underwent metamorphic transformation in a subduction zone and accretionary prism prior to their overthrusting onto the Alay-Tarim continent. The Shaydan and Shankol units are composed of oceanic rocks; the Toguzbulak unit, of continental sediments.

[115] In the Alay tectonic zone the two lower nappe storeys are similar to the lower structural storeys of the Fergana setting (Figure 10 and Table 1). The Paleozoic ophiolitic nappes that form III and IV storeys in the Fergana setting, are unknown in the Alay zone. In the Yassy-Alay region the highest position in the section is occupied by the Sugut unit composed of rocks of a volcanic island arc, which were metamorphosed prior to overthrusting. It is a probable analog of nappes of the IV structural storey in the Fergana setting. The Dzhirgatal unit is likely such an analog in the Zeravshan-Alay region.

[116] Nappes of the upper storey represent an accretionary complex that was formed nearby the Kazakh-Kyrgyz microcontinent margin prior to the collision. Ophiolites of the III storey were separated from the oceanic crust prior to collision and were included in the accretionary prism. They became an allochthonous body during the collision when the accretionary prism was overthrusted onto the Alay-Tarim continent. Formation of nappes of the II storey resulted from the collision of the Alay-Tarim and Kazakh–Kyrgyz terranes.

[117] In the Carboniferous and Early Permian the following ensemble of the autochthon and primary nappes appeared (downward from the top): the Shankol-Shaydan, Sugut, and Toguzbulak accretionary nappes (IV storey); the Taldyk-Kerey accretionary collisional nappe (III storey); the Abshir-Ontamchi-Tar collisional nappe (II storey); the Isfayram-Baubashata-Chekantash autochthon (I storey). In the Permian the Karaunkur strike-slip fault and Uzgen-Sanzar thrust fault subdivided the nappe ensemble of the western Tien Shan into parts described above as the Northern Fergana, Southern Fergana, and Alay tectonic zones.

⇐ **Figure 10.** Structure of major units of the South Turkestan domain in the western Tien Shan. 1 – Continental sediments; 2 – Conglomerates and breccias at the neoautochthon base; 3 – Shallow carbonate shelf sediments; 4 – Limestones and cherts accumulated in deeper shelf; 5 – Volcanogenic sedimentary and volcanic rocks; 6 – Deep-water terrigenous and siliceous-terrigenous sediments accumulated on continental slope and rise (flysch, olistostromes, clayey rocks, etc.); 7 – Condensed deep-water siliceous and carbonate siliceous sediments accumulated on continental slope and oceanic bottom; 8–9 – Oceanic basalts, hyaloclastites, ignimbrites: 8 – slightly metamorphosed, 9 – metamorphosed; 10–11 – Age of overthrusting: 10 – most like (or most intense), 11 – less like (or less intense). D-2, D-3, D-4 – deformation stages; neo-1, neo-2, neo-3 – neoautochthons.

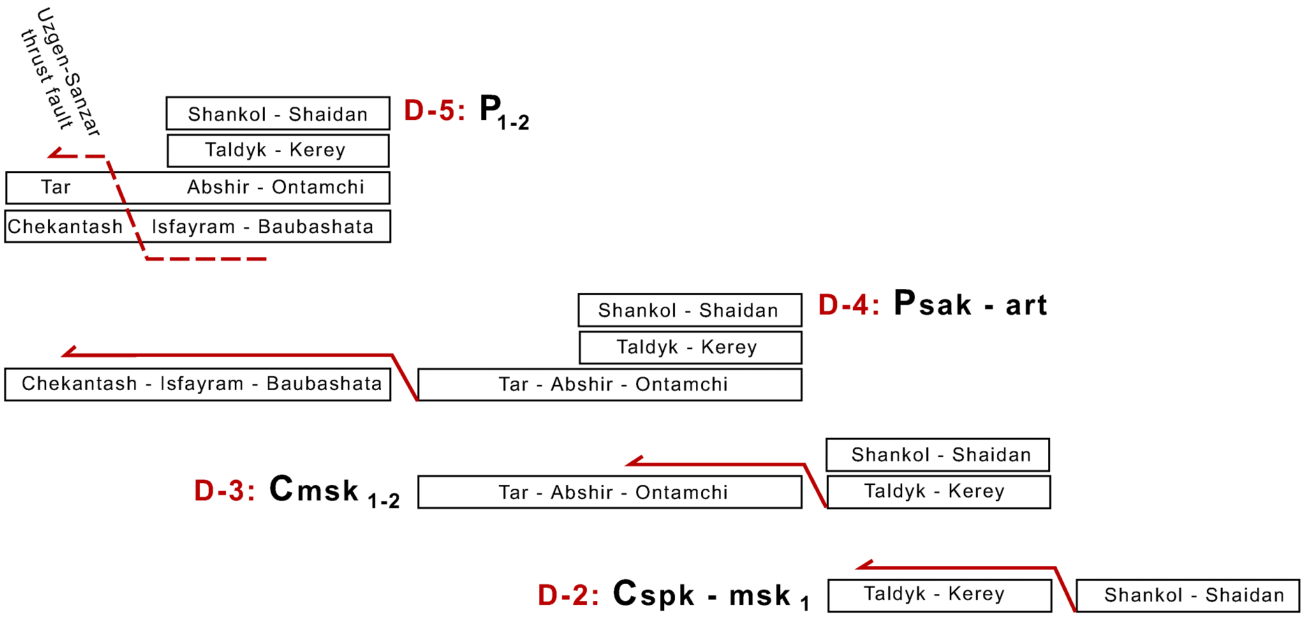

Figure 11. Overthrusting scheme of the western Tien Shan units. D-2, D-3, D-4. and D-5 – deformation stages.

Deformation Stages

[118] **D-1.** Several deformation stages can be recognized in the formation of nappes in the region. The earliest are the deformations of metamorphic schists of the upper structural storey. In the Shankol and Shaydan units metamorphic rocks are strongly crumpled and these folds appeared prior to the overthrusting. They occurred not later than the Silurian since the deformed metamorphic schists are unconformably overlain by slightly modified Late Silurian sediments. In the Shaydan unit Silurian conodonts were encountered in the deformed metamorphic rocks, which reduces the age interval of D-1 deformations to the Silurian.

[119] Among the deformation structures of stage D-1 several generations were revealed in the Shankol unit. The earliest were recumbent isoclines; the second generation is represented by vertical folds with axial-plane cleavage. They were followed by thrust faults which movement resulted in plastic deformations of folds of the second generation [*Duk,* 1995]. At stage D-1 the recumbent folds were formed in metamorphic rocks of the Dzhirgatal unit. The isograds of the Devonian zonal metamorphism cut these folds [*Melnichuk,* 1989].

[120] The next three deformation stages correspond to three overthrust episodes that resulted in formation of the western Tien Shan nappe ensemble (Figures 10 and 11). The nappe ensemble had been formed with interruptions during 60–70 million years, from the Serpukhovian to Artinskian.

[121] **D-2.** At stage D-2 the Shankol-Shaydan nappe was overthrusted onto the Taldyk and Kerey units which were separated from the subducting oceanic crust. The youngest rocks in the Taldyk and Kerey sections are Serpukhovian in age defining the oldest age limit of stage D-2 lower boundary. Neoautochthon-1 composed of Serpukhovian–Early Moscovian rocks onlaps onto the Shankol and Shaydan nappes and on the Shaydan nappe root zone in the Kan unit. These relationships indicate the Serpukhovian age of the overthrusting. Accumulation of the Neoautochthon-1 sediments on the Shankol-Shaydan nappe could occur concurrently with underthrusting of the Taldyk-Kerey sheet beneath the Shankol-Shaydan metamorphic schists. The upper age limit of stage D-2 is defined by the beginning of Neoautochthon-2 accumulation in the Late Moscovian. This neoautochthon onlaps onto Neoautochthon-1, the Shankol-Shaydan, Taldyk-Kerey, and Abshir-Ontamchi nappes, and on the Kan unit.

[122] **D-3.** At stage D-3 the Taldyk unit together with the overlying Shankol nappe and Neoautochthon-1 were overthrusted onto the Abshir unit; the Kerey unit together with the Shaydan nappe and Neoautochthon-1 were overthrusted on the Ontamchi unit. The youngest sediments of the Ontamchi and Abshir units are of Bashkirian and Early Moscovian age, respectively. The Neoautochthon-2 base corresponds to the Late Moscovian. This defines the Moscovian age of stage D-3 deformations.

[123] The overthrusting at stage D-3 was accompanied by deformations of the allochthon and of rocks overlain by nappes. A large part of the gabbro-ultrabasite complex in the allochthon was transformed to mélange and the allochthon was decoupled by secondary overthrust faults. Twinned sections of the allochthon produced by these processes are described above in the Kyrgyzata and Hodjagoir oreades and were recorded in other objects. The rocks of the Abshir and Ontamchi units underwent tectonic impact as well. A part of tectonic mixtite occurring at the top of

the Abshir unit was most likely formed at stage D-3.

[124] **D-4.** At stage D-4 the Tar-Abshir-Ontamchi nappe with the overlying nappes and neoautochthons was overthrusted onto the Chekantash-Isfayram-Baubashata autochthon. The youngest rocks at the autochthon top in the Northern Fergana, Southern Fergana, and Alay tectonic zones are of Bashkirian, Kasimovian, and Asselian age, respectively. Neoautochthon-3 that unconformably overlies the rocks deformed at stage D-4, was dated as the Kungurian-Ufimian. These records indicate that the most probable (or the most intense) nappe movement occurred in the Sakmarian-Artinskian (Figures 10 and 11). The earlier nappe movements at stage D-4 probably took place concurrently with flysch formation on the moving allochthon beginning from the Moscovian. These movements, if they ever occurred, were less intense.

[125] The Abshir-Ontamchi-Tar nappe underwent a significant tectonic transformation during its movement. This nappe is composed of easily deformed flysch and shale sequences that were tectonically processed, differently in various parts. Tectonic structures produced at this deformation stage are of the following origin.

[126] 1. During the nappe movement the allochthon mass was tectonically subdivided by secondary overthrust faults to sheets that overthrusted one another.

[127] 2. Recumbent and flexure-drag folds at the boundaries of tectonic sheets and the flow folds were formed in the moving allochthon. In the Tegermach oreade (Figure 6, *10*) the tectonic flow folds occur throughout the 2-km-thick allochthon sequence. The magnitude of over 100 studied folds varies there from 0.5 m to 10 m; of 160 folds, from 10 m to 100 m; and that of 13 folds, from 100 m to 400 m [*Burtman,* 1976]. The folds commonly form cascades.

[128] 3. The most intense tectonic processing resulted in formation of the mixtite containing rocks of the whole stratigraphic range of the allochthonous sheet. Its matrix is composed of the deformed Silurian rocks. Such mixtite was discussed above in the Abshir unit description.

Direction of Nappe Movement

[129] Direction of the nappe movement was investigated in the Abshir and Tar units which form the second structural storey of the western Tien Shan nappe ensemble. For this purpose the folds formed in tectonic sheets in the course of nappe movement were studied.

[130] In the Abshir unit this research was conducted in the Tegermach oreade (Figure 6, *10*). It represents a gently curved allochthonous sheet, about 2 km thick and 18×20 km in size, that overlies the Carboniferous rocks of the Isfayram unit. The most part of the sheet is composed of Silurian flysch. The folds do not expand beyond the allochthonous sheet, they were formed at stage D-4 during the Abshir nappe movement. Stereograms in Figure 12 demonstrate the F_4 fold vergence as it was at stage D-4. In the stereogram compilation the corrections removing the effect of later deformations were made. Stereogram "a" shows records on 53 isoclines and stereogram "b" is based on the parameters of 220 tight folds [*Burtman,* 1976]. The research revealed that the Abshir unit was overthrusted southwards. The data on other parts of the unit also indicate the prevailing southward vergence of F_4 folds and the southward movement of the Abshir nappe (in modern system of coordinates).

[131] In the Tar unit the F_4 fold vergence was studied in the Belauli oreade (Figure 7, *3*) representing an allochthonous sheet, about 3 km thick, that overlies the Archaltur oreade (Figure 8, *2*) referred to the Chekantash unit. The upper part of the Archaltur oreade is composed of Lower Carboniferous carbonate flysch and limestones. The lower part of the Belauli oreade is formed by clayey and siliceous shales with tuff and limestone beds bearing Middle and Upper Devonian fossil fauna. They are overlain by the Carboniferous terrigenous flysch. At later stages of deformation in the Permian the Belauli nappe together with the underlying rocks was crumpled in a synform fold and then was curved in a horizontal fold. The parameters of 188 isoclines and flexures of magnitude from 0.2 to 30 m were measured at and nearby the synform centrocline. Figure 13 shows stereograms of the F_4 fold vergence with corrections removing effects of deformations that took place after the stage D-4 [*Burtman,* 2006a; *Klishevich and Klishevich,* 1983]. The vergence of F_4 folds favors the inference on south- or southeastward movement of the Tar nappe (in modern system of coordinates).

Kyzylkum

[132] The Kyzylkum geologic section similar to that of the western Tien Shan is four-storeyed and is composed of (downward from the top): accretionary Tamdy nappe (IV storey); accretionary collisional Kulkuduk nappe (III storey); the Bukan collisional nappe (II storey); the Murun autochthon and para-autochthon (I storey).

[133] Stratigraphic sections of the Kyzylkum units were described by *Burtman* [1973, 2006a] and *Mukhin et al.* [1991].

Murun

[134] This unit occupies a vast territory (Figure 14). The visible basal part of the Murun unit in the Kuldzhuktau Mountains is composed of sediments bearing the Late Ordovician benthic fauna. The Silurian rocks conformably overlie the Ordovician. The Llandovery in the South Kuldzhuktau Mountains is represented by offshore sediments, namely, conglomerates, cross-bedded quartz sandstones, and volcanic tuffs, interbedded with limestone containing brachiopods, tabulates, and stromatoporids (Darbaza Formation, 500 m thick). In the North Kuldzhuktau Mountains this sequence is replaced by limestones bearing trilobites, brachiopods, and tabulates (Yangikazgan Formation, 500 m thick).

[135] Upward from the base these sediments grade into a carbonate sequence that is 2000–3000 m thick in the Kuldzhuktau and Tamdytau Mountains and half as much

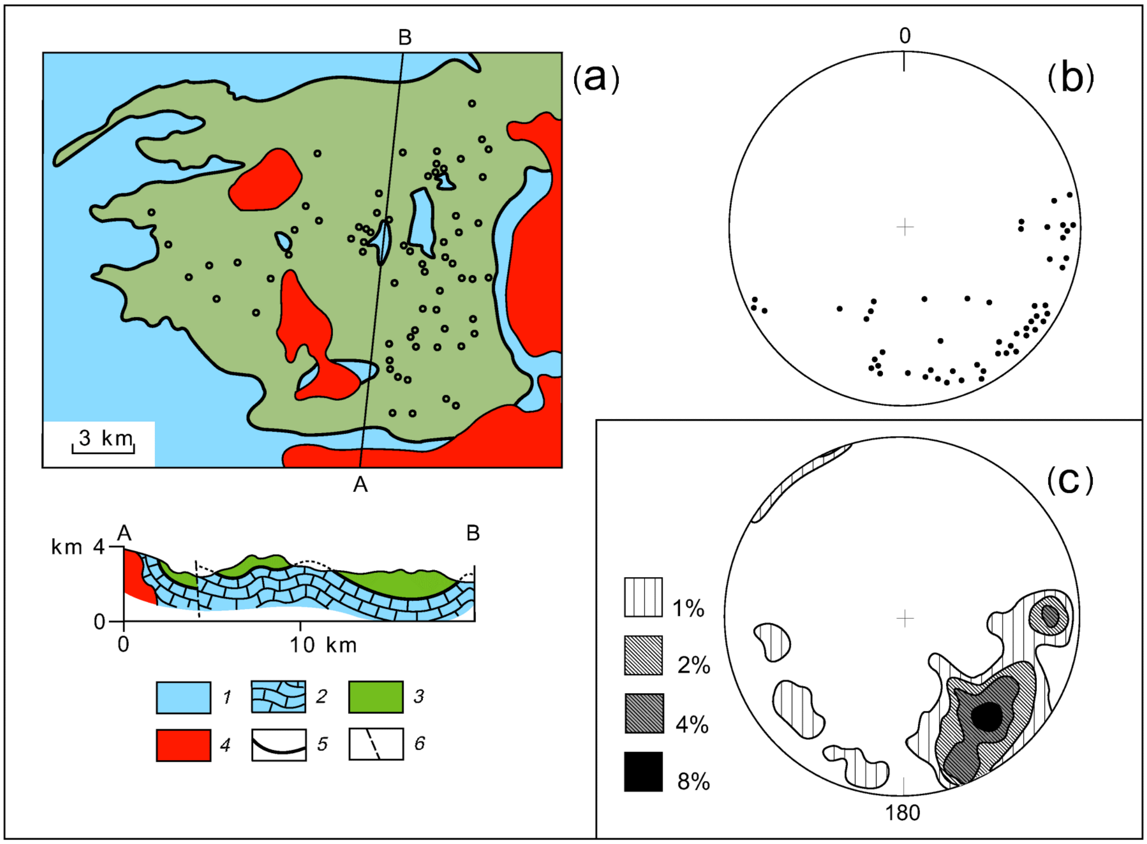

Figure 12. Vergence of F_4 folds in the Tegermach oreade, Abshir unit. a – map and cross-section of the Tegermach oreade (Figure 6). Points indicate places of studied folds. 1–2 – Isfayram unit (1 – on the map, 2 – on the cross-section); 3 – Tegermach oreade; 4 – Granites; 5 – Overthrust fault; 6 – Other faults. b – stereogram of isoclinal fold vergence with plotted junctions of fold axial surface raised lines with the upper semisphere (53 folds, polar equally intermediate projection, modern system of coordinates). c – stereogram of tight fold vergence (220 folds in the same projection and system of coordinates).

in the North Bukantau Mountains. In the Kuldzhuktau Mountains this sequence corresponds to a time span ranging from Wenlock to Early Carboniferous. A hiatus is recorded in the Early Devonian. The carbonate sediments contain benthic fauna, chert nodules and quartz sandstone beds. The upper part of the autochthon is composed of flysch and olistostrome sequence (Taushan and Kamysty formations, 1000 m thick). The youngest fauna in the olistoliths is of Moscovian age.

[136] North of the Kuldzhuktau Mountains the basal part of carbonate sediments is of Early Devonian age; the uppermost, of Early Moscovian. This sequence overlies the Silurian rocks with angular unconformity. Hiatuses are widespread in the Serpukhovian–Early Bashkirian interval that is characterized by formation of karst hollows and bauxite accumulation in them.

[137] In the Tamdytau and Bukantau Mountains the Early Moscovian limestones are overlain by carbonate terrigenous flysch sequence that composes the upper part of the Murun section (Azhrikty, Keriz, and other formations, 500 m thick). Upward from the base of the sequence the clastic material gets coarser and olistoliths and conglomerate beds appear. The lower part of the sequence bears Early Moscovian foraminifers and the youngest fauna from limestone fragments is of Late Moscovian age. In the western Tamdytau Mountains at the top of the Murun unit beneath the Bukan overthrust fault, the 250-m-thick tectonic mixtite was recorded and described [*Burtman,* 1973, 1975].

[138] In the South Nuratau Mountains the Murun rocks are exposed in an antiform core in the Debelyand tectonic window (Figure 14, *4*).

[139] In the North Nuratau Mountains the Murun rocks compose several allochthonous massifs overlying the Late Carboniferous flysch and olistostrome sequence that terminates the stratigraphic section of the Bukan unit. These allochthonous massifs most likely represent the erosionally prepared gigantic olistoplaques transported a second time during the autochthon and allochthon deformation. The largest massif, Basragata oreade (Figure 14, *1*), represents a set of thrust sheets that overlie the flysch bearing Early Moscovian foraminifers. The thrust sheets together with the underlying rocks compose flanks and trough of the Shokhtau

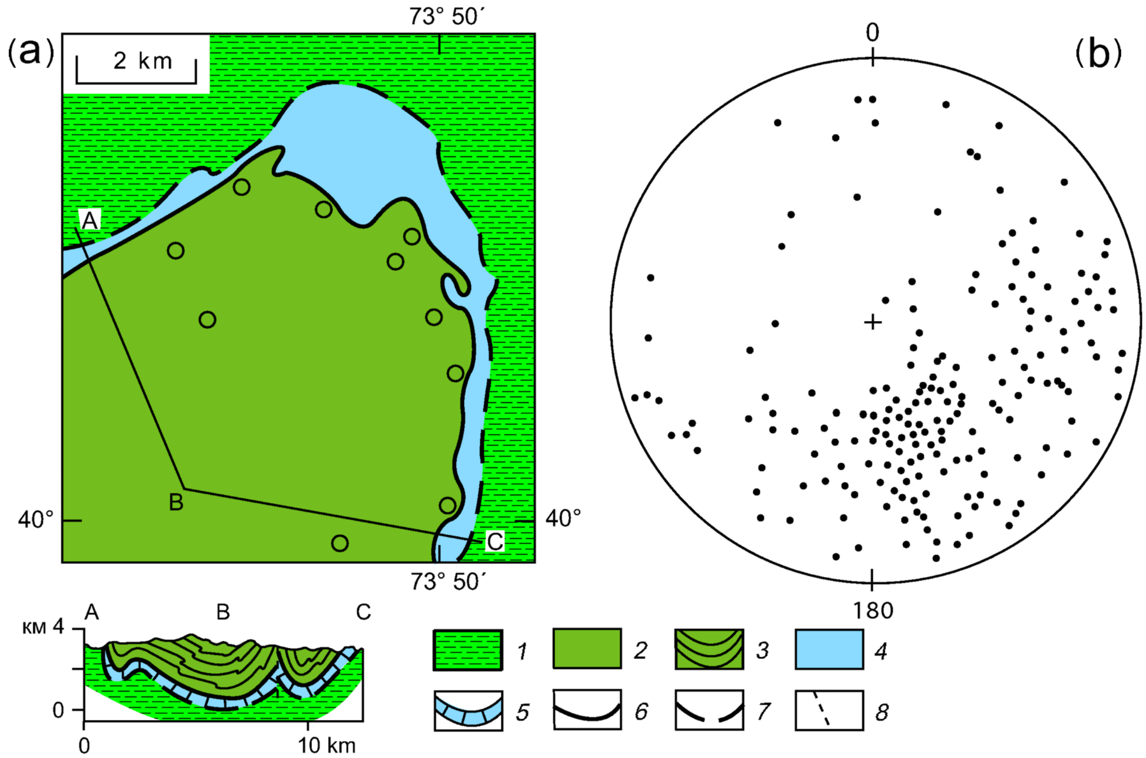

Figure 13. Vergence of F_4 folds in the Belauli oreade, Tar unit ([after *Klishevich,* 1983], modified). a – map and cross-section of the northern Belauli oreade (Figure 8). Circles indicate places of studied folds. 1–3 – Oreades of the Tar unit: 1 – Irkesh, 2–3 – Belauli (2 – on the map, 3 – on the cross-section); 4–5 – Archaltur oreade of the Chekantash unit (4 – on the map, 5 – on the cross-section); 6–7 – Overthrust faults (6 – primary, 7 – secondary); 8 – Other faults. b – stereogram of isoclinal folds and F_4 tight flexures vergence in the Belauli oreade, with plotted junctions of normals to fold axes with the upper semisphere (188 folds, modern system of coordinates).

synform fold. The Basragata oreade base is marked by a breccia formed by chert and limestone fragments. At the allochthon base the 400-m-thick carbonaceous siliceous shales, siltstones, limestones and dolomites containing the Wenlock and Ludlow graptolites and Pridoli brachiopods, are recorded. They are overlain by an over 2500-m-thick limestones and dolomites. The limestones bear Early–Middle Devonian and Frasnian brachiopods, corals, and conodonts. The geologic section of the Basragata oreade is crowned by a thin thrust sheet composed of cherts and clastic limestones with the Visean brachiopods and foraminifers.

[140] The Dzhalpak and Kyzkol oreades (Figure 14, *3 and 5*) are the allochthonous bodies of smaller size. They occur in synform troughs over the Late Carboniferous flysch and olistostrome sequence that terminates the Bukan section. The Dzhalpak oreade is composed of Silurian, Devonian, and Lower Carboniferous rocks; the Kyzkol oreade, of Silurian sediments.

[141] In the Murun facies zone the shallow, mainly biogenic carbonate sediments were accumulated in the Middle Paleozoic. In the inner, southern, part of the zone carbonate accumulation started in the Ordovician and Early Silurian; in the outer part, in the Late Silurian and Lochkovian. It continued with rare interruptions up to the Moscovian when all the facies zone area was submerged to pelagic depths and the turbidity accumulation began.

Bukan

[142] The Bukan unit is characterized by incomplete and condensed Devonian and Carboniferous sections and by the Late Carboniferous flysch and olistostrome sequence.

[143] The Silurian sediments composing isolated fragmentary sections are known in the Nuratau Mountains. The sediments bearing Llandovery and Wenlock graptolites are represented by argillites, carbonaceous siliceous clayey shales and mainly quartz sandstones. They are commonly rhythmical and contain basalt flows. The Late Silurian sediments are represented by terrigenous and carbonate rocks bearing benthic fauna.

[144] The Devonian sediments unconformably overlie the underlying rocks. In the western North Nuratau Mountains, on the flanks of the Shokhtau synform (Figure 14) the

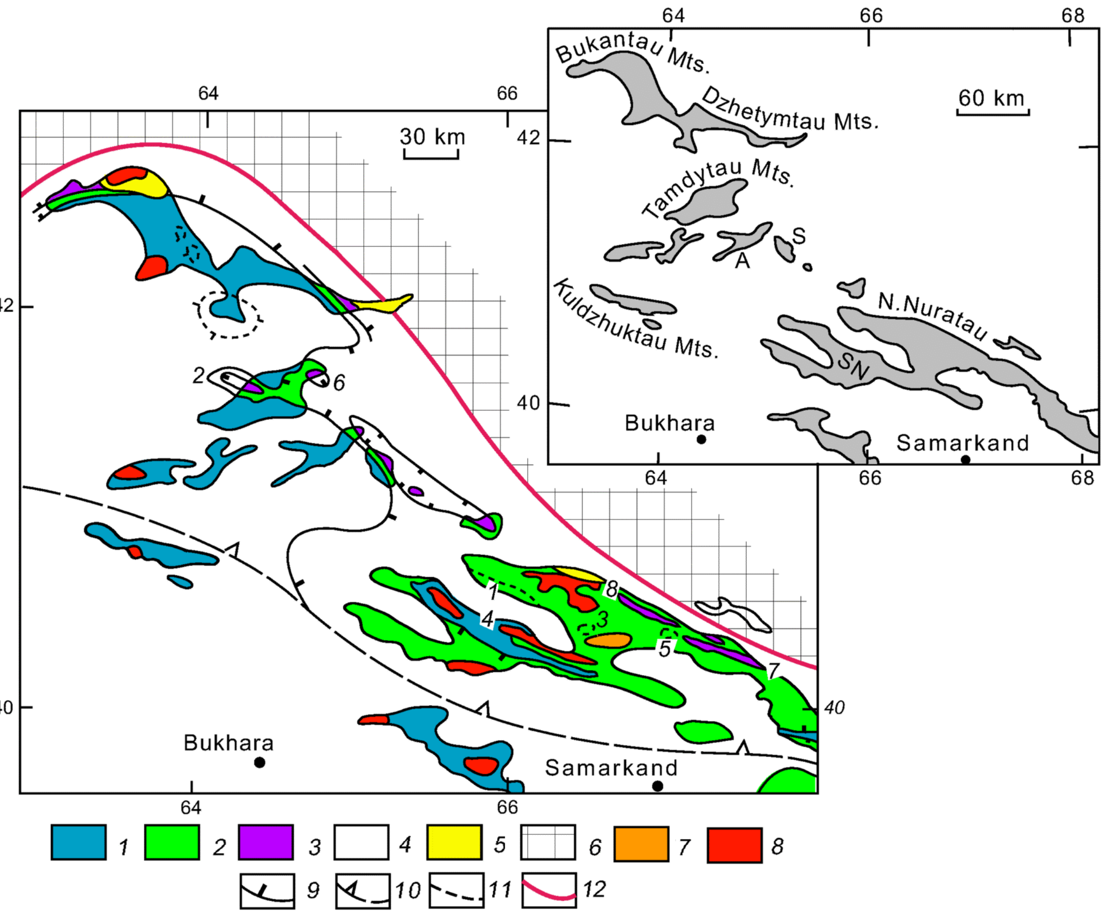

Figure 14. Kyzylkum units. 1–3 – South Turkestan domain, units: 1 – Murun, 2 – Bukan, 3 – Kulkuduk and Tamdy; 4 – Cenozoic and Mesozoic; 5 – neoautochthon; 6 – North Turkestan domain; 7–8 – Late Paleozoic intrusions (7 – alkalic, 8 – granites); 9 – Primary overthrust faults; 10 – Probable western extension of the Uzgen-Sanzar thrust fault; 11 – Other faults; 12 – Position of the Turkestan oceanic basin suture. *Oreades: 1* – Basragata in Shokhtau synform, *2* – Bassumar in Tyumenbai synform, *3* – Dzhalpak in Merishkor synform, *4* – Debelyand, *5* – Kyzkol in Daristan synform, *6* – Kynyr in Tyumenbai synform, *7* – Ustakhan in Yatak-Arvaty synform, *8* – Khissar in Sentyab synform. *Inset map* shows hills and mountains (shadowed) in the Kyzylkum Desert: A – Aristantau Mts., N. Nuratau – North Nuratau Mts., SN – South Nuratau Mts., S – Sangruntau Mts.

Silurian sediments are overlain with angular unconformity by a carbonate sequence bearing abundant corals, brachiopods, and foraminifers. The sequence base is of Lochkovian age, the top, of the Early Moscovian. A lot of hiatuses are recorded in the section. It lacks the Eifelian, Upper Devonian, Lower Tournaisian, Serpukhovian, and partly Bashkirian rocks. Thickness of the carbonate sequence in the Shokhtau synform is about 1000 m. Within the same stratigraphic range it decreases eastwards down to 400 m in the Merishkor synform and to 200 m in the Daristan synform. In the same direction a number and range of hiatuses increase. In the Daristan and Sentyab synforms the Middle and Late Devonian and Early Carboniferous rocks are missing. In the southeastern North Nuratau the 150-m-thick Late Bashkirian–Early Moscovian limestones with basal conglomerates overlie Silurian shales and sandstones.

[145] In all the sections the carbonate sequence is conformably overlain by a finely rhythmical flysch bearing rare conglomerate beds. In the Daristan synform the flysch member yields Moscovian foraminifers. Its visible thickness is over 500 m. In the Sentyab synform the carbonate terrigenous flysch is overlain by a 300-m-thick mixtite formed as a result of olistostrome tectonic processing.

[146] The flysch and olistostrome sequence (Murynkuduk and other formations) is widespread in the Bukan nappe. It was studied in the Tamdytau, Bukantau, Sangruntau, Dzhetymtau, and North Nuratau Mountains. The olistostromes contain large olistoliths and olistoplaques of organogenic limestones bearing fauna of different age and of sandstones, cherts, alkalic basalts, metamorphic schists, and rocks of all oceanic crust beds. Some limestone olistoliths are of authigenic origin, another part is composed of shallow-

water rocks derived from the Murun facies zone. Fragments of oceanic crust rocks and metamorphic schists arrived at the flysch from the oncoming Kulkuduk and Tamdy nappes.

[147] The blocks are commonly tens of meters in size. In the North Nuratau and Tamdytau Mountains some olistoplaques are as great as kilometers in size. Gigantic olistoplaques in the North Nuratau Mountains which are composed of the Murun rocks are described above in the Murun unit discussion. In the Tamdytau Mountains gigantic olistoplaques are formed by metamorphic schists (Uchkuduktau Formation), Early Paleozoic trachybasalts (Elmesashchi Formation), and Middle Paleozoic limestones (Balpantau and Dzhamankyngyr Mountains).

[148] In the western Tamdytau the mixtite formed as a result of tectonic processing of a flysch and olistostrome sequence compose a tectonic sheet overthrusted onto the Bukan and Kulkuduk rocks along the secondary overthrust fault. Characteristic of the mixtite are gabbroid olistoliths and plagiogranite olistoplaques, the greatest of which is 800 m long.

[149] The youngest organic remains found in the flysch and olistostrome sequence are the Moscovian foraminifers. They were identified in an olistolith from the Bukantau Mountains, in olistostrome cement in the Sangruntau Mountains, and in the Tamdytau Mountains flysch. The total thickness of the discussed sequences is several kilometers, however, their true stratigraphic thickness is difficult to estimate owing to widely distributed secondary overthrust faults and tectonic slices.

[150] The Middle Paleozoic sediments of the Bukan unit were formed on the continental crust in unstable conditions. In the Early Silurian pelagic sediments containing terrigenous input were accumulated. Subsequently the area of the Bukantau facies zone repeatedly occurred below and above the carbonate compensation depth. The deposits were also washed out by submarine currents. Fractures of the basement were accompanied by local volcanism. In the Moscovian the collision and beginning of overthrusting led to a more contrast bottom topography and generated conditions for accumulation of thick flysch and olistostrome sediments.

Kulkuduk

[151] The Kulkuduk unit is composed of slightly transformed ophiolites and the associated sediments. It is of comparatively limited distribution in the Tamdytau, North Bukantau, and North Nuratau Mountains.

[152] The Bassumar oreade (Figure 14, *2*) in the western Tamdytau Mountains is formed by thrust sheets of the Kulkuduk and Tamdy units gently overlying the Bukan rocks. Ophiolites compose the lower tectonic sheet of the Bassumar oreade. Its base is represented by a 50-m-thick serpentinite mélange with peridotite, pyroxenite, and gabbro blocks. The mélange is overlain by 120-m-thick cumulates composed of dunite, peridotite, wehrlite, lherzolite, websterite, and pyroxenite stripes. Upward from the base they grade into a 150-m-thick olivine gabbro, gabbro–norite, gabbro–diabase, and gabbro–pyroxenite member. Still upwards occurs the 200-m-thick complex of parallel basic dikes and leucogabbroids with prevailing plagiogranites [*Burtman,* 1973; *Mukhin et al.,* 1991; *Sabdyushev and Usmanov,* 1971].

[153] The above members are overlain by 300-m-thick lavas that along the tectonic contact onlap all parts of the gabbro-ultrabasite complex. A breccia consisting of gabbro and pyroxenite fragments in a tuffaceous carbonate cement is retained in places at the lavas base. The breccia is of sedimentary origin and indicates the erosion of the gabbro-ultrabasite complex before lava eruption. The lavas are represented by amygdaloidal basalts and andesite-basalts. The structure and petrochemical properties of the lavas suggest a highly differentiated magma in a chamber, which occurs with low spreading rate. This rate estimated from the titanium oxide content and dike morphology ranges from 0.5 to 2 cm year^{-1}. The vesicular lavas, eroded underlying sediments, and the occurrence of carbonate deposits among them indicate a high level of the speading range. The lavas are of low-titanium composition and belong to different series, namely, alkalic, tholeiitic, and calc-alkalic. They were likely formed in a marginal sea or oceanic island arc [*Mukhin et al.,* 1991].

[154] In the Sangruntau and Aristantau Mountains the volcanogenic terrigenous sequence of the Kulkuduk unit is composed of calc-alkalic basalts, andesite-basalts, andesites, dacites, and tuffs referred to island arc volcanites according to their petrochemical properties (Sangruntau Formation, 500 m thick). Clastic rocks of the sequence yield cherts with Late Devonian–Early Carboniferous conodonts and limestone pebble bearing Bashkirian foraminifers.

[155] In the Tamdytau Mountains, in the Kynyr oreade (Figure 14, *6*) the Bukan olistostrome is covered by a 500-m-thick sheet composed of amygdaloidal basalts, tuffaceous conglomerates, and tuffstones with chert beds containing Frasnian conodonts.

[156] On the northern slope of the North Nuratau Mountains, the Sentyab and other synforms are formed by the Kulkuduk thrust sheets composed of lavas and tuffs of alkalic pyroxene and olivine-pyroxene high-titanium basalts. Among them gabbro-diabase sheet bodies and chert beds with Famennian conodonts are recorded (Shavaz and other formations, 500 m thick).

[157] The Kulkuduk volcanites are of different age in certain Kyzylkum regions. The Cambrian, Ordovician, Silurian, Devonian, Early Carboniferous, and Bashkirian fossil fauna was found in various sites in lahar limestone fragments and in pebble occurring among basic lavas and tuffs. Carbonate rock fragments could have been derived from reef constructions on volcanic mountains.

[158] The Kulkuduk thrust sheets overlie the Bukan Carboniferous rocks and are overlain by schists of the Tamdy unit. In many areas the Kulkuduk unit is represented only by serpentinite mélange slices squeezed between the Bukan and Tamdy nappes.

Tamdy

[159] The schists of the Tamdy unit compose thrust sheets that in the North Nuratau and Tamdytau Mountains overlie the Kulkuduk and Bukan rocks in synform troughs (Madzherum, Ittynusay, Kumbulak, and other formations).

In the North Nuratau Mountains, in the Khissar oreade (Figure 14, *8*) the Tamdy unit overlies the Kulkuduk lavas. The thrust sheet is composed of 2000-m-thick basic volcanites and graywackes metamorphosed to greenschists that contain high-baric crossite and winchite. In the Ustakhan oreade (Figure 14, *7*) tectonic lenses of amphibolites and garnet-biotite gneisses occur at the base of the Tamdy section. In the Tamdytau Mountains tectonic sheets of metamorphosed basalts and gabbro of the Tamdy unit are the uppermost element in the geologic sections of the Bassumar and Kynyr oreades. The Tamdy rocks are also included in olistoliths of the Bukan olistostrome.

[160] Composition of most of metabasites corresponds to that of oceanic tholeiites. The rocks also include volcanites assigned to the alkalic trap and calc-alkalic island arc series. The rocks were metamorphosed in the garnet-amphibolite facies and underwent a low-temperature diaphthoresis. Geochemical properties of the metabasites are within the oceanic portion of discrimination diagrams and in the transitional area between oceanic and island arc series.

[161] The rocks of the unit contain Ordovician chitinozoans. The oldest K-Ar ages of metamorphic rocks correspond to Neoproterozoic.

Neoautochthon

[162] A thick sequence of coarse molasse (Arkhar, Kynyr, Takhtatau, and other formations, 3000 m thick) unconformably overlies the Tamdy and Kulkuduk rocks. In the North Bukantau Mountains the base of the neoautochthon is formed by nonsorted block-bearing conglomerates. They are overlain by a sandstone, argillite, siltstone, gravelstone, and conglomerate sequence characterized by cross-bedding, traces of sediment erosion, suspending and slides, and by mud cracks. Early Moscovian goniatites and foraminifers were found in the lower part of the sequence; in other points Late Moscovian foraminifers and Late Carboniferous brachiopods, pelecypods, and floral remains were recorded. The neoautochthon is intruded by granites of Permian K-Ar biotite and amphibole age. The Kyzylkum molasse, according to clastic material composition and geologic position, corresponds to Neoautochthon-2 in the western Tien Shan where it is of Late Moscovian–Sakmarian age. The formation of Neoautochthon-2 in the Kyzylkum probably began earlier than in the western Tien Shan, or the Early Moscovian organic remains were redeposited.

Deformation Stages

[163] **D-1.** At stage D-1 the Murun unit underwent tectonic flow accompanied by formation of large and small recumbent isoclinal folds, thrust faults, and overthrust faults and by distribution of cleavage and tectonic lenses. Deformations were followed by greenschist metamorphism and occurred before the Early Devonian limestone accumulation. In the Kuldzhuktau Mountains the upper age limit for D-1 deformations is the Early Silurian. The K-Ar ages of the metamorphism were estimated as ranging from the Ordovician to Silurian [*Babarina,* 1999; *Mukhin et al.,* 1991].

[164] In the Tamdy unit, North Nuratau Mountains, one can see three generations of structural forms in metamorphic schists, namely, the oldest recumbent isoclinal folds and two subsequent generations of superimposed vertical folds with different trends of axial surfaces [*Burtman,* 1973]. The two earliest generations of these structures refer to stage D-1. In the Tamdytau Mountains two generations of isoclines were recorded in the Tamdy unit fragment [*Mukhin et al.,* 1991].

[165] **D-2.** At stage D-2 the Kulkuduk rocks moved beneath the Tamdy metamorphic schists and were decoupled from the subsiding oceanic crust. The thrust sheets therewith underwent internal deformations.

[166] In the Kulkuduk unit the youngest lavas were erupted on an island arc in the Early Carboniferous. Subsequently the rocks were included in the accretionary prism that was formed near a Kazakh–Kyrgyz microcontinent margin. The upper age limit for the stage D-2 deformations is the Moscovian, i.e. the beginning of the accretionary prism overthrusting onto the Alay-Tarim continental slope.

[167] **D-3.** At stage D-3 the accretionary prism composed by Kulkuduk and Tamdy rocks was overthrusted on the Bukan unit. Flysch and olistostrome sediments bearing rock fragments of this accretionary prism occur at the top of the Bukan unit and are of Moscovian age.

[168] In the Tamdytau Mountains, in the Bassumar oreade, the lower part of the Kulkuduk unit was transformed to a 50-m-thick serpentinite mélange and the overlying ultrabasites attained a pressurized appearance. In the Nuratau Mountains similar rock deformations are recorded at the Kulkuduk overthrust fault in tectonic sheets that form the Khissar and Ustakhan oreades. These deformations probably occurred at stages D-2 or D-3.

[169] The upper part of the Bukan unit was also subjected to deformations at stage D-3 and was intensely deformed at later stages as well. The drag folds beneath the base of the upper nappe can be reliably referred to stage D-3. These folds described in the Bassumar oreade indicate a southward shift of material [*Burtman,* 1973].

[170] **D-4.** At stage D-4 the Bukan unit together with the overlying allochthons was overthrusted onto the Murun unit. The top of the Murun section underlying the Bukan nappe contains Late Moscovian foraminifers. The youngest organic remains in the Bukan rocks are of Moscovian age. These records define the Late Moscovian as the lowest age limit of the Bukan nappe formation. The upper limit is not determined. The Bukan nappe likely moved prior to formation of analogous nappes in the southern Fergana region, where this process was the most intense in the Sakmarian–Artinskian.

[171] The Bukan nappe is the largest in the Kyzylkum and is characterized by a complicated structure owing to intense inner deformations. They mainly resulted from a tectonic flow in flysch and olistostrome sequences. Recumbent isoclinal folds with amplitude up to several kilometers are widespread there [*Mukhin et al.,* 1991]. Hinge trends and

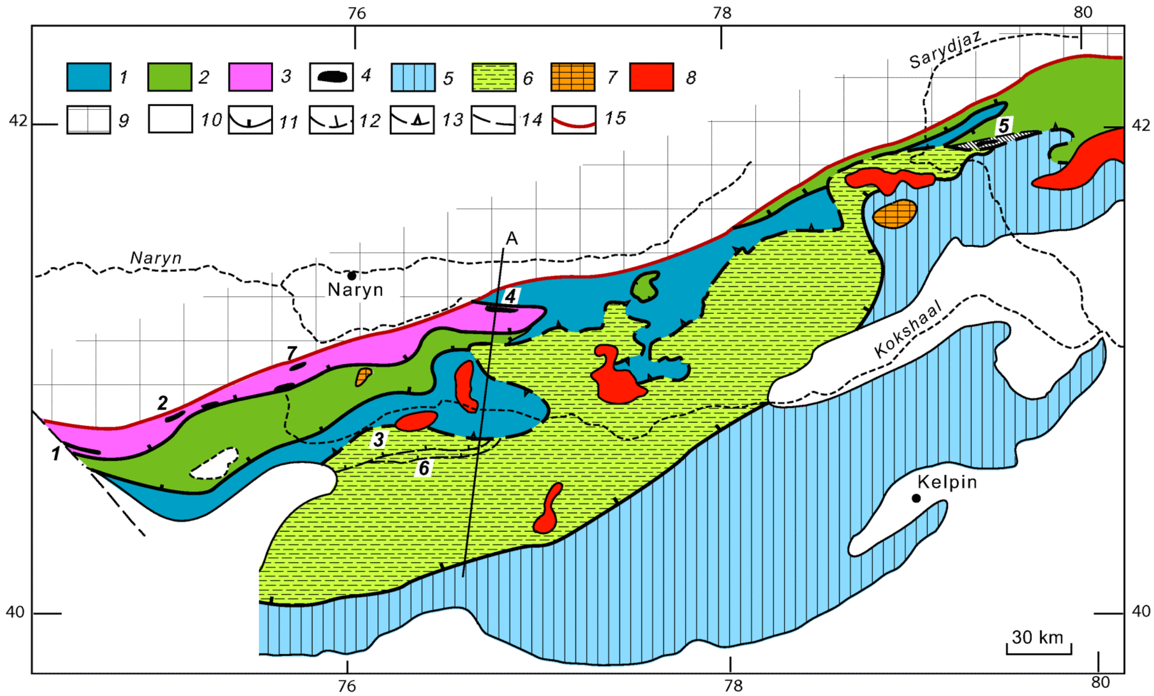

Figure 15. Units of the South Turkestan domain in the central Tien Shan. 1–4 – Units of the Atbashi-Inylchek tectonic zone: 1 – Kokkiya, 2 – Chatyrkul, 3–4 – Keltubek, Atbashi and Balykty (4 – ultrabasites); 5–6 – Units of the Kokshaal tectonic zone: 5 – Muzduk, 6 – Maidantag; 7 – Late Carboniferous granosyenites; 8 – Permian granites; 9 – North Turkestan domain; 10 – Cenozoic and Mesozoic; 11 – Primary overthrust faults of the D-3 and D-4 stages and complicating faults; 12–13 – Secondary overthrust faults and thrust faults (13 – Borkoldoi secondary overthrust fault); 14 – Other faults; 15 – Turkestan oceanic basin suture (Atbashi-Inylchek fault). A – geologic section line, see Figure 16. *Oreades: 1* – Aigyrbulak, *2* – Akbeit, *3* – Aksay, *4* – Djanydjer, *5* – Karaarcha, *6* – Ortosu, *7* – Sarybulak.

vergence of folds vary in different areas reflecting an irregular tectonic flow.

Central Tien Shan

[172] Nappe ensembles of the Atbashi-Inylchek and Kokshaal tectonic zones are situated in the central Tien Shan (Figures 15 and 16). The zones are separated by the Borkoldoi secondary overthrust fault, along which the Atbashi-Inylchek nappe ensemble was overthrusted onto the Kokshaal nappe ensemble. Stratigraphic sections of the autochthon and allochthons were described previously [*Biske et al.,* 1985; *Biske and Shilov,* 1998; *Burtman,* 1976, 2006a].

The Atbashi-Inylchek Zone

[173] The Atbashi-Inylchek nappe ensemble is formed by the Kokkiya (storey I), Chatyrkul (storey II), Keltubek (storey III), and Atbashi and Balykty (storey IV) units.

[174] **Kokkiya.** The Kokkiya unit mainly includes shallow carbonate rocks. The base of the unit in the Ulanskii, Borkoldoi, and Torugart Ranges is composed of sandstones and clayey shales interbedded with basalt flows and limestones bearing Ludlow and Pridoli brachiopods and tabulates (Karachukur and other formations, 1000 m thick). They are overlain by an up to 4000-m-thick carbonate sequence that yields benthic faunal remains and foraminifers. The lower boundary of the sequence ranges within the Ludlow–Lochkovian; the upper, within the Bashkirian–Early Moscovian (Figure 17). Among the Middle–Upper Devonian carbonate sediments, volcanogenic sedimentary rocks and basalt and andesite-basalt lavas are recorded (Tekelitor and Ashusu formations, 100–1000 m thick). Petro- and geochemical properties of the basalts [*Biske and Tabuns,* 1996] indicate an intraplate position of the volcanic manifestations and allow their association with a continental crust fracture. Limestones in the Lower Carboniferous part of the section contain chert beds. The section is crowned by a carbonate terrigenous flysch with olistostromes. The youngest fauna derived from the limestone olistoplaques is of Bashkirian age and the flysch bears Early Moscovian foraminifers.

[175] The Kokkiya limestones also form olistoliths and olistoplaques in the Upper Paleozoic flysch. In the Kokshaal tectonic zone, in the Aksay oreade (Figure 15, *3*) the flysch of the Maidantag unit includes gigantic tectonic blocks of limestones. They are probably olistoplaques that experienced tectonic impact in the Late Paleozoic. The limestones contain brachiopods, corals, and foraminifers indicat-

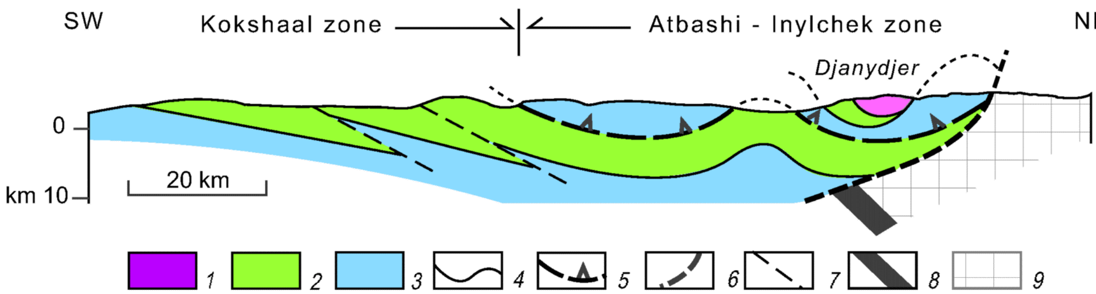

Figure 16. Units of the Atbashi-Inylchek and Kokshaal tectonic zones in geologic section along the line A in Figure 15. 1–3 – Units: 1 – Keltubek and Inylchek, 2 – Chatyrkul and Maidantag, 3 – Kokkiya and Muzduk; 4 – Primary overthrust faults; 5 – Borkoldoi secondary overthrust fault; 6 – Atbashi-Inylchek fault; 7 – Other faults; 8 – Turkestan oceanic suture; 9 – North Turkestan domain. *Djanydjer* – Djanydjer synform.

ing that the accumulation took place from the Ludlow to Early Moscovian (Kulsu, Sarybeles, and other formations, 2000 m thick).

[176] The Kokkiya unit is located at the base of the nappe ensemble and was autochthonous in the Atbashi-Inylchek zone. Subsequently it was overthrusted onto the Kokshaal tectonic zone and now occupies an allochthonous position.

[177] **Chatyrkul.** The Chatyrkul unit is mainly composed of pelagic sediments. Its stratigraphic sections are substantially condensed.

[178] The lower visible part of the sections is composed of clayey and siliceous shales yielding Llandovery graptolites, and of finely rhythmical flysch and carbonate terrigenous sediments bearing Late Silurian benthic fauna (Belkarasu, Karachukur, and other formations, 1000 m thick). The overlying Devonian and Carboniferous sediments are of variable structure which provides the distinction of several types of stratigraphic sections among them. The major types are carbonate siliceous, volcanogenic siliceous, and siliceous facies types of the sediments.

[179] **The carbonate siliceous type** of sediments is known in the Atbashi and Kokshaaltau Ranges. It is marked by accumulation in the Pridoli–Lochkovian of coral and crinoid limestones (Kargantash, Chirmash, and other formations, 300–1500 m thick). Upward from the base these rocks grade into a condensed sediment sequence (Karagir and other formations). The lower part of the sequence is composed of pelagic limestones bearing Pragian and Emsian tentaculitids and Frasnian conodonts; the upper part, of variegated argillites, siltstones, and radiolarites with Famennian and Tournaisian conodonts and Visean and Early Moscovian foraminifers. In the Atbashi Range the sequence is 200 m thick. These rocks are overlain by a 1000-m-thick terrigenous flysch with olistostromes. Limestone beds in the flysch sequence contain Early Moscovian foraminifers. Olistoliths in the olistostrome are built up of Bashkirian limestones. Sandstones contain schist grains derived from nappes of the upper structural storey.

[180] Thrust sheets made up of sediments of **the volcanogenic siliceous type** participate in the structure of synform folds in the Dzhanydzher and Borkoldoi Ranges. The lower part of this type of section is composed of clayey and siliceous shales yielding Late Silurian graptolites. Upward from the base the shales alternate and then grade into volcanogenic sedimentary rocks and lavas of basalt and andesite (Chakyrkorum, Borlutor, and other formations, 1500 m thick) or basalt and rhyolite-dacite (Kainar Formation, 1000 m thick) composition. The contrast extrusive rocks were produced by the mantle and continental crust as evidenced by their geochemical characteristics [*Biske and Tabuns,* 1996]. Limestone beds in the volcanogenic sequence contain Pridoli and Lower Devonian tabulates and tentaculitids and Emsian–Eifelian brachiopods and corals. Condensed pelagic sediments are recorded higher in the section. They are represented by cherts with micritic limestone beds bearing Tournaisian and Visean–Serpukhovian foraminifers (Kensu and other formations, 100–300 m thick), and are overlain by a flysch and olistostrome sequence with limestone olistoliths (Charatash Formation, 500 m thick).

[181] Thrust sheets characterized by **a siliceous type** of sediments occur in the eastern Atbashi-Inylchek zone. Their stratigraphic section differs from the volcanogenic siliceous one in the lack of lavas, lesser proportion of tuffs, and lesser thickness.

[182] In the geologic section of the Atbashi-Inylchek tectonic zone the Chatyrkul nappe sheets cover the Kokkiya unit.

[183] **Keltubek.** The Keltubek unit is formed by oceanic crust rocks. The Aigyrbulak oreade (Figure 15, *1*) on the eastern slope of the Fergana Range represents a series of tectonic slices composed of mylonitized apoharzburgite serpentinites, flaser gabbro-amphibolites, basic volcanites and cherts. The lavas include limestone beds bearing Early Devonian corals.

[184] The Akbeit oreade (Figure 15, *2*) is located in the western Atbashi Range and represents a set of thrust sheets and slices. Its lower part is built up of serpentinite mélange that contains metamorphic schist and gabbro blocks and serpentinized pyroxenites and peridotites, gabbro and gabbro-amphibolites. Upward from the base they are replaced by cherts, tholeiitic basalts, hyalobasalts and their tuffs meta-

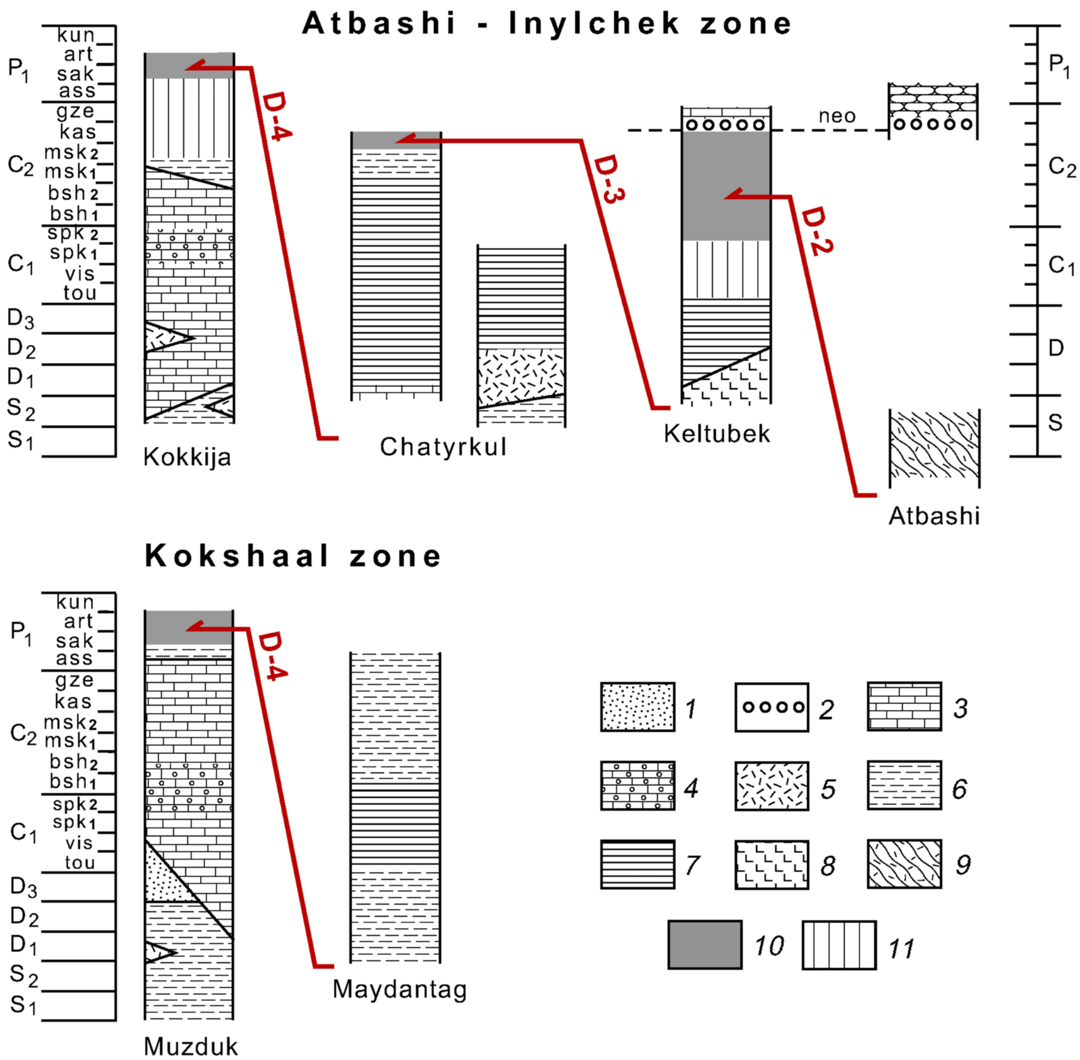

Figure 17. Major units of the South Turkestan domain in the central Tien Shan. 1 – Continental sediments; 2 – Conglomerates and breccias at the neoautochthon base; 3 – Shallow carbonate shelf sediments; 4 – Limestones and cherts accumulated in deeper shelf; 5 – Volcanogenic sedimentary and volcanic rocks; 6 – Deep-water terrigenous and siliceous-terrigenous sediments accumulated on continental slope and rise (flysch, olistostromes, clayey rocks, etc.); 7 – Condensed deep-water siliceous and carbonate siliceous sediments accumulated on continental slope and oceanic bottom; 8–9 – Oceanic basalts, hyaloclastites, ignimbrites: 8 – slightly metamorphosed, 9 – metamorphosed; 10–11 – Age of overthrusting: 10 – most like (or most intense), 11 – less like (or less intense). D-2, D-3, D-4 – deformation stages; neo – neoautochthon.

morphosed to greenschists and blueschists. Geochemical properties of the basalts correspond to that of mid-oceanic ridge rocks [*Biske and Tabuns,* 1996]. The cherts contain Devonian conodonts.

[185] In the Sarybulak oreade (Figure 15, *7*), in the Atbashi Range, a thrust sheet composed of serpentinized peridotites and cumulative gabbroids is recorded. They are covered with a tectonic contact by 200-m-thick cherts bearing Middle and Late Devonian conodonts. Further upwards occur 700-m-thick, partially amygdaloidal and pillow tholeiitic basalts with chert beds.

[186] The Dzhanydzher oreade (Figure 15, *4*) is formed by thrust sheets and slices with a total thickness of 3 km on the northern slope of the Dzhanydzher Range. They are composed of ultrabasites and volcanites including pillow basalts. The ultrabasites represent a mélange with a serpentinite matrix and blocks of serpentinized peridotites, gabbro, basalts, cherts, greenschists, and ophiolitoclastic breccia-conglomerates. The cherts bear Middle–Late Devonian conodonts and Tournaisian radiolarians.

[187] The Karaarcha oreade (Figure 15, *5*) in the Kokshaal Range is an up to 2.5-km-thick thrust sheet made up of ser-

pentinized ultrabasites, wehrlite-pyroxenite-gabbro cumulates, a complex of parallel dikes, and of basalts, hyaloclastites and cherts.

[188] **Atbashi.** The Atbashi unit in the Atbashi Range is composed of schists, gneisses, garnet amphibolites, marble, and glaucophane schists. Initially the rocks were metamorphosed to the epidote-amphibolite facies following which they underwent regressive metamorphism to the greenschist facies. The glaucophane schists were likely formed during a later dislocation metamorphism [*Bakirov,* 1978]. The discussed sequence probably includes crystalline limestones bearing Pridoli tabulates.

[189] Lenslike eclogite bodies are recorded among the metamorphosed rocks. Geochemical properties of the eclogites correspond to those of mid-oceanic ridge basalts [*Sobolev et al.,* 1989]. The Rb-Sr isochronous age of the eclogite metamorphism, defined by garnet, omphacite, phengite and by the rock, is 267±5 Ma [*Tagiri et al.,* 1995].

[190] **Balykty.** Thrust sheets of the Balykty unit participate in the structure of synform folds in the Dzhanydzher and Inylchek Ranges. They are composed of a 2000-m-thick rhythmical sequence of quartz and volcanic sandstones, siltstones, and clayey shales with limestone beds. The silty pelitic sediments in the Dzhanydzher Range are characterized by graded bedding. The rocks are partially metamorphosed to greenschists. Corals and floral remains indicate the Early Silurian-Early Devonian age of the sequence. In synform folds the Balykty unit overlies the Chatyrkul and Keltubek rocks.

[191] Structure and geologic position of the Balykty unit suggest the accumulation of its sediments on the Kazakh–Kyrgyz continental rise, where they were partially metamorphosed on the accretionary prism formation.

[192] **Neoautochthon.** On the northern slope of the Atbashi Range the ophiolites are onlapped by nonsorted conglomerates bearing fragments of cherts from the ophiolite section and metamorphic schists of the Atbashi unit. The overlying limestones contain Gzhelian foraminifers. Still above-lying beds of this terrigenous sequence (Arpa Formation, 2000 m thick) include calcareous sandstones and limestones bearing Asselian foraminifers.

[193] According to the position in the section and age of the rocks, the described sediments are analogous to Neoautochthon-2 in the western Tien Shan.

Kokshaal Zone

[194] The Kokshaal tectonic zone includes the autochthonous Muzduk unit and allochthonous Maidantag unit (Figure 15).

[195] **Muzduk.** On the Tarim Depression margin, in the Kelpintag Range, the Silurian and Devonian beds are represented by a thick sequence of terrigenous and carbonate terrigenous sediments yielding acidic and intermediate lava beds. A significant part of the sequence is composed of flysch. The Devonian flysch is in places conformably or with an angular unconformity overlain by 1000-m-thick conglomerates and red cross-bedded quartz sandstones that were accumulated on an alluvial plain in the Early Carboniferous. The cross-bedding and conglomerate texture indicate the northern direction of the flows [*Carroll et al.,* 1995]. North of the Kelpintag Range the red sandstones alternate with limestone breccias and still further grade into carbonate rocks bearing brachiopods, corals, and foraminifers.

[196] In the Kelpintag Range the red sandstones are overlain by limestones with benthic fauna and foraminifers indicating that the limestones, with the thickness of up to 100 m, embrace the Late Visean–Asselian interval. This was the inner part of the northern Tarim carbonate platform. Further northward, in the Muzduk Mountains and other uplands, the Late Carboniferous–Asselian shallow carbonate sediments are 1000 m thick.

[197] The rocks of the northern Tarim carbonate shelf are exposed in the eastern Kokshaal Range. The base of the carbonate sequence (Dzhangart and other formations, 2000 m thick) is there as old as the Emsian or Pragian and its top is Asselian in age (Figure 17). Limestones in the upper part of the section include beds of rhyolite and trachydacite tuffs and lavas. Upward from the base the limestones grade into carbonate terrigenous flysch containing olistostromes (Sauktor Formation, 700 m thick). The flysch bears Early Permian foraminifers.

[198] **Maidantag.** The Maidantag unit is formed by thrust sheets composed of pelagic sediments that were accumulated on a continental slope and rise. In the Maidantag and Kokshaal Ranges the visible basal part of the section is built up of terrigenous distal flysch with quartz prevailing in the clastic fraction (Airytor, Tysbel, Bozdzhalpak, and other formations, 2000–3000 m thick). The flysch contains Early-Middle Devonian tabulates and tentaculitids and, in the upper part, Late Devonian conodonts and flora. The Lower Carboniferous is represented by a condensed section of pelagic sediments (Karasainyn and other formations, 80–300 m thick), namely, by radiolarites bearing Early–Late Tournaisian conodonts, argillites and silicites with the Visean conodonts, and by variegated clayey micrites and calcarenites yielding Serpukhovian conodonts and goniatites. Among these sediments volcanogenic sedimentary rocks and andesite-basalt lavas are recorded in places.

[199] Upward from the base the condensed sediments are replaced by terrigenous and carbonate terrigenous flysch with limestone and silicite olistoplaques (Kipchak and other formations). The flysch bears Late Bashkirian, Moscovian, Kasimovian and Asselian foraminifers and conodonts and is several kilometers thick.

[200] The Ortosu oreade (Figure 15, *6*) includes rocks that made up submarine volcanoes. The basal part of the thrust sheet is composed of siliceous and clayey shales bearing Devonian foraminifers. They are overlain by a 300–1500-m-thick sequence of tuff breccias, tuffs, and reef limestones alternating with basalt, andesite and trachyandesite lava flows. Geochemical records indicate the intraplate genesis of the basalts [*Biske and Tabuns,* 1996]. The sequence is Givetian–Late Devonian in age as estimated from corals, stromatoporoids, and foraminifers. The Devonian rocks

are overlain with a hiatus by 100-m-thick condensed carbonate siliceous sediments yielding Late Visean to Early Moscovian foraminifers. The section is terminated by a 500-m-thick coarse flysch bearing olistostromes and including Early Moscovian foraminifers in the sandstone cement.

[201] In the northern foothills of the Maidantag Range the upper part of the unit is composed of the Aksay oreade thrust sheets and slices (Figure 15, *3*). In the oreade's section the Llandovery–Lochkovian graptolite shales are overlain by a sequence of condensed sediments, among which prevail cherts (Karasainyn, Kuldzhakbashi, Urusai, and other formations, 200–400-m thick). The lower part of the sequence yields Emsian conodonts; the above sediments, Late Devonian–Serpukhovian radiolarians and conodonts; and the uppermost part, Early Baskirian conodonts, respectively. In places the limestone breccia with benthic fauna is recorded, probably as a result of turbidity currents activity.

[202] Further upward from the base of the Aksay section a terrigenous flysch and olistostrome sequence occurs. The flysch bears Bashkirian and Early Moscovian foraminifers. The flysch sandstones include basalt grains likely derived from the upper nappes of the Atbashi-Inylchek tectonic zone. Several lenslike tectonic slices in the flysch are composed of thick shallow limestones of the Kokkiya unit, which most likely have initially got to the continental slope as gigantic olistoplaques. A brief characteristics of these limestones, the youngest of which are Early Moscovian in age, was given above, in description of the Kokkiya unit.

Correlation of Units

[203] The Atbashi-Inylchek nappe ensemble is of fourstoreyed structure. The Kokshaal ensemble consists of two storeys corresponding to the lower ones of the Atbashi-Inylchek nappe ensemble (Figure 17). In the Muzduk and Kokkiya units of the first storey the section is mostly composed of shelf carbonate sediments. The Muzduk unit in the Kokshaal zone is autochthonous representing a margin of the ancient Tarim massif. The Kokkiya unit, prior to its shifting by the Borkoldoi secondary overthrust fault, was autochthonous in the Atbashi-Inylchek zone. The Muzduk and Kokkiya units formed the inner and outer Tarim shelf, respectively.

[204] The Maidantag and Chatyrkul units of the second storey are mainly composed of pelagic sediments accumulated on the Tarim continental slope. Composition of extrusive rocks that occur among the pelagic sediments also indicates that they were formed on a continental basement. The Maidantag-Chatyrkul nappe overlying the Muzduk and Kokkiya units resulted from a collision of the Kazakh–Kyrgyz and Alay-Tarim continental terranes.

[205] Several allochthonous units, namely, Keltubek, Atbashi, and Balykty, located nearby the Turkestan oceanic suture, form the upper structural storeys of the Atbashi-Inylchek nappe ensemble. The primary relationships between these units in many cases were broken by secondary overthrust faults and thrust faults during and after the collision.

Deformation Stages

[206] Tectonic structure of this region is more compressed compared to the western Tien Shan.

[207] Prenappe deformations of unclear age are recorded in metamorphic rocks of the Atbashi unit. Several generations of these deformations referred to stage D-1 are recognized [*Duk,* 1995].

[208] Accretionary nappes were formed at stage D-2. In the course of the accretionary prism growth near the Kazakh–Kyrgyz terrane margin, the Atbashi rocks were overthrusted onto the younger oceanic crust sediments which formed the allochthonous Keltubek unit at a subsequent overthrusting stage (Figure 18).

[209] At stage D-3 owing to the collision of the Kazakh–Kyrgyz microcontinent and Alay-Tarim continent, the accretionary prism that occurred near the Kazakh–Kyrgyz microcontinent margin was overthrusted on the continental slope of the Alay-Tarim continent, i.e. onto the rocks of the future Chatyrkul unit. The youngest Chatyrkul rocks are of Early Moscovian age. They include fragments of metamorphic rocks derived from the accretionary prism. The neoautochthon is of Gzhelian and younger age. These data indicate the Moscovian–Kasimovian age of stage D-3.

[210] The collisional Maidantag-Chatyrkul nappe composed of the rocks that were accumulated in the Silurian, Devonian, and Carboniferous on the Alay-Tarim continental slope and rise, was formed at stage D-4. This complex together with the overlying allochthonous Keltubek, Atbashi, and Balykty units was overthrusted onto the autochthonous Muzduk-Kokkiya zone. The youngest rocks in the Muzduk section are estimated as the Asselian, marking the oldest age limit for the Maidantag-Chatyrkul nappe in the Kokshaal tectonic zone. In the Atbashi-Inylchek zone which is closer to the nappe roots, its shifting could have begun earlier (Figure 17).

[211] The Carboniferous and Early Permian tectonic events provided the formation of an ensemble that included an autochthon and three storeys of primary nappes, among which those of the upper storey originated earlier than the lower ones (Figure 18). The geologic section includes downward from the top: the Balykty and Atbashi accretionary nappes (IV storey), the Keltubek accretionary collisional nappe (III storey), the Maidantag-Chatyrkul collisional nappe (II storey), and the Muzduk-Kokkiya autochthon (I storey).

Eastern Tien Shan

[212] The published records on geology of the southern Turkestan domain in the eastern Tien Shan indicate the occurrence in the area of Late Paleozoic nappes that broke a primary succession of facies zones. In the discussed region the zones of autochthon and allochthonous complexes can be outlined (Figures 19 and 20). The autochthon corresponds to the Muzduk and Kokkiya units; the allochthonous zone, to all allochthonous units in the central Tien Shan.

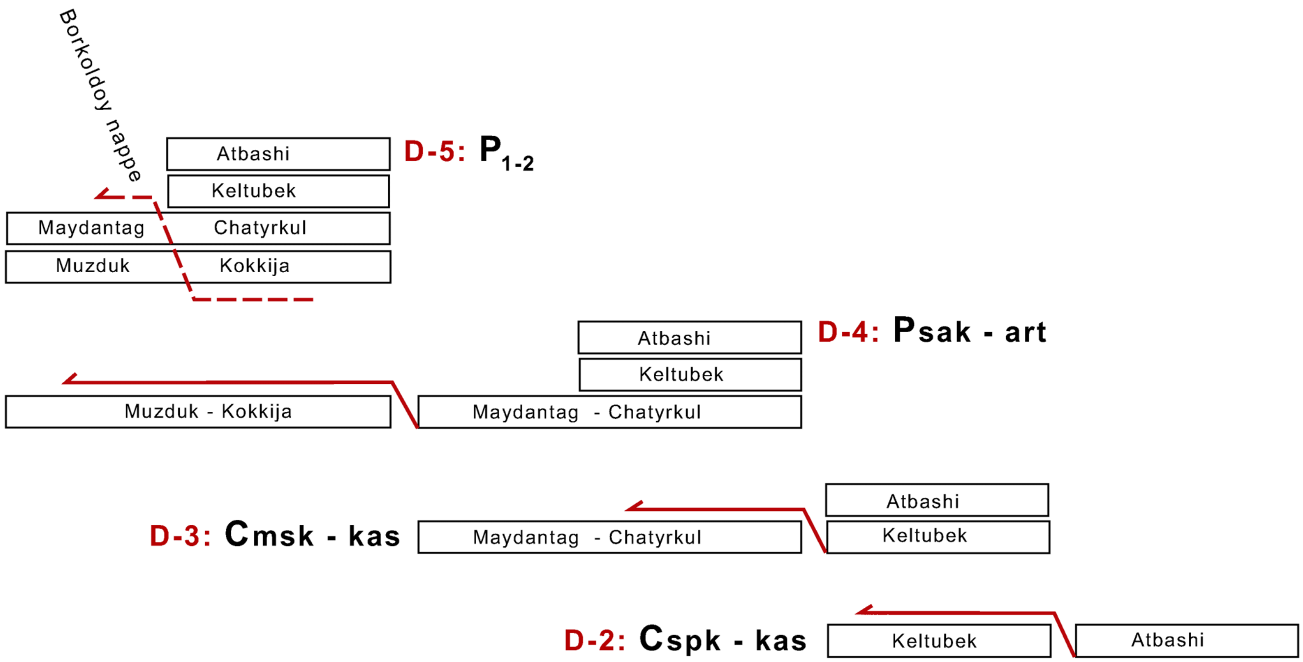

Figure 18. Overthrusting scheme of the central Tien Shan units. D-2, D-3, D-4, and D-5 – deformation stages.

Autochthon

[213] In the Kuruktag Range the Ordovician and Lower Silurian are represented by a thick, conodont and graptolite-bearing flysch sequence that was accumulated in an aulacogen in the Tarim platform [*Liu et al.,* 1996; etc.]. The Upper Silurian is unknown in the Kuruktag Range. The Devonian section is composed of red arkosic sandstones with floral remains. The Lower Carboniferous sediments transgressively overlie the Lower Paleozoic and Precambrian rocks. The lower part of the Carboniferous section is composed of clastic sediments; the upper, of brachiopod-bearing limestones. The Permian rocks are missing [*Hsu et al.,* 1994].

[214] In the Haerke Range, in the Silurian, carbonate sediments yielding Wenlock–Ludlow corals, brachiopods, and trilobites were accumulated. The Lower Devonian is represented by carbonate terrigenous sediments, partly by turbidites, bearing tuff and acidic or intermediate lava beds. The Middle–Upper Devonian sections are made up of shallow limestones containing numerous organic remains and sandstone beds. In the Carboniferous the shallow carbonate terrigenous sediments yielding brachiopods, foraminifers, and conodonts, were accumulated. In the Erbeng Mountains the Middle Devonian–Lower Carboniferous section is also composed of carbonate rocks with brachiopods, corals, and foraminifers [*Wang et al.,* 1990, 1994].

[215] In the discussed zone the Carboniferous turbidites and olistostromes [*Liu et al.,* 1996] that likely make up the autochthon top, are recorded. The presence of intermediate and acidic volcanites in the Devonian sediments and of Late Devonian granite intrusions dated by U-Pb method as 378 Ma old, was also reported [Bureau..., 1993].

Allochthon

[216] In the Haerke Range the allochthonous Silurian flysch occupies a considerable area [*Hsu et al.,* 1994]. This zone also includes cherts bearing Late Devonian–Early Carboniferous radiolarians (probable allochthon with a condensed section) and basic lavas and silicites with Early Devonian conodonts and radiolarians [*Gao et al.,* 1998; *Wang et al.,* 1994]. The rocks of different age are unconformably overlain by Late Carboniferous sandstones [*Gao et al.,* 1998] that are likely referred to the neoautochthon.

Ophiolitic allochthons

[217] The ophiolites were obducted onto the rocks of different age and transported for a distance of up to 75 km south of the Turkestan oceanic suture. Several large ophiolitic bodies are located in the Haerke Range. A complete ophiolitic section, i.e. mantle peridotites, cumulates, a dike complex, pillow tholeiitic basalts, and cherts, was described in the Serikeiailake oreade (Figure 19, *5*). The Kulafu ophiolitic mélange (Figure 19, *3*) includes blocks of ultrabasites, gabbro, tholeiitic basalts, cherts yielding Late Devonian–Early Carboniferous radiolarians, and of limestones bearing conodonts of the same age. The chemical composi-

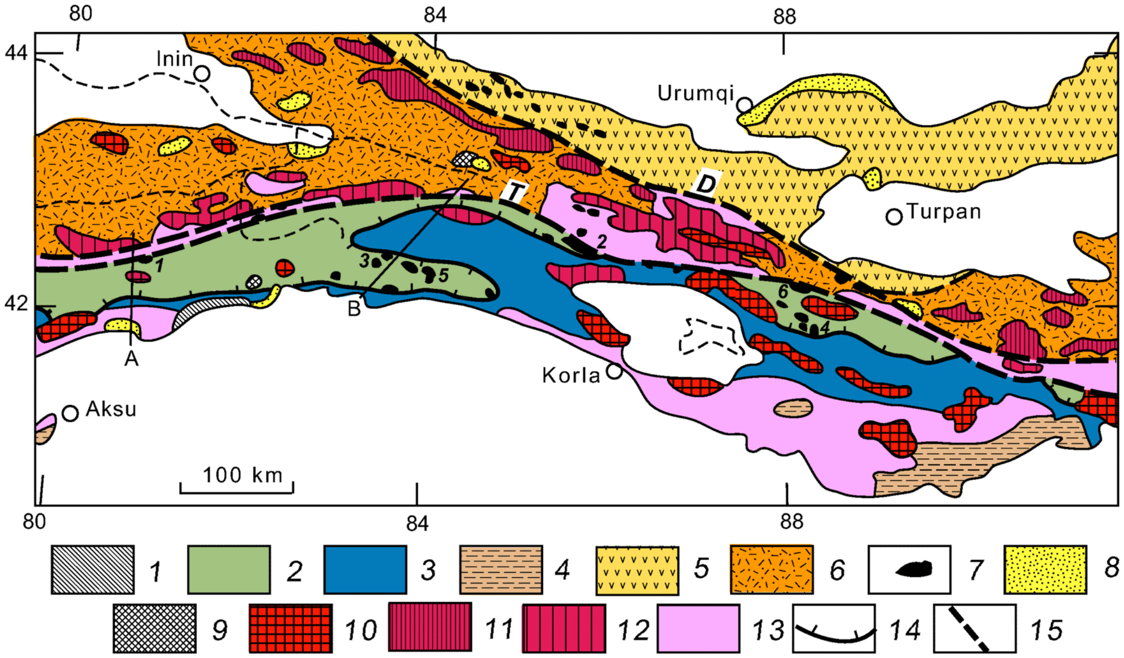

Figure 19. Paleozoic of the eastern Tien Shan [after *Bureau...,* 1993]. 1–4 – South Turkestan domain: 1 – Lower Permian volcanogenic sediments; 2 – Allochthonous Middle Paleozoic sediments of the Alay-Tarim continental slope and Turkestan oceanic bottom, 3–4 – Autochthonous rocks of the Alay-Tarim continent passive margin (3 – Middle Paleozoic, 4 – Lower Paleozoic and Proterozoic); 5–6 – North Turkestan domain: 5 – Carboniferous volcanogenic sedimentary deposits of the Bogdashan island arc, 6 – Middle Paleozoic volcanogenic terrigenous sediments of the Kazakh-Kyrgyz microcontinent active margins; 7 – Ophiolites: *1* – Changawuzhi, *2* – Gulugou, *3* – Kulafu, *4* – Liuhuang, *5* – Serikeyayilake, *6* – Youshugou; 8 – Late Permian molasse; 9–12 – Intrusive rocks: 9 – Upper Paleozoic syenites, 10 – Upper Paleozoic collisional and postcollisional granites, 11–12 – Subductional granites (11 – Carboniferous, 12 – Middle Paleozoic); 13 – Lower and Middle Proterozoic; 14 – Inferred front of nappes; 15 – Other faults (*T* – Turkestan oceanic suture, *D* – Dzhungar fault). A and B – lines of geologic sections, see Figure 20.

tion of lavas from the Haerke Range ophiolites is similar to that of mid-oceanic ridge lavas. The rare elements ratio in the basalts indicates that the lavas were produced by depleted mantle [*Gao et al.,* 1998]. The Ar-Ar (plateau) biotite ages of quartz-mica schists from the mélange, is 370±5 and 259±3 Ma old [*Chen et al.,* 1999].

[218] Another group of allochthonous ophiolites occurs eastwards. The Youshugou oreade (Figure 19, *6*) is formed by the mélange, dunite, serpentinite, and gabbroid sheets thrusted on the pelites referred to the Devonian. A part of cumulates is metamorphosed to greenschists, others to garnet amphibolites. Geochemical properties of the basalts from dikes extruding gabbro suggest their formation in the ocean outside a mid-oceanic ridge [*Allen et al.,* 1993; *Chen et al.,* 1999].

[219] The Rb-Sr isochronous age of 340±4 Ma was estimated for lavas from the nonmetamorphosed ophiolitic mélange in the Liuhuang oreade (Figure 19, *4*). Radiolarians from cherts of this mélange are of Early Carboniferous age as well. Gabbro from the ophiolitic mélange was dated by Ar-Ar (plateau) method as 333 Ma old [*Gao et al.,* 1995, 1998].

[220] The geologic map of Xinjiang shows that the youngest rocks overlain by or including ophiolites are Late Carboniferous in age [*Bureau...,* 1993].

Metamorphic rocks and ophiolites nearby the Turkestan suture

[221] Similar to the more westward regions, the metamorphic rocks near the Turkestan suture are associated with ophiolites. In the west of the eastern Tien Shan a belt of eclogite-bearing blue- and greenschists and the Changawuzhi and Gulugou ophiolites (Figure 19, *1 and 2*) are located near the suture. The metamorphic complex includes oceanic crust rocks (MORB basalts), argillites, sandstones, marbles, and graywackes. The greenschists were formed from volcanic and carbonate sediments yielding Late Silurian corals, trilobites, and brachiopods. The blueschists are recorded among greenschists in the form of blocks and lenses. The blueschists include gabbro and basalts metamorphosed to eclogites.

[222] The rocks that underwent a blueschist metamorphism are characterized by heterochronous protoliths. The

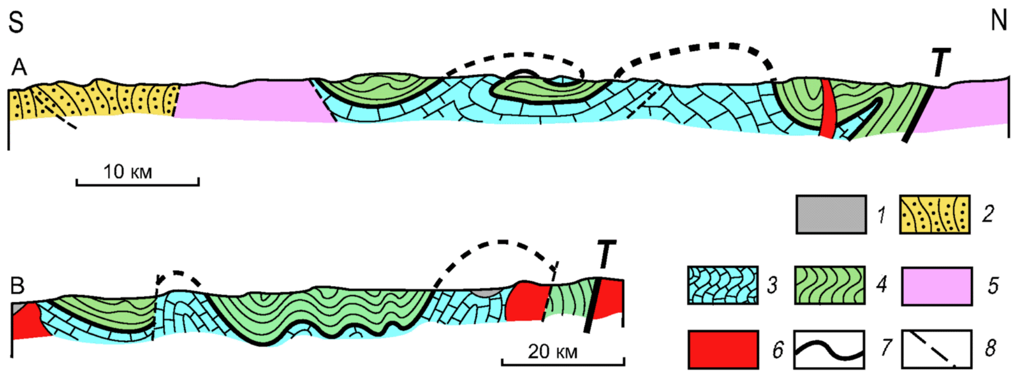

Figure 20. Geologic sections of the eastern Tien Shan along the A and B lines in Figure 19 [after *Wang et al.,* 1994; *Bureau...,* 1993] in the interpretation by *Biske and Shilov* [1998] and the author. 1 – Cenozoic sediments; 2 – Triassic and Permian (neoautochthon, molasse); 3–4 – Middle Paleozoic (3 – autochthonous, 4 – allochthonous); 5 – Proterozoic; 6 – Granites; 7 – Overthrust faults; 8 – Other faults. T – Turkestan oceanic suture.

Sm-Nd isochronous ages of 1570, 1128, 729, and 634 Ma were determined for them. The Ar-Ar crossite and phengite ages of the blueschist metamorphism are 415±2 and 420±3 Ma, respectively. The age of retrograde metamorphism of these rocks was estimated by the same method at 351±1 and 345±7 Ma [*Gao et al.,* 1995, 1998; *Siao et al.,* 1994].

[223] The Rb-Sr isochronous age of plagiogranites from the Gulugou ophiolites was defined at 358±15 Ma [*Gao et al.,* 1998]; the Ar-Ar (plateau) age of pyroxene from gabbro of the Changawuzhi ophiolites, at 439±27 Ma [*Chen et al.,* 1999; *Siao et al.,* 1994]; that of amphibole from the ophiolitic mélange, at 430–420 Ma [*Liu et al.,* 1996]; that of biotite from the ophiolitic mélange, at 246 Ma [*Chen et al.,* 1999]. The latter dating likely indicates the age of movements along the thrust fault, near which the ophiolites are located.

[224] The metamorphic rocks and the associated ophiolites presumably made up an accretionary prism at the foot of the Kazakh–Kyrgyz microcontinent. Judging from the age of blueschist and retrograde metamorphism of the rocks, the accretionary prism was formed in the Devonian and Early Carboniferous.

Formation of the Southern Tien Shan Nappe Ensembles

[225] The collision of the Alay-Tarim continent and Kazakh–Kyrgyz microcontinent started in the Moscovian. By that time the oceanic part of the Turkestan basin was closed but its marginal parts persisted as a vast marine basin over a thin continental crust. The Alay-Tarim crust corresponded to the most portion of the basin and the Kazakh–Kyrgyz one, to the lesser part. This intracontinental marine basin, the successor of the Turkestan ocean, is convenient to name the Turkestan sea. The Turkestan sea occurred from the Moscovian to Permian and occupied the area between the northern Turkestan and Tarim landmasses. Flysch bearing olistostrome beds was accumulated in most of the Turkestan sea area. Carbonate sediments entered the flysch from the Alay-Tarim shelf and the fragments of approached nappes, from the opposite side. The sediment accumulation was interrupted in areas overthrusted by nappes and continued on moving thrust sheets and in front of the nappes represented by Neoautochthon-2. The vast Turkestan sea survived up to the Sakmarian; at the northern Tarim margin the residual marine basin occurred up to the Late Permian. The drying up of the territory resulted from the collisional emergence of the Turkestan sea bottom.

[226] With the beginning of the collision, the oceanic crust subduction beneath the Kazakh–Kyrgyz microcontinent was replaced by subduction of the Alay-Tarim continental crust in the same direction. The collision and continental subduction resulted in the formation of collisional nappes at the Turkestan sea bottom.

[227] Let us outline the age limits for tectonic processes caused by or associated with the microcontinent collision. The ophiolitic nappes are overthrusted onto the Early Moscovian sediments of the Alay-Tarim continental slope. The turbidite formation in the Turkestan sea completely terminated in the Sakmarian. Radiologic ages of the orogenic granites are within the Permian period; the continental orogenic molasse is dated as the Late Permian. These records indicate the Moscovian–Permian interval of the tectonic activity.

[228] The four-storeyed nappe ensemble was gradually formed at the margin of the Alay-Tarim terrane; the upper nappes arose earlier than the lower ones (Figure 21). The nappes of storey IV, i.e. the Tamdy, Sugut, Shankol, Shaydan, and Atbashi units, are of accretionary origin and were formed prior to the terrane collision. The Toguzbulak and Balykty units likely originated in the accretionary prism as well. The ophiolitic nappes of storey III, namely, the Kulkuduk, Taldyk, Kerey, and Keltubek units are probably of accretionary collisional genesis. That is, the isolating of ophiolite sheets from the subducting oceanic crust took place nearby the accretionary prism at the Kazakh–Kyrgyz mar-

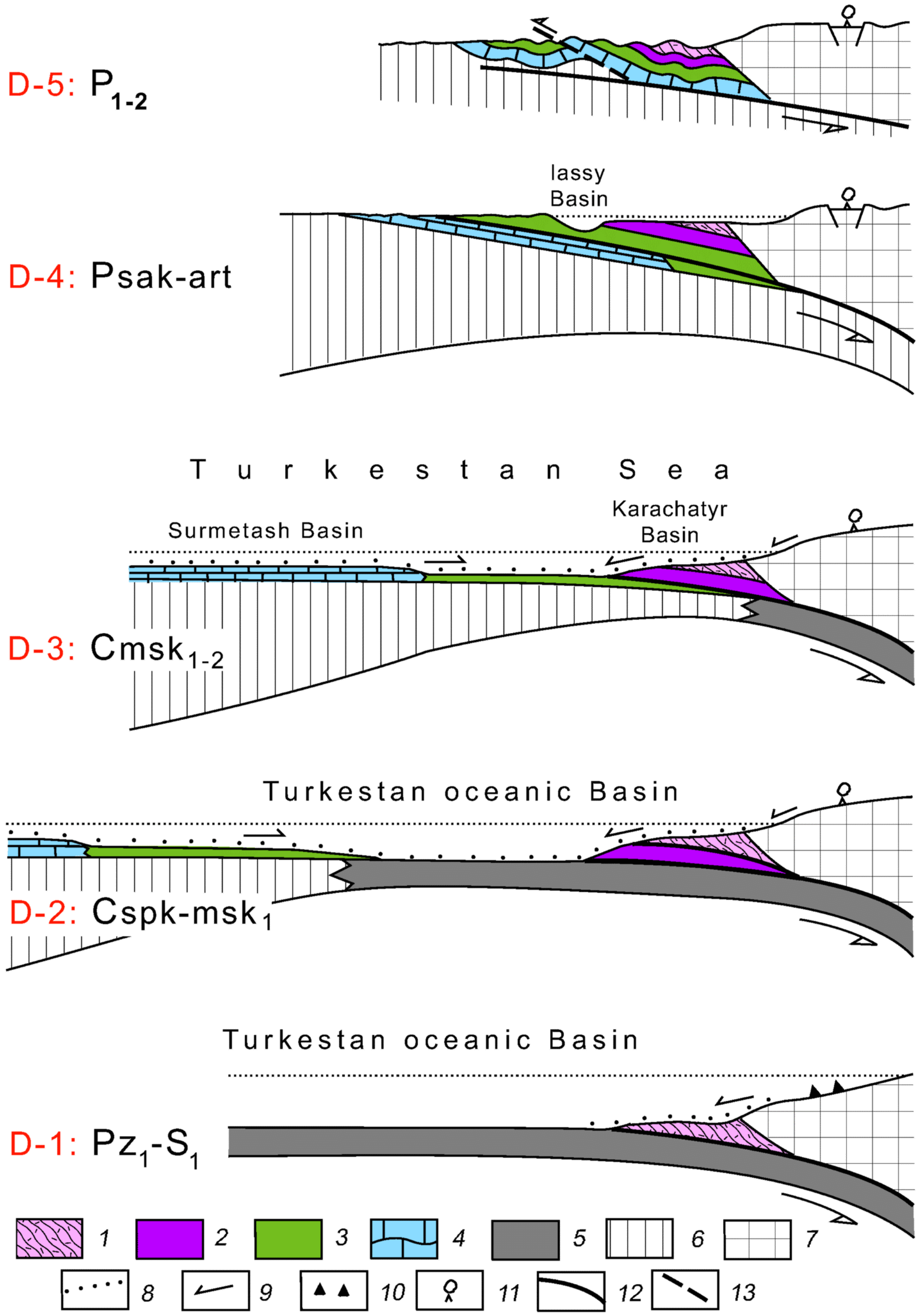

Figure 21. Tectono-geodynamic model for the western Tien Shan. 1–4 – Units: 1 – Shankol-Shaydan-Kan, 2 – Taldyk-Kerey, 3 – Tar-Abshir-Ontamchi; 4 – Chekantash-Isfayram-Baubashata; 5 – Oceanic crust; 6–7 – Continental crust (6 – Alay-Tarim terrane, 7 – Kazakh-Kyrgyz terrane); 8 – Sediments synchronous with overthrusting; 9 – Sediment input direction; 10–11 – Volcanism (10 – submarine, 11 – subaerial); 12 – Active zones of subduction and underthrusting, overthrust faults; 13 – Uzgen-Sanzar thrust fault. D-1, D-2, D-3, D-4, D-5 – deformation stages.

gin of the oceanic basin (at deformation stage D-2), whereas the ophiolites were overthrusted onto the Alay-Tarim continental slope after the collision began, in response to underthrusting of the Alay-Tarim continental slope beneath the accretionary prism (at deformation stage D-3). This was occurring in the Moscovian. As a result of the described processes the nappes of storeys IV and III were found to be overlying the rocks that accumulated on the Alay-Tarim continental slope (Figure 21).

[229] During or after the formation of the upper nappes the tectonic decoupling of sediments at the Alay-Tarim terrane margin began. The decollement fault surface occurred in Silurian shales. It became the base of future nappes of storey II. The tectonic decoupling took place in higher beds as well and affected to the largest extent flysch sequences of the Bukan, Tar, Abshir, Ontamchi, Chatyrkul, and Maidantag units.

[230] The decoupled sediment complex of the former Alay-Tarim continental slope, together with the overlying ophiolitic nappes and Neoautochthon-1, was displaced inside the terrane and overthrusted on the Murun–Chekantash–Isfayram–Baubashata–Kokkiya–Muzduk facies megazone in the form of the Bukan, Tar, Abshir, Ontamchi, Chatyrkul, and Maidantag nappes (deformation stage D-4). This took place in the Sakmarian–Artinskian but could have begun still earlier (Figures 9 and 17). The secondary overthrust faults, recumbent folds and flexures were formed in the moving nappe owing to tectonic flow and drag processes.

[231] **On the overthrusting mechanism.** Much research of nappe formation conditions, including the author's work [*Burtman,* 1973], is dedicated to the mechanics of allochthonous sheets' generation (decoupling) and shifting. Investigations showed the lack of physical constraints of an allochthon transportation for long distances. By an overthrusting mechanism discussed below is meant an allochthon displacement mode.

[232] The upper storey (IV) allochthons of the southern Tien Shan nappe ensemble were formed in accretionary prism through the underthrusting. The decoupling of ophiolitic sheets which make up the storey III nappes, likely also occurred in the accretionary prism on underthrusting of the subducting oceanic crust beneath the sheets. With the beginning of the collision in the Moscovian both tectonic and gravitational ways of nappe formation were possible. The accretionary prism nearby a margin of the Kazakh–Kyrgyz terrane was elevated relative to the Turkestan sea bottom composed of deep-water sediments overlying the Alay-Tarim continental basement. This made possible a gravitational input of the prism rocks to the sea bottom. The continental subduction, i.e. underthrusting of the Alay-Tarim crust beneath the accretionary prism and Kazakh–Kyrgyz terrane, occurred concurrently. The extent of participation of each mechanism in the ophiolite nappe formation is difficult to recognize. The cases when a storey IV nappe directly overlies a storey II one (Sugut and Chekantash units in the western Tien Shan or Tamdy and Bukan units in the Kyzylkum) were probably provided by gravitational movement of allochthonous sheets.

[233] The decoupling and movement of the allochthon making up the storey II of the nappe ensemble directly resulted from the Alay-Tarim continental crust subduction under the Kazakh–Kyrgyz terrane. There is no parental territory that could be a source of vast gravitational sheet and the parental territory could not disappear on subduction. The subduction of the continental crust resulted in underthrusting of the autochthon beneath the decoupled allochthonous sheet. The allochthon was deformed in the course of overthrusting, which provided the formation of secondary tectonic and gravitational nappes, numerous inside the units of storey II in the nappe ensemble.

[234] In the Permian the nappes and autochthon of the southern Tien Shan were folded (Figures 5, 7, 16 and 20) and experienced other deformations [*Burtman,* 2006a].

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