Lower Permian formations of the Buqingshan Mountains in the A'nyemaqen ophiolitic zone (Eastern Kunlun, Qinghai Province, China): On the beginning of the Paleotethys closure

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[1] Several Lower Permian formations are most completely represented within the Buqingshan Mountains (eastern portion of the Eastern Kunlun orogenic belt), a part of the Paleotethyan ophiolite suture commonly considered as the A'nyemaqen ophiolite zone. The formations were formed in the following paleogeodynamic environments (in a southward direction): (1) shelf and slope of a passive continental margin of a marginal sea; (2) partially Permian metamorphic rocks representing a subduction-accretion complex of an ensimatic island arc and volcanogenic rocks of an ensimatic island arc, of the age limited from above by the Asselian and Sakmarian stages; and (3) slope of an island arc and oceanic trench. The formations of the subduction-accretion complex and of the island arc volcanites are overlain with a sharp angular unconformity by a carbonate conglomerate sequence, which presents as a local molasse of the Lower Permian age. Based on fusulinids contained in the basal limestones, the age of the local molasse is first defined as the Yakhtashian–Bolorian, i.e. Artinskian–Kungurian (?). The sediments of the northern shelf and slope of the passive continental margin in the marginal sea representing at that time as the Paleotethys relict, are synchronous. The thorough investigations revealed that the initial closure of the eastern Paleotethys within the Eastern Kunlun corresponded to the Sakmarian–Yakhtashian (Artinskian) boundary, whereas in the western portion (Northern Pamirs) the closure occurred considerably earlier, prior to the Late Bashkirian time. Thus, the idea that the Paleotethys in the Eastern Kunlun reached its maximum width in the Permian, is highly questionable. During the Early Permian the A'nyemaqen branch of the Paleotethys intensely decreased. Beginning from the Bolorian (Kungurian) time and up to the end of the Permian this branch represented its relict in the form of a marginal sea depression. It may be suggested that the Paleotethys closure in the A'nyemaqen took place gradually from the west to the east and covered a long period from the Late Carboniferous to the terminal Early Permian. The final closure of the Paleotethys branches corresponded to the Permian–Triassic boundary and was accompanied by an intensive orogeny and deposition of a thick continental molasse. *INDEX TERMS:* 8102 Tectonophysics: Continental contractional orogenic belts and inversion tectonics; 8140 Tectonophysics: Ophiolites; 9320 Geographic Location: Asia; *KEYWORDS:* Ophiolites, Lower Permian formations, China.

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Introduction

[2] The A'nyemaqen ophiolitic belt extends along the A'nyemaqen Range in the eastern Qinghai Province up to the Huanghe River meander in the Gansu Province (Figure 1), and presents a southern branch of the Late Paleozoic Eastern Kunlun ophiolite suture. The latter

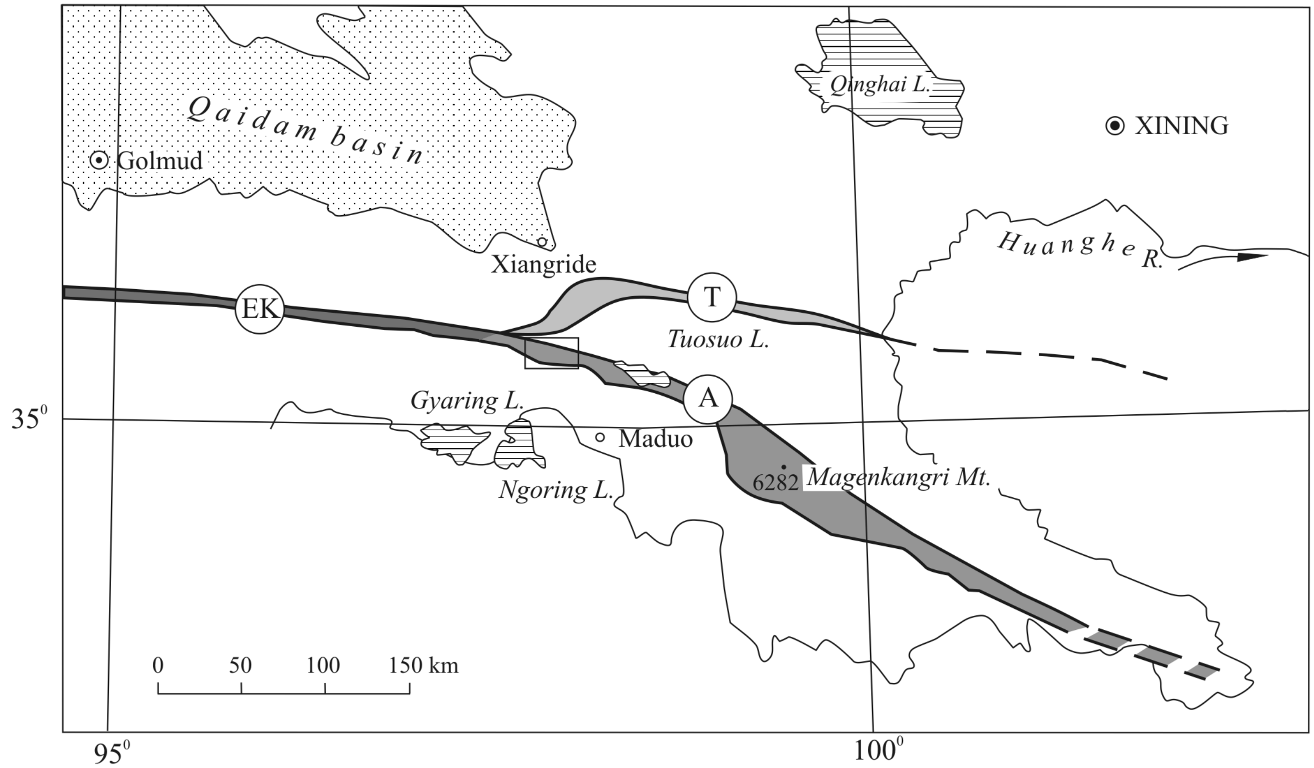


Figure 1. Location of the Late Paleozoic Paleotethys ophiolite zones in the eastern sector of the Eastern Kunlun. Notes: EK (dark grey color) – Eastern Kunlun ophiolite suture; T (grey color) – Tatuo ophiolite suture; A (light grey color) – A'nyemaqen ophiolitic zone. Rectangle marks the thoroughly studied area in the Buqingshan Mountains.

is a part of the global Trans-Asian Late Paleozoic–Early Mesozoic orogenic belt that stretches along the Afghan Hindu Kush, Northern Pamirs, and Eastern Kunlun. It represents a narrow linear, sometimes branching, collision structure.

[3] The study of the Lower Permian rocks from the A'nyemaqen ophiolitic zone, which over the last 20 years was considered as the Eastern Kunlun Paleotethyan relict (suture), is of considerable interest for the reconstruction of the paleocean filling and its main evolutionary stages. The first reconstructions of the Paleotethys in China [*Huang and Chen,* 1987] suggested that during the Early Permian the ocean reached its maximum width, i.e. since its opening in the terminal Middle(?)–Late Devonian it experienced only a spreading extension. Only in the terminal Late Permian the Paleotethys was closed owing to the continental collision, on accretion of the Eastern Gondwanaland blocks to the south of the Eurasian paleocontinent.

[4] However, based on the structure, types, and age of major formations in the Paleotethyan ophiolite zones of the Northern Pamirs, it was previously revealed [*Ruzhentsev et al.,* 1977] that the Paleotethys width attained there its peak in the Visean of the Early Carboniferous. By the Late Bashkirian time in place of its northern branch (Kalaikhumb basin) an ophiolite orogenic zone was formed as a result of the stage-by-stage collision of the south Eurasian Afghan–Tajik block and the intraoceanic structures, namely, the ensimatic island arc and the Kurgovat microcontinent. The final closure of that Paleotethyan branch was terminated by the formation of the Late Bashkirian–Early Moscovian neoautochthon. The southern, Karakul branch of the Paleotethys therewith occurred by the terminal Late Permian [*Pospelov,* 1987] and resulted in the accumulation of terrigenous carbonate formations with the most complete sections of the Permian sediments stratigraphically subdivided by complexes of fusulinids [*Leven,* 1967]. A wide fusulinids distribution in the Permian rocks of the Paleotethyan ophiolitic zones in the Northern Pamirs [*Leven,* 1967] and Karakorum–Kunlun [*Zhang,* 1998] permits the age determination of major formations and, therefore, the reconstruction of main stages of the Paleotethys tectonic evolution.

[5] In 1999–2004 the joint Chinese–Russian investigations on the themes: "Tectonic evolution of the Early Paleozoic paleocean in the eastern sector of the Eastern Kunlun and its relationship with the Paleotethys evolution" and "Tectonics of the Eastern Kunlun orogenic belt", were conducted by the Institute of Geology and Geophysics, Chinese Academy of Sciences, and by the Geological Institute, Russian Academy of Sciences. The research included the studies of the Lower Permian carbonate and terrigenous carbonate sediments within the A'nyemaqen ophiolite zone. The available records

on the structure, composition, and age of the Lower Permian formations supplemented with the new fusulinid collections, provided the elucidation and revision of some problems on the Paleotethys evolution in the Eastern Kunlun.

Tectonic Zonation and Lower Permian Formations

[6] The Buqingshan Mountains are a part of the A'nyemaqen ophiolitic suture where the formations corresponding to the main stages of the Paleotethys evolution and to various paleogeodynamic environments, are most completely represented. The most common formations are the ophiolite and island arc complexes and the associated sedimentary facies. At least three major groups of the Lower Permian terrigenous carbonate formations are recognized there. Within the modern ophiolitic zone they are tectonically drawn together and are characterized by a different structural position. In a paleogeodynamic aspect the Lower Permian formations correspond to a reduction of the Paleotethyan A'nyemaqen branch. In the eastern A'nyemaqen zone the areas of the Mount Muyangshan, southern slope of the Mount Maqenkangri, and regions southeast of Maqen Country are similar in a set of the recovered Lower Permian formations.

[7] The A'nyemaqen ophiolite zone within the Buqingshan Mountains is 18–20 km wide. It is bordered from the south by the Southern Kunlun fault. This is an active sinistral upthrow strike-slip fault, along which the A'nyemaqen complexes are thrown up above the Triassic dynamometamorphic rocks and even above the Miocene–Quaternary loose sediments of the Bayankala continental block. The latter is included in the system of the North Tibet blocks of Gondwanaland origin and is overlain throughout by the shallow red- and grey-colored Lower–Middle Triassic sediments, from under which the Lower Permian limestones are recovered in narrow tectonic slices [*Regional...,* 1991]. The northern boundary of the A'nyemaqen zone is a seismically active sinistral Tuosuo strike-slip fault that separates the Xialawen block of the Southern Kunlun zone. The block is composed of the Lower–Middle Proterozoic intensely granitized amphibolites, schists, and gneisses intruded by the Early Triassic subalkalic granites that are overlain by the Lower Triassic continental molasse bearing the olistostrome beds.

[8] In the discussed area within the A'nyemaqen zone we distinguish the following tectonic structures in a southward direction.

[9] **The Buqingshan nappe** (Figure 2) represents a system of five thrust sheets composed of carbonate, terrigenous, and volcanogenic carbonate detrital rocks.

[10] **The Northern A'nyemaqen subzone** (Figure 2, dark grey color) is a system of tectonic slices composed of greenschist amphibolitic metamorphic rocks bearing narrow lengthy serpentinite and serpentinized harzburgite lenses. Metamorphic rocks are intruded by granodiorite-tonalites.

[11] **The Central A'nyemaqen subzone** is a complicated system of tectonic slices and nappes formed by the Delisitan ophiolitic melange, basalt-andesite volcanics and volcanogenic sedimentary rocks, and by black siliceous alevrolite and argillites bearing diabase sills and numerous tectonic lenses of protrusive serpentinites.

[12] The rocks of the Northern and Central A'nyemaqen are overlain with a sharp angular unconformity by a sequence of polymictic conglomerates bearing thin limestone beds at the base.

[13] **The Southern A'nyemaqen subzone** (Figure 2, light grey color) is composed of the flyschoid meso- and polymictic feldspar-quartz sandstones (rarely gravelstones), and of siltstones and argillites admixed with an intermediate and acidic tephrogenic material. The calcarenite terrigenous flyschoid beds are common. In the southern part of the subzone adjacent to the Southern Kunlun fault the terrigenous flyschoid rocks are metamorphized under conditions of a greenschist facies. All the flyschoid units of the subzone are overlain with a sharp angular unconformity by the coarsely detrital, poorly sorted subaqueous molasse (T_{1-2}) that represents an intermediate facies link between the continental molasse in the Southern Kunlun zone (Xialawen block) and grey-colored shallow flyschoid sediments of the Northeastern Tibet (Bayankala block).

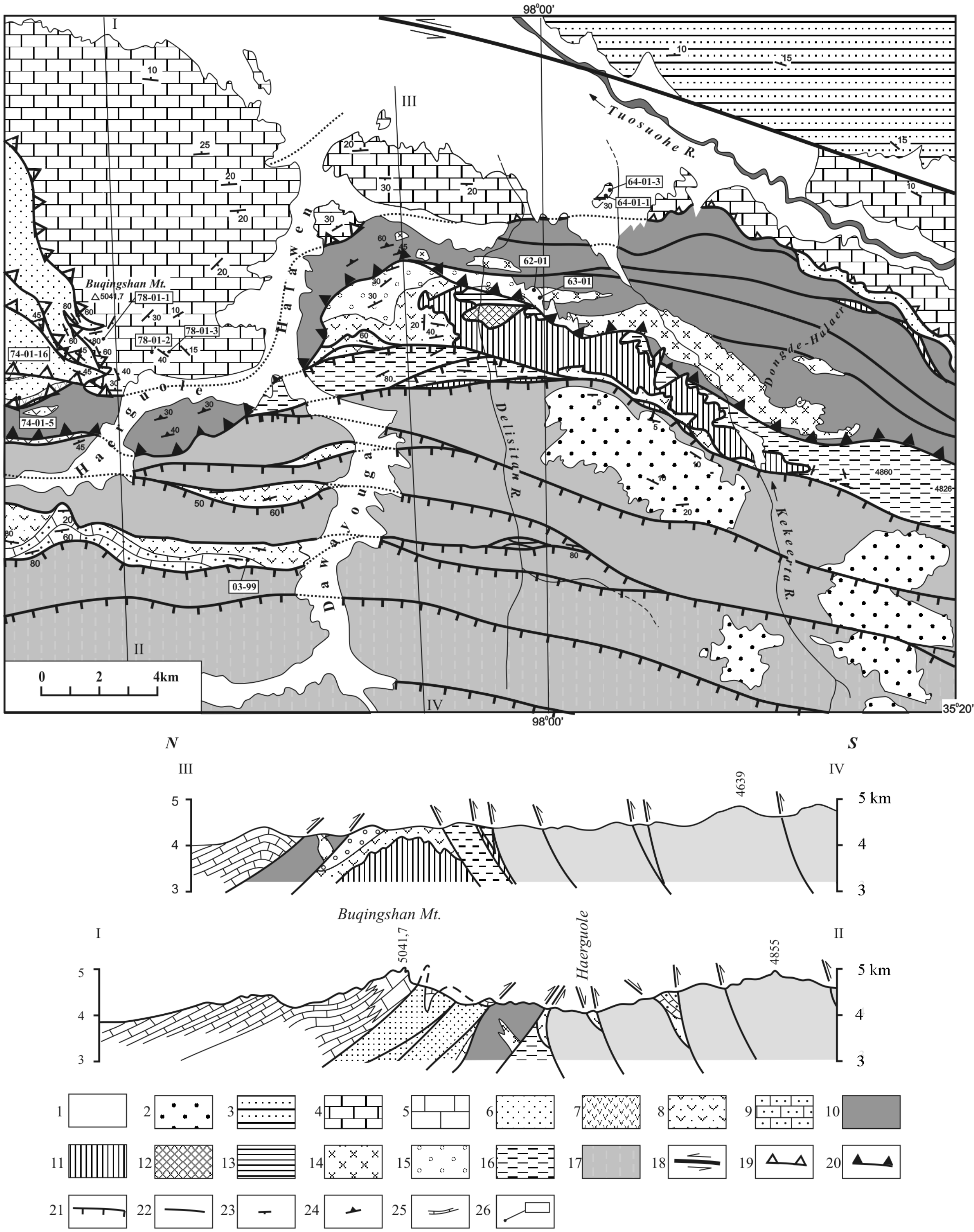
[14] Each of the discussed structural elements, except for the southernmost one, includes the Lower Permian terrigenous carbonate sediments dated by means of numerous fusulinid and first conodont findings.

The Buqingshan Nappe

[15] A thorough geologic survey in 1999–2001 revealed that the Buqingshan nappe named after the corresponding mountain peak of 5041.7 m high, consists of five thrust sheets formed by the different in composition and structure rocks and comprising a single formation order (Figure 2, Section I-II). Fusulinids were collected fron the lower and upper sheets.

[16] The upper (fifth) sheet with a tectonic contact at the base is composed of the facially variable carbonate and carbonate detrital sediments representing in a cross section a shelf reef-rock construction. The nonbedded and massive-bedded reef-rock limestones form the Mount Buqingshan peak. The visible thickness of the reef-rock limestones is 260 m. In a southward direction they grade into the coarsely detrital, almost nonsorted calcirudites with block- to gravel-sized, mostly nonrounded fragments. In a paleofacial aspect they represent back-reef sediments likely formed in the reef surf zone, at the shelf edge. Six meters above the tectonic contact, on the southern slope of the Mount Buqingshan, where the massive reef-rock limestones grade into the transreef calcirudites, fusulinids *Chalaroschwagerina* sp. and *Pseudofusulina* cf. *dzhamantelensis* (Leven) were found (Sample 78-01-1, see Figure 3).

[17] The reef-rock limestones are gradually replaced northwards by the light grey, medium-bedded limestones bearing layers 1.2 m to 0.6 m thick and interbedded with fine- and coarse-grained calcarenite layers of 0.1 m to 0.35 m thick. The biolithocalcarenites consist of limestone frag-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ments to the extent of almost 100% and are free of terrigenous admixture. This sequence was most likely accumulated within a relatively wide lagoon. The maximum visible thickness of the lagoon deposits is about 400 m. The sequence is conformably overlain by the bedded (0.05–0.2 m) yellowish-grey clays, coarse- to fine-grained (up to calcilutite) calcarenites that also can be considered as lagoon sediments. Their maximum thickness is recorded in the brachysyncline core east of the Mount Buqingshan peak, on the left bank of the Halawen River valley. In this locality the lagoon limestones beneath the clayey calcarenites yield *Leeina* sp. (at 45 m below the contact; Sample 78-01-2), and *Pseudofusulina exiqua* (Schellwien et Dyhrenfurth) and *Leeina* cf. *fusiformis* (Schellwien et Dyhrenfurth) (24 m below the contact; Sample 78-01-3). The enclosing lagoon sediments correspond to a stratigraphically higher part of the reef construction, i.e. occur above the point of Sample 78-01-1.

[18] Finally, the youngest parts of the shelf formation are recovered in separate hills, among the recent alluvial deposits in the Kekeerta River low reaches (Figure 2). The lagoon facies are mainly represented there by fine-gravel to fine-pebble calcarenites and calcirudites bearing scarce, 1.6 to 6-m-thick beds of fusulinid limestones and dark green, clayey calcarenite layers 0.4 m to 0.7 m thick. The organogenic limestones contain *Misellina (Brevaxina) olgae* Leven, *Darvasites ordinatus* (Chen), *Chalaroschwagerina vulgarisiformis* (Morikawa), *Leeina* cf. *fusiformis* (Schellw. et Dyhrenfurth), and *L.* aff. *isomie* (Igo) (Sample 64-01-3). Eight meters upward the following fusulinids *Misellina (Brevaxina) dyhrenfurthi* (Dutkevich), *Mesoschubertella* sp., *Toriyamaia laxiseptata* Kanmera, *Darvasites* sp., *Chalaroschwagerina* aff. *vulgaris* (Schellw. et Dyhrenfurth), and *Leeina kraffti* (Schellw. et Dyhrenfurth) were encountered in the fusulinid limestones (Sample 64-01-2, see Figure 3). This part of the section corresponds to the Bolorian stage of the Lower Permian as evidenced by the occurrence of *Misellina*. The attendant fusulinid species are also characteristic of this stage.

[19] According to the fusulinid assemblage, the lagoon, reef, and back-reef sediments of the Buqingshan nappe correspond to the Darvazian series of the Lower Permian, namely, to the Yakhtashian and Bolorian stages [*Leven,* 2004].

[20] This does not contradict the accepted notion on the Early Permian age of these carbonate sediments. The upper sheet represents a monocline declining north- and northeastward at dip angles of 15–30° and complicated by simple brachyform folds. The sheet is included in the Huashixia-Buqingshan nappe that marks the northern margin of the A'nyemaqen ophiolite zone. The nappe extends over 400 km from the Alakol Lake on the west to the Huanghe River meander at the Gansu Province border on the east. In certain places the Upper Carboniferous carbonate sediments are recorded within it, however, the Middle and Upper Permian rocks were not encountered [*Regional...,* 1991]. In a process of the Buqingshan nappe formation the Lower Permian carbonate rocks were tectonically shifted southward [*Wang et al.,* 1997; *Yin and Zhang,* 1997].

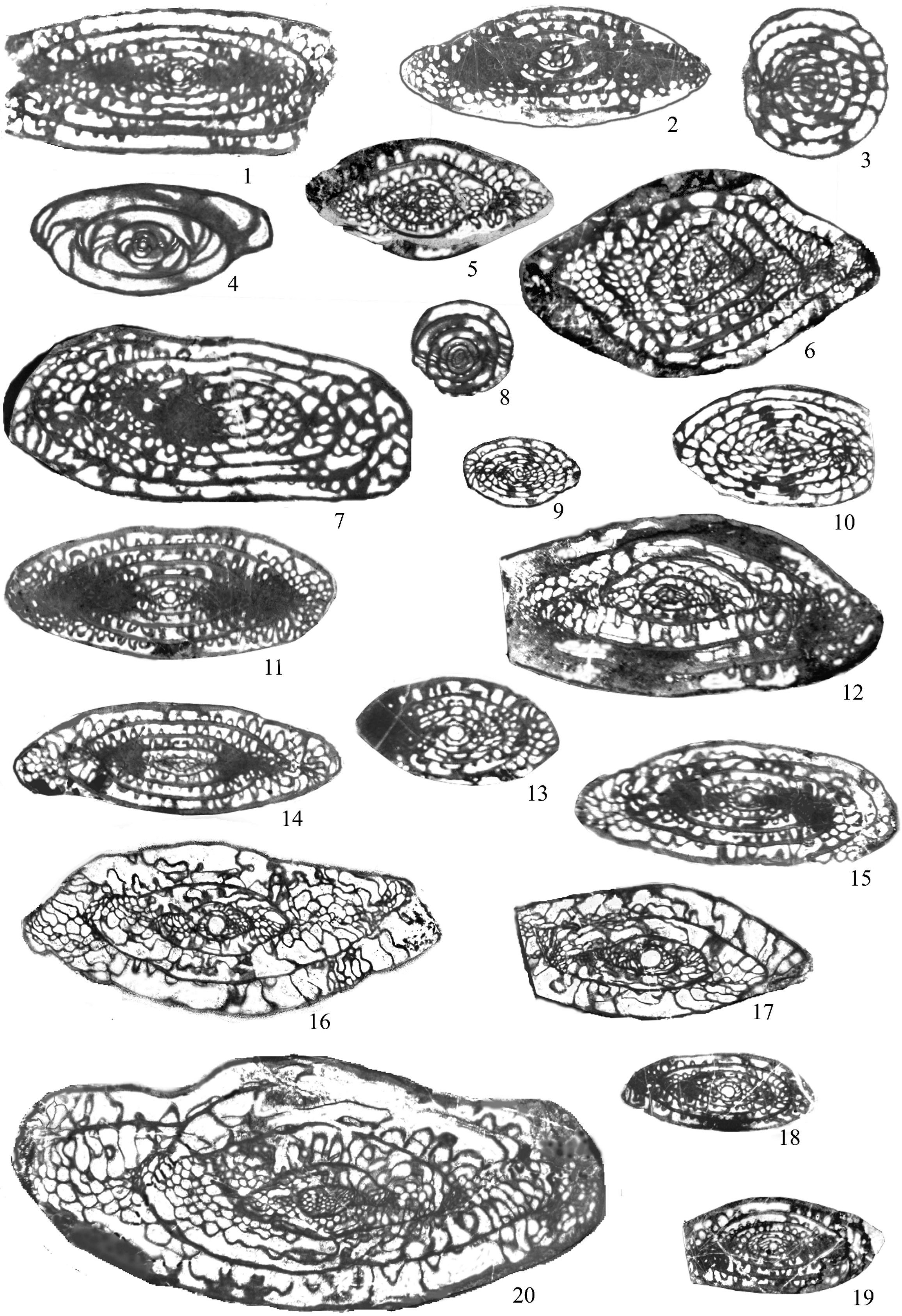
[21] The fourth, third, and second sheets of the Buqingshan nappe are composed of the flyschoid terrigenous sediments barren of organic remains.

[22] The fourth sheet includes the flyschoid alternation of pebble and partially boulder conglomerates and fine-pebble conglomerates and gravelstones. The coarse-grained sandstone beds are scarce. The flyschoid rhythms are 0.8 m to 3.5 m thick. The detrital portion mainly consist of different metamorphic rocks (gneisses, granite-gneisses, schists, micaceous included, rarely amphibolites), and of granites, quartzites, jasper, and others. Judging from their composition, the flyschoid sediments were formed as a result of the erosion of the Precambrian, likely Early and Middle Proterozoic(?) basement of the Xialawen block (north of the Tuosuo strike-slip fault in the modern structure) or of the Southern Kunlun zone [*Yin and Zhang,* 1997]. The thickness of the sheet decreases southward from 280 m to 20 m.

[23] The third sheet represents a flyschoid interbedding of gravelstones, sandstones, and, rarely, siltstones with the rhythms of 0.2–0.6 m thick. The detrital portion of the terrigenous sediments is similar in composition to the rocks of the overlying (fourth) sheet. Owing to the tectonic truncation its thickness also declines southward from 120 m to 0 m.

[24] The second sheet is composed of a sandy siltstone flysch with the rhythms from 0.06 m to 0.2 m thick. The com-

Figure 2. Geological map of the A'nyemaqen ophiolitic zone in the Buqingshan Mountains: (1) Quaternary sediments; (2) coarse detrital molasse bearing olistostrome beds (T_{1-2}); (3) gravelstones, sandstones, aleurolites (P_3-T_1); (4–7) Buqingshan nappe: (4) bedded limestones (P_1ar-k), (5) reef-rock limestones (P_1ar-k), (6) conglomerates, gravelstones, sandy aleurolites flyschoids, calcarenites (P_1), (7) pillow andesitobasalts and tuffs (P_1ar-k); (8–15) Northern A'nyemaqen subzone: (8) basalts, andesitobasalts, tuffs, volcanomictic rocks, siliceous argillites and tuffites (C_1-P_1as-s), (9) reef-rock limestones and calcarenites (P_1as-s), (10) greenschist-amphibolite metamorphites (C_1?-P_1), (11) Delisitan ophiolite melange (harzburgites, dunites, serpentinites, pyroxenites, gabbro, diabases), (12) gabbro blocks in melange, (13) Ordovician tuffite block in melange, (14) granodiorite-tonalite intrusions, (15) conglomerates bearing limestone beds at the base (P_1ar-k); (16) siliceous clayey argillites bearing dolerite and diabase sills (C_1?-C_2); (17) sandstone siltstone and calcarenite siltstone flysch (C_2-P_1); (18–22) disjunctive deformations: (18) modern seismoactive Tuosuo strike-slip fault, (19) intraformation faults of the Buqingshan nappe, (20) paleosubduction thrust, (21) Yanshanian thrusts and reversed faults, (22) other disjunctive deformations; (23) bed attitude of sedimentary rocks; (24) bed attitude of metamorphic rocks; (25) limestone beds; (26) localities of the Early Permian faunal remains.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position of the sandstones is almost unchanged compared to that of the upper sheets. In the mineral portion quartz is dominant, which imparts an oligomictic or subarkose character to the rocks. The thickness of the sheet decreases southward as well from 220 m to 35 m.

[25] Thus, the thickness of the three sheets sharply declines from the north to the south owing to a tectonic truncation. It is possible that all the three types of the terrigenous flyschoid section are in facies relations and represent the sediments of a continental slope: (1) coarsely detrital flyschoids are a proximal part, (2) gravel-sandy varieties, a middle, and (3) sandy aleurolite flysch is a distal part of the slope deposits. Unfortunately, the complete absence of organic remains does not permit the correlation of the carbonate shelf and terrigenous slope sediments, though we assume that they can be mostly synchronous.

[26] The section of the lower (first) sheet differs from those of the overlying tectonic slices. The composition and structure of its rocks are important for further reconstructions and hence we discuss the section in greater detail. It is located on the left flank of the Haerguole valley, 3 km southwest of the Mount Buqingshan peak.

[27] In the section the meta-amphibolites, greenschists, and metabasalts intruded by granodiorite-tonalites, are overlain along the tectonic contact by:

[28] 1. Dark green, pillow, amygdaloidal basalts bearing the calcareous tuff material in the pillow interstices, 40 m thick;

[29] 2. Dark green, bedded, siliceous tuffites, 8 m thick;

[30] 3. Pillow amygdaloidal basalts analogous to that from Bed 1, 22 m thick;

[31] 4. Variegated psammitic and lapilli tuffs of basalts bearing thin, dark green, siliceous tuffite beds, 5.5 m thick.

[32] 5. Grey and dark grey, massive, bituminous, algal fusulinid biomicritic and biosparitic limestones with an incrustational calcitic cement. The limestones yield *Schubertella giraudi* (Deprat), *Chalaroschwagerina tibetica* Nie et Song, *Pseudofusulina crassispira* Chang, *Ps. incomparabilis* Leven, *Ps.*(?) *pavlovi* Leven, *Ps.*(?) aff. regularis Chen, *Ps.*(?) aff. *exiqua* (Schellwien et Dyhrenfurth), and *Praeskinnerella* sp. (Sample 74-01-5, see Figure 4), 3.2 m thick;

[33] 6. Brown, thin-bedded, calcareous sandstones and aleurolites (terrigenous calcarenites), 4.0 m thick;

[34] 7. Dark grey, thin-platy aleurolites, 8.0 m thick;

[35] 8. Grey, bituminous, lumpy, nonbedded organogenic limestones and calcirudites, 1.2 m thick;

[36] 9. Grey siltstones, 4.0 m thick;

[37] 10. Grey, bituminous limestones and calcirudites, 1.8 m thick;

[38] 11. Brown, calcareous sandstones and terrigenous calcarenites, 8.0 m thick;

[39] 12. Calcirudites of mixed limestones (fragments of light grey, grey, and dark grey, almost black sparkling limestones), 2.3 m thick;

[40] 13. Brown calcareous sandstones, 2.2 m thick;

[41] 14. Variegated, fine-pebble calcirudites and calcarenites, 1.8 m thick;

[42] 15. Dark grey, sandy calcarenites and their chaotic interbedding with calcirudites, black calcareous-carbonaceous aleurolites and argillites, and with black bituminous calcarenites, 45 m thick;

[43] 16. Grey, organogenic, medium-bedded, biomicritic limestones; calcirudites at the base. The limestones contain *Minojapanella elongata* Fujimoto et Kanuma, *Chalaroschwagerina tibetica* Nie et Song, *Ch. ngariensis* Nie et Song, *Dutkevitchia jipuensis* (Nie et Song), *Pseudofusulina* cf. *crassispira* Chang, and *Leeina* sp. (Sample 74-01-16, see Figure 4), 8–20 m thick;

[44] 17. Yellowish-brown calcareous sandstones grading into black argillites and siltstones and in the upper part turned to a tectonic breccia along the contact with the overlying sheet, over 40 m thick.

[45] The visible thickness of the reported part of the section is 220 m.

[46] The discussed sheet, like the upper ones, represents a monocline declining northward at dip angles of 30–50°. On the southern slope of the Mount Buqingshan it is completely truncated by the overlying sheet (Figure 2). Its thickness increases eastward up to 350 m at the cost of the upper

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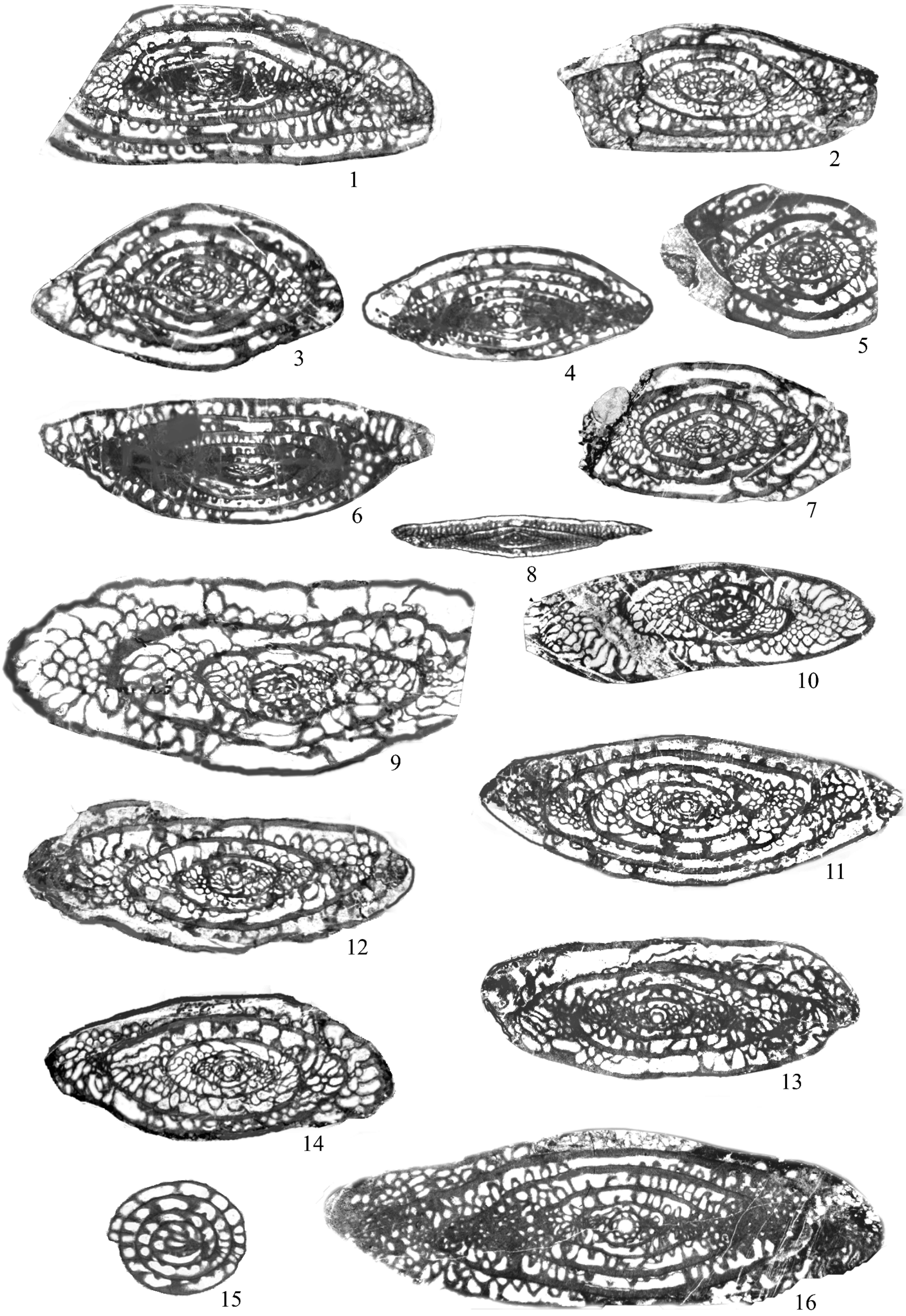
Figure 3. All ×10, except 3, 4 and 8.
1. *Leeina fukasensis* (Suyari). Axial section, sample 64-01-3.
2. *Leeina* cf. *fusiformis* (Schellwien et Dyhrenfurth). Tangential section, sample 64-01-3.
3. *Misellina (Brevaxina) olgae* Leven. ×15. Oblique section, sample 64-01-3.
4. *Toriyamaia laxiseptata* Kanmera. ×20. Axial section, sample 64-01-2.
5. *Pseudofusulina* (?) *kueichihensis* (Chen). Axial section, sample 64-01-2.
6. *Chalaroschwagerina vulgarisiformis* (Morikawa). Oblique section, sample 64-01-3.
7. *Leeina kraffti* (Schellwien et Dyhrenfurth). Oblique section, sample 64-01-2.
8. *Misellina (Brevaxina) dyhrenfurthi* (Dutkevich). ×15. Subaxial section, sample 64-01-2.
9, 10. *Darvasites ordinatus* (Chen). Subaxial sections, sample 64-01-3.
11. *Leeina* (?) *nalivkini* (Leven). Axial section, sample 78-01-1.
12. *Chalaroschwagerina solita* Skinner et Wilde. Axial section, sample 78-01-1.
13, 18, 19. *Pseudofusulina* (?) aff. *exigua* (Schellwien et Dyhrenfurth). 13 – subaxial section, sample 78-013; 18, 19 – subaxial sections, sample 74-01-5.
14, 15. *Pseudofusulina* (?) *edelshteini* Kalmykova. Axial sections, sample 78-01-1.
16, 17, 20. *Chalaroschwagerina tibetica* Nie et Song. 16, 20 – subaxial sections, sample 74-01-16; 17 – subaxial section, sample 74-01-5.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calcarenite and aleurolites sediments. The marker limestone bed bearing fusulinids (Bed 16) is well-traced throughout the sheet.

[47] The structure and composition of the lower sheet rocks permit the suggestion that the sequence with the pillow basalts at the base and carbonate detrital, mainly calcarenite sediments bearing sandstone and aleurolite beds, was accumulated at the base of the continental slope at a considerable distance from the shelf. It might have been a transitional zone from the continental crust of the Xialawen block (Southern Kunlun) to the marginal sea crust in the Early Permian Paleotethys. Based on palinspastic reconstructions with regard to relative positions of tectonic elements and various types of sections, and assuming their relative synchrony and the complete synchrony of the upper and lower sheets, we consider it's possible to reconstruct a single formation order of the northern passive continental margin in the Early Permian Paleotethys for the Bolorian and Yakhtashian, i.e. Artinskian and Kungurian stages. This formation order includes in a southward direction: (1) shelf with lagoonal, reef, and transreef sediments; (2) continental slope with terrigenous coarse proximal to fine distal flyschoids; and (3) mainly calcarenite, siltstone, and argillite sediments bearing scarce limestone beds and overlying the basalt basement.

Northern A'nyemaqen Subzone

[48] The subzone is formed by a system of relatively narrow and extended tectonic slices interrupted by serpentinite and serpentinized harzburgite lenses (Figure 2, dark grey color). The subzone as a whole is fan-shaped with the northern slices inclined southward at 70°–80° and the southern ones, northward at 45°–60°. This structure is strongly discordant with the monocline Buqingshan nappes.

[49] The general picture of the subzone structure is seen in the section in the Kekeerta River low reaches. Here, below the Lower Permian calcarenite limestone sequence of the Buqingshan nappe the following units are recovered in a southward direction:

[50] 1. Strongly deformed, terrigenous, sandy aleurolite flysch. The sandstones are turned to light grey sericitized quartzites and the aleurolites to chlorite-sericite-quartz schists. The outcrop is 600–800 m wide.

[51] 2. Dark grey, almost black meta-amphibolites after basalts and diabases(?). The outcrop is 300–350 m wide.

[52] 3. Strongly deformed serpentinite melange with gabbro, amphibolite, and diabase blocks, 120 m thick.

[53] 4. Epivolcanogenic greenschists mainly after basalt and andesitobasalt tuffs, and, to a lesser degree, after lavas and tuffites, over 1000 m thick.

[54] 5. Greenschists after tuffs and tuffites, with scarce beds and lenses of marmorized limestones bearing small recrystallized fusulinids; 800 m thick.

[55] 6. Black and dark grey, sericitized schists after aleurolites and argillites, with thin beds of grey microquartzites, up to 1500 m thick.

[56] All these tectonic slices and most of their contacts are intruded by granodiorite-tonalites that were formed, judging from petrochemical records, in the island arc environments [*Bian et al.,* 1999a, 1999b]. According to the types of rock complexes composing the tectonic slices, and to their structural and metamorphic peculiarities, the subzone represents a system of accretionary wedges formed in the subduction zone within the ensimatic island arc that separated the Paleotethyan A'nyemaqen oceanic basin on the south from the marginal basin located to the north. Further northwards the latter basin graded into continental margins, nowadays represented as the Buqingshan nappes.

[57] Metamorphic rocks and granodiorite-tonalites of the subzone are overlain with a sharp angular unconformity by the conglomerate sequence bearing a limestone bed at the base, which will be discussed below.

Central A'nyemaqen Subzone

[58] In the system of thrust sheets composing the Central A'nyemaqen subzone the Delisitan ophiolite melange is a central and the lowest structural element, which base is not recovered. Along with the gabbro, diabase, gabbrodiabase, and amphibolite blocks, it includes the asynchronous blocks of siliceous tuffite argillite rocks. In the Delisitan River valley the siliceous sediments of certain blocks yield the Ordovician acritarchs [*Bian et al.,* 2001], and 30 km to the east in the similar melange of the Muyangshan Mountains the Early Carboniferous radiolarians *Callela parvispinus*? Won and *Entactinia variospina?* Won were encountered [*Bian et al.,* 1999a, 1999b].

[59] The Delisitan ophiolitic melange represents a linear

Figure 4. All ×10, except 8 and 15.
1. *Pseudofusulina* ex gr. *crassispira* Chang. Axial section, sample 74-01-5.
2, 3, 5, 7, 11. *Pseudofusulina crassispira* Chang. Axial and subaxial sections, sample 74-01-5.
4. *Pseudofusulina* (?) aff. *regularis* Chen. Axial section, sample 74-01-5.
6. *Pseudofusulina* (?) *pavlovi* Leven. Subaxial section, sample 74-01-5.
8. *Minojapanella elongata* Fujimoto et Kanuma. ×30. Axial section, sample 74-01-16.
9. *Chalaroschwagerina* (?) sp. Subaxial section, sample 74-01-16.
10. *Dutkevitchia jipuensis* (Nie et Song). Oblique section, sample 74-01-16.
12–14. *Pseudofusulina incomparabilis* Leven. Axial sections, sample 74-01-5.
15. *Misellina (Misellina) parvicostata* (Deprat). ×15. Oblique section, sample 63-01-2.
16. *Pseudofusulina* aff. *procera* Leven. Axial section, sample 63-01.

antiform 12 km long with the maximum width of 1.8 km (Figure 2, Section III-IV). Its eastern pericline is overlain by the thin-bedded siliceous clayey rocks bearing numerous dolerite and diabasic porphyrite sills and sheets. In the Delisitan River valley, on the left flank of the antiform they contain Early Carboniferous radiolarians *Entactinia variospina*? Won [*Bian et al.,* 1999a, 1999b]. Thus in both melange blocks and overlying tectonic nappes the synchronous and similar in composition sedimentary rocks can occur. The western pericline of the ophiolite melange antiform between the Halawen and Delisitan valleys is overlain by andesitobasalt lavas and tuffs. Only the fragments of tectonic nappe between the Haerguole and Dawayouga valleys can help to reconstruct a complete section of the volcanogenic rock series. The nappe was subdivided into several separate blocks as a result of the Mesozoic (Yanshanian) retrocharriage process. In this area, judging from the three fragments of a single Late Paleozoic tectonic nappe, the following combined volcanogenic section can be reconstructed upward from the base:

[60] 1. Black and black-green, pillow, aphyric basalts bearing a dark green siliceous tuffite material in the pillow interstices, over 60 m thick;

Hiatus between the blocks and in the section.

[61] 2. Variegated, dark green and wine-colored, pillow, aphyric basalts (with pillow diameter of 1–1.2 m) and agglomerates, 45–50 m thick.

[62] 3. Dark red and wine-colored, crutch-like and needle tuffaceous argillites and tuff aleurolites, 38–40 m thick.

[63] 4. Explosive part of the section: uneven alternation of variegated (green and wine-colored), amygdaloidal, andesitobasalt pillow lavas, their agglomerates, and nonbedded bomb to psammitic tuffs bearing thin beds of dark grey argillites and siltstones, over 90 m thick.

Hiatus between the blocks and in the section.

[64] 5. Facially variable sequence represented by alternated green and wine-colored andesite and andesitobasalt pillow lavas, agglomerates, bomb to ash tuffs, volcanomictic rocks (from boulder conglomerates to sandstones), lahar nonsorted conglobreccias, and separate lenslike beds of pink calcarenites admixed with volcanomictic material. The latters also fill the tuff cement and pillow interstices in the pillow lavas. The thickness is over 400 m.

[65] 6. Light grey calcarenites bearing lenslike beds of lithobioclastic calcirudites. Stratigraphic contact with the underlying volcanites is sharp. Above the contact the calcarenites include scarce lenslike lava breccia and tuff beds. The calcirudites contain numerous Late Asselian–Sakmarian conodonts *Mesogondolella* ex gr. *bisselli* (Clark et Behnken) and the calcarenites yield small fragments of the conodont family Gondolellidae. The maximum thickness is 1200 m.

[66] The analysis of the volcanogenic sedimentary section permits the inference that this consecutively differentiated rock group characterized by the increase of explosion coefficient upward from the base, was formed within the geomorphologically pronounced volcanic uplift of an ensimatic island arc. At least this is true for the part of the section above the dark red tuffaceous argillites. The latters together with the underlying pillow basalts can be considered as an oceanic basement, on which the volcanic uplift was generated. The Rb-Sr age determination of 340.3±11.6 Ma was obtained for these basalts in the Delisitan River valley [*Bian et al.,* 1999a, 1999b], which corresponds to the Visean of the Early Carboniferous.

[67] The active island arc volcanism was terminated at the beginning of the Early Permian and in the Late Asselian–Sakmarian time a reef lagoon atoll was formed around the island arc volcano.

[68] The thrust-nappe structure of the Central, the same as of Northern A'nyemaqen is also overlain with a sharp angular unconformity by a conglomerate sequence. The thickest exposure of the sequence is recorded nearby the western pericline of the Delisitan ophiolitic melange antiform between the Halawen and Delisitan valleys. The conglomerate sequence overlies there the pillow lavas and bomb-lapilli of andesitobasalts and andesites tuffs.

Southern A'nyemaqen Subzone

[69] The tectonic nappes composed of the Central A'nyemaqen volcanogenic sedimentary complexes, that tectonically overlie the flysch sediments of the Southern A'nyemaqen subzone.

[70] The general structure of the Southern A'nyemaqen represents a system of the Late Paleozoic thrust slices complicated by the younger Yanshanian reversed faults. The northern slices are composed of flyschoid meso- and polymictic feldspar-quartz sandstones, rarely gravelstones, admixed with an intermediate or acidic tephrogenic material. The Late Carboniferous radiolarians *Albaillella amplificata* Nazarov et Ormiston, *Camptoalatus* cf. *benignus* Nazarov and *Camptoalatus* sp. were encountered in the siliceous argillites of the flysch sequence in the Delisitan River upper reaches [*Bian Qiantao et al.,* 1999a, 1999b]. The calcarenite terrigenous flyschoid beds are common in the section, together with moderately thick, up to 12 m, lenses of calcarenites and fine-detrital calcirudites. The calcirudite lenses commonly yield fusulinid shell fragments reminiscent of the Early Permian forms. These flyschoids were most likely accumulated on the slopes of island arc rises owing to the erosion of volcanic basement and reef construction.

[71] The southern tectonic slices adjacent to the Southern Kunlun fault are characterized by a steady composition. They are composed of thin-bedded flyschoid sandstones and aleurolites, generally metamorphized under conditions of a greenschist facies. The carbonate detrital rocks were not found there. However, the polymictic sandstones and siltstones to the extent of over 60% consist of volcanomictic, basalt-andesite material, after which the dynamometamorphic greenschists were formed. We assume that the accumulation of that flysch occurred at the base of island arc volcanoes or even in the depression of a suprasubduction trench in relatively deep-water conditions.

[72] It is likely that the formation of volcanogenic sedimentary units of the island arc system and the flyschoid accumulation on the slopes and at the base of volcanic constructions and in an oceanic trench (?) were synchronous

and ocurrred a period from the Late (end of the Early?) Carboniferous to the beginning of the Early Permian.

Lower Permian Neoautochthon

[73] The analysis of the structure, distribution, and composition of the conglomerate sequence permits the statement that it was accumulated subsequent to the formation of the thrust-nappe structure composed of the subduction-accretion metamorphic rocks (Northern A'nyemaqen) and of the island arc volcanogenic sedimentary rocks (Central A'nyemaqen). This sequence by its nature is a neoautochthon. It was commonly considered as the Upper Permian molasse and its age was defined by a single finding of radiolarian *Latentibifistula* sp. in the flint pebble of conglomerates on the Delisitan-Haerguole watershed [*Bian et al.,* 1999a, 1999b]. The Late Permian age of the molasse was demonstrated on all geological maps with the scale 1:200000 to 1:1000000, which showed the Buqingshan Mountains area.

[74] Our research first provided a considerably exact age determination of the conglomerate sequence and the reconstruction of paleotectonic conditions of its deposition.

[75] One of the best outcrops with the recovered base of the conglomerate sequence is located on the watershed between the low reaches of the Delisitan and Kekeerta rivers, 16 km east (azimuth 90°) of the Mount Buqingshan peak (Outcrops 62 and 63). In this location the granodiorite-tonalites intruding amphibolites and schistose tuffs of basaltic rocks, are overlain with a sharp angular unconformity (70°–90°) by the following units:

[76] 1. Yellowish-brown and whitish, dense, nonbedded, clayey sediments representing a weathering surface or thin weathering crust; 0.8–1.5 cm thick;

[77] 2. Grey pelitomorphic organogenic limestones bearing numerous large fusulinids and coral and algae remains. Among fusulinids *Pseudofusulina* aff. *incomparabilis* Leven was identified (Sample 62-01); 40 cm thick;

[78] 3. Variegated polymictic-limestone gravelstone; limestone fragments constitute up to 50% of rock volume; 22–25 cm thick;

[79] 4. Limestone boulder bed; limestone in fragments corresponds to that of Bed 2 and also contains a lot of fusulinids. The cement is gravel sandy, polymictic as in Bed 3. Limestone fragments are poorly rounded, flattened, with a maximum length up to 0.8 m and thickness of 0.3 m to 0.8–2.5 m;

[80] 5. Dispersed polymictic puddingstones: fragments of grey fusulinid limestones (10–30 cm in diameter) among the relatively sorted, variegated, polymictic fine-pebbly gravel matrix with particles up to 5 cm in diameter. The cement is dominated by various metamorphic (amphibolites and greenschists) and siliceous rocks (black and grey flints, red jasper, quartz, quartzite, and chalcedony). Granodiorites, often feldspathized, and diabases and plagiophyres modified to a variable degree, are common; up to 40 m thick;

[81] 6. Polymictic, coarsely bedded conglomerates and gravelstones. Limestone fragments are almost missing. Pebbles are represented by the same rocks as in Bed 5. Single fragments of ophiolitic gabbro and serpentinized harzburgite occur; 60 m thick.

[82] The conglomerates of Bed 6 are overthrusted by serpentinites of the Delisitan ophiolite melange along the younger Yanshanian retrocharriage.

[83] One hundred twenty meters east of the outcrop, in the basal sandy limestones and quartz sandstones bearing carbonate and biogenic intraclasts, 28 cm thick, fusulinids *Misellina (Misellina) parvicostata* (Deprat), *Darvasites* sp., and *Pseudofusulina* aff. *siarykensis* Leven were collected (Sample 63-01).

[84] The composition of the detrital part of conglomerates indicates that almost exclusively metamorphic rocks with granodiorite-tonalites of the Southern A'nyemaqen (subduction-accretion complexes) and the volcanogenic sedimentary units and ophiolites of the Central A'nyemaqen (island arc complexes) were eroded. A sharp angular stratigraphic unconformity terminates the complicated thrust-nappe structure, and the overlying Bolorian basal limestones indicate the ultimate time (end of the Early Permian) when the structure was formed.

[85] The discussed conglomerate sequence by its geodynamic nature represents a neoautochthon or a local molasse formed at early stages of the Paleotethys closure. The formation of the thrust-nappe structure resulted in the growth of a subaerial linear uplift, which provided great masses of detrital material. At sites where intense erosion stopped, the shallow organogenic limestones came to be accumulated. As the structure was still active, in some contiguous places the basal limestones were eroded and redeposited as conglomerates at a relatively short distance, above the limestones. This likely explains the nonuniversal occurrence of limestones at the base of the neoautochthon.

[86] We associate the formation of the Late Paleozoic thrust-nappe belt with south vergence of tectonic units and its overlying by the Early Permian neoautochthon, with the closure of the A'nyemaqen oceanic basin as a result of collision of the ensimatic island arc and northern margin of the Tibetan Bayankala block, a fragment of the Eastern Gondwanaland. This collision represented a terminal stage of the Late Carboniferous–Early Permian (including the Sakmarian) subduction of the oceanic lithosphere beneath the ensimatic island arc. The thrust-nappe structure also included the flyschoid slope and foot sediments of the island arc (deep-water oceanic trench?) volcanoes, though the axial part of the subaerial uplift was composed of only metamorphic rocks, ophiolites, and volcanogenic sedimentary units. This explains the absence of flyschoid fragments in the conglomerate part of the neoautochthon.

[87] The neoautochthon (local molasse) had likely a rather restricted area and was accumulated only above the paleosubduction zone, i.e. actually in the epicollision basin. In any case, within the Bayankala block, north of the Ngoring-Co and Gyaring-Co lakes and of Maduo Country only the shallow shelf Artinskian carbonate sediments are known in tectonic wedges beneath the grey-colored Triassic flysch [*Regional...,* 1991].

Conclusions on the Early Permian Tectonic History

[88] The available records on the structure and age of the Lower Permian formations and their geodynamic nature infer a new concept of the Paleotethyan tectonic evolution for the Buqingshan region of the eastern Eastern Kunlun.

[89] In the cross section of the A'nyemaqen ophiolitic zone in the Buqingshan Mountains the following major Permian formations are recognized from the north to the south:

[90] (1) carbonate shelf formation (according to the geological survey at the scale 1:200000, its base is of Late Carboniferous age and the upper part includes the Midean stage);

[91] (2) carbonate detrital formation of the base of continental slope or of the marginal sea cover;

[92] (3) subduction-island arc neoautochthon or epicollision local conglomerate molasse;

[93] (4) shallow-water shelf carbonate formation of the Tibetan Bayankala continental block.

[94] It is generally recognized that the Paleotethys opening in this part of the Kunlun occurred in the Late Devonian–earliest Early Carboniferous as a result of the Eastern Gondwanaland dispersion [*Ren et al.,* 1999; *Wu,* 1999; *Zhong et al.,* 2000; etc.]. However, other researchers stated that the A'nyemaqen spreading basin began its formation only in the Early Permian [*Wang et al.,* 1997], or that its closure started at that time as a result of subduction beneath the northern (Qaidam) continental margin with the formation of an Andean-type volcanic belt [*Yin and Zhang,* 1997].

[95] We assume that the opening of the Paleotethyan A'nyemaqen basin occurred in the terminal Devonian–Early Carboniferous and, according to the available records on the Lower Permian formations, we reconstruct the Paleotethys evolution in the Early Permian as follows.

[96] The exact time of the Paleotethys initial closure is unknown; it might have been the terminal Early–beginning of the Late Carboniferous when the ensimatic island arc system started formation above the subduction zone with the northward submergence of the oceanic lithosphere. The following paleostructures were formed in a southward direction both in the present and paleocoordinates: Xialawen continental block as a large microcontinent within the Paleotethys (South Kunlun zone) – marginal sea – ensimatic island arc – A'nyemaqen oceanic basin – Bayankala continental block. This lateral succession of structures was retained up to and including the Sakmarian of the Early Permian, when the volcanic activity of the island arc was damped out and the subaerial volcanoes were surrounded by carbonate reef-rock atolls.

[97] The Sakmarian–Yakhtashian (Artinskian) boundary was the most important stage in the process of the A'nyemaqen oceanic basin closure. The long-term subduction of the oceanic lithosphere produced the collision of the island arc system and the northern passive continental margin of the Bayankala block. As a result a thrust-nappe south-verging structure appeared, which partially overlay the Bayankala block margin. A linear subaerial uplift and the adjacent epicollision basin were formed, where the conglomerate Yakhtashian–Bolorian, i.e. Artinskian–Kungurian sequence was accumulated. The A'nyemaqen oceanic basin left only the northern marginal sea; on its northern shelf and in the depression mainly carbonate and carbonate detrital sediments of the same Yakhtashian–Bolorian age were accumulated. Judging from the type of the marginal sea formations, the collision of the island arc with the Bayankala continental block and the formation of thrust-nappe structures in the collision belt almost did not affect its structure and sediment accumulation.

[98] The final A'nyemaqen closure with the formation of the Late Paleozoic linear ophiolite zone took place at the Permian–Triassic boundary. This is indicated by the alluvial-shallow-water molasse of the Yangqu Formation, the age of which is reliably determined only from the early Middle Triassic, though the Early Triassic age of its lower part is also possible [*Luo et al.,* 2001].

[99] Thus we consider the standpoint that the Paleotethys within the A'nyemaqen Range reached its maximum width in the Permian [*Huang and Chen,* 1987] rather questionable. At that time the widest part of the Paleotethys was represented by its northern branch – the Tatuo paleoceanic basin – which closure occurred at the Permian–Triassic boundary concurrently with the intense orogeny and accumulation of a thick continental molasse. In the A'nyemaqen part of the Paleotethys in the Early Permian the paleobasin intensely decreased and beginning from the Bolorian (Kungurian) time up to the terminal Permian it retained only as a marginal sea depression.

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