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GEOLOGY

Manifestations of the Late Carboniferous and Early Permian Stages of Formation of Nappe-Fold Structures in the Southern Framework of the Siberian Platform (East Sayany, South Siberia)

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The geological structure of the Tunka Goltsy (the Tunka Range) of the East Sayany is characterized by a complex nappe-fold structure, composed mainly of Paleozoic terrigenous and carbonate rocks and their metamorphosed analogues [1–3]. It is generally recognized that the nappe-fold structure of the East Sayany, including its southeastern segment, regarded as the Tunka terrain [3] or Ilchirskaya zone [4], formed in the Ordovician as a result of collision between the Tuva–Mongolian microcontinent and the Siberian continent. As referred to in [5], the Ordovician–Middle Paleozoic deformations over the entire vast territory of Central Asia, from the Olkhon zone of the Pribaikalie to the North Kazakhstan, were manifested as a result of the closing of the oceanic basin and the subsequent collision between the Kazakhstan–Baikalian complex continent (including the Tuva–Mongolian microcontinent) and the Siberian continent. In the Ordovician the Olkhon nappe-overthrust zone was formed along the southeastern framework of the Siberian Craton. In addition, the metamorphism was manifested over the entire vast territory of the East Sayany that could probably be connected with nappe formation. In the Late Ordovician–Silurian, the oblique slip-thrust structures, magmatism, and metamorphism were manifested in the Sangilen highlands and Tuva. Later, the deformations continued. In the Late Devonian–Early Carboniferous, the dextral strike-slip fault Charysh–Terektinskaya zone was formed; in the Late Carboniferous, the Kurayskaya and Kuznetsko–Teletsko–Bashkaus sinistral strike-slip shear zones were formed.

In the Late Carboniferous–Permian, the collision between the East European, Kazakhstan–Baikalian, and Siberian continents took place [5, 6]. In East Kazakhstan, the sinistral strike-slip movements took place in the band of more than 400 km width along the Chara ophiolite zone and the Irtysh and Northeastern shear zones. The age of deformation rejuvenates regularly to the east towards the internal part of the Siberian continent; the movement amplitude along shears decreases in the same direction from several thousand to a hundred kilometers.

In the late Palaeozoic in the Tunka Goltsy and the adjacent regions, a number of geological events of Late Carboniferous and Early Permian age are distinguished. For example, the rubidium–strontium 312 ± 20 Ma isochrone for the two-mica-garnet-staurolite schists from the central part of the Tunka range (the Bogdo-Khongoldoy River basin) was constructed [7]. According to the geological data, the metamorphism isogrades cut across the stratigraphic boundaries and the Ordovician tectonic zones, separating the tectonic plates of different compositions. Granitoid rocks of the Araosheiskii complex, which lie in the axial part of the Tunka range and break through the Ordovician nappe-fold structure of the region, are 320–315 Ma old (K–Ar age dating on biotite) [8]. In the southeastern part of the Tunka Goltsy, the tectonic nappes were found during medium scale geological survey work. They are made of granite-gneisses, overthrusted gently on the Late Devonian-Carboniferous molasse of the Sagansairskaya formation [2]. In addition, there appeared recently new geochronological data about Late Carboniferous age of deformations in the zone of the Main Sayan Fault [9], located to the north in the vicinity of the area investigated (Fig. 1).

This article is devoted to the characteristics of the Late Palaeozoic nappe-fold structures of the Tunka Goltsy of the East Sayany, which has as a whole an Ordovician age of structure formation and metamorphism [1, 2]. As a result of the field works in the period of 2006–2008, the Tunka range area was mapped in detail in the basins of the Kyngarga, Bukhota, and Tolta rivers, and near the settlement Arshan as well

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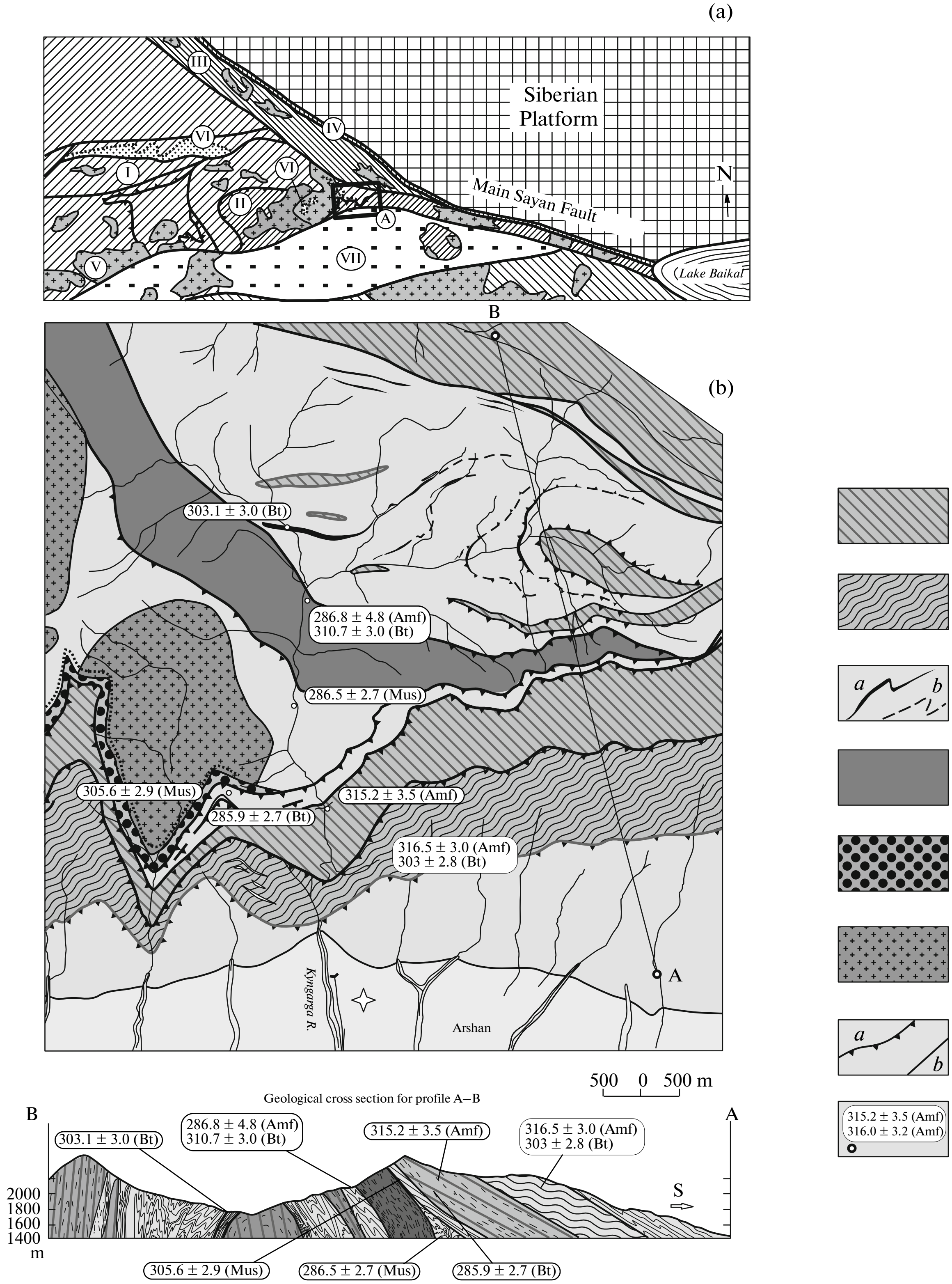

Fig. 1. Location of the area of the settlement of Arshan in the structure of the southern framework of the Siberian platform (a) and the geological structure of this area (b). I—Area of development of the Early Paleozoic deformation complexes; II—area of development of the Late Paleozoic deformation complexes; III—Late Paleozoic Kitoy-Kinskaya deformation zone; IV—Zone of the Main Sayan Fault; V—Late Paleozoic granitoids; VI—Late Paleozoic molasse; VII—Cenozoic Tunka depression. *1*—Gneisses, crystalline schists, and garnet amphibolites; *2*—melange zone, including diaphtorized plagiogneisses, crystalline schists, garnet amphibolites, and milonitized marbles; *3*—milonitized marbles with bodies of garnet-biotite blastomilonites, revealed (*a*) and proposed (*b*); *4*—green schists; *5*—Late Devonian–Early Carboniferous molasses (Sagansairskaya suite); *6*—Late Devonian microcline granites and granosyenites; *7*—faults with inclined location of the fault plain (*a*), sleep dip of fault plain (*b*); *8*—localities of samples and Ar–Ar age dating results.

(Fig. 1). During the mapping there was conducted a study of small plicated forms, the measurements of directional deformation structures (mineral, aggregate banding, and linearity), and also the sampling of metamorphic rocks for the Ar–Ar age dating.

It has been found that the investigated area consists of two packets of the tectonic plates of the Late Carboniferous and Early Permian ages, which form an antiform structure with the south and north dips of the thrust surfaces, and the north dip with ~30° angle of the bend (see Fig. 1).

The lower packet of plates associated with the central and northern parts of the area being investigated is represented by (1) metacarbonate rocks (milonitized marble with rare bodies of garnet-biotite schists), which are regarded as the metamorphic analogues of the Vendian–Cambrian Gorlykskaya suite; (2) gneisses, crystalline schists, and garnet amphibolites; (3) green schists, which are regarded as the metamorphic analogues of terrigenous–volcanogenic carbonate rocks of the Verkhneshumakskaya suite.

The fault zones between the plates are made of muscovite-carbonate milonites, amphibole-biotite, and garnet-biotite schists.

Metacarbonate rocks are intruded by Late Devonian microcline granites, and they are overlapped together by the molasse of the Sagansairskaya suite [2].

From the north they are bounded by the tectonic plate made of greenschist strata. Its structure is characterized by isoclinal folding. The planar directional structure emphasized by biotite is formed near the fault contact zones. In schists, amphibole crystals of late paragenesis not having any orientation are also observed. The Ar–Ar age for the rock-forming biotite from biotite–amphibole schist (sample 06-94) is 310.7 ± 3.0 Ma; for amphibole, 286.8 ± 4.8 Ma. In the metacarbonate rocks, the Ar–Ar age for muscovite, which grows along the differential sliding planes, is 286.5 ± 2.7 Ma (sample 06-92).

North of the greenschist strata, the tectonic plates of metacarbonate rocks and gneisses lie in the antiform core. For biotite from the quartz–garnet–biotite schist (sample 06-95), located among the milonitized marbles, the age is 303.1 ± 3.0 Ma.

Garnet crystals have “snowball” structures due to the seizure of biotite grains that indicates the growth of minerals during deformation, which are associated with the nappe formation.

The Late Carboniferous–Early Permian overthrust structure is manifested in the southern part of the area. This is represented by the upper packet of plates made of (1) gneisses, crystalline schists, and garnet amphibolite and greenschist diaphtorites after them; (2) metacarbonate rocks. Tectonic plates gently overlap (from 35° to 5°) the different elements of the structure of the lower packet of the tectonic plates (see Fig. 1).

The results of Ar–Ar age dating for amphiboles and mica from rocks of the areas of the settlement of Arshan (Tunka Goltsy, East Sayany)

Number of sample	Coordinates	Rock type	Mineral	Age / Plateau-integral age (Ma)
07-51	N 51°56′10.1″ E 102°26′17.7″	Quartz–biotite–amphibole schist	Biotite	303.0 ± 2.8 / 283.6 ± 2.7
			Amphibole	316.5 ± 3.3 / 313.5 ± 3.4
06-94	N 51°57′48.7″ E 102°26′17.7″	Same	Biotite	310.7 ± 3.0 / 308.4 ± 2.9
			Amphibole	286.8 ± 4.8 / 266.2 ± 5.7
06-95	N 51°58′23.4″ E 102°24′55.7″	Quartz–biotite–garnet schist	Biotite	303.1 ± 3.0 / 300.1 ± 3.0
06-92	N 51°57′04.7″ E 102°25′07.7″	Marble	Muscovite	286.5 ± 2.7 / 282.1 ± 2.7
06-90-1	N 51°56′21.7″ E 102°25′25.7″	Quartz–amphibole–plagioclase schist	Amphibole	316.1 ± 3.2 / 291.9 ± 2.9
06-90-3	N 51°56′21.7″ E 102°25′25.7″	Garnet amphibolite	Amphibole	315.2 ± 3.5 / 309.1 ± 5.7
07-37-1	N 51°55′46.3″ E 102°24′23.5″	Milonitized marble with biotite cleavage zones	Biotite	305.6 ± 2.9 / 299.9 ± 2.9
07-37-5	N 51°55′46.3″ E 102°24′23.5″	Biotite–quartz schist after plagiogneisses	Biotite	285.9 ± 2.7 / 276.9 ± 2.6

Note: Analyst A.V. Travin, Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia.

The Ar–Ar age for the hornblende sampled from garnet amphibolite (sample 06-90-1) located among the gneisses is 316.1 ± 3.2 Ma. The Ar–Ar amphibole age from the diaphtorized garnet amphibolite (sample 06-90-3) is 315.2 ± 3.5 Ma. The age of biotite from the schistosity zones superimposed on amphibolites has been determined as 303.0 ± 2.8 Ma.

The melange zone with thickness up to several ten of meters is located in the basement of the upper packet of tectonic plates. This is characterized by the alternation of biotized plagiogneisses and muscovitized milonites. The age of biotite from the plagiogneisses (sample 07-37-5) is 285.9 ± 2.7 Ma; the age of muscovite from metacarbonate schists (sample 07-37-1), 305.6 ± 2.9 Ma).

The revealed relationships of tectonic plates and the age of metamorphic rocks characterize the Late Carboniferous and Early Permian collision stages, superimposed on the Ordovician deformation structure [1–3]. In the area studied, the Late Palaeozoic faults are mainly concentrated near the Main Sayan Fault zone and the margin of the Siberian Platform. The Ordovician structure here is complicated by the Late Palaeozoic deformation and metamorphism processes of the structure (Fig. 1, table).

The new geological–geochronological data presented make it possible to consider that the formation of tectonic nappes in the Tunka Goltsy (the southeastern part of the East Sayany) occurred during two stages: in the Late Carboniferous and the Early Permian. In the Late Carboniferous, the Main Sayan Fault reactivation was also manifested [9]. One should assume that these events are interconnected and that they characterize the collisional stage of the formation of the East Sayany structure in the framework of the Siberian platform. At this time, in the Altai–Sayan folded region, located to the west of the Siberian platform, the sinistral strike-slip shear structures (Teletsko-Bashkaus, Kurayskaya, and some others), associated with the collision between the Kazakhstan–Baikalian and Siberian continents were formed [5, 6].

In the Altai–Sayan folded region and East Kazakhstan in the Early Permian, shear structures such as Chara, Irtysh, Northeastern, and other fault zones were formed as a result of collision between the East European, Kazakhstan–Baikalian, and Siberian continents [5, 6]. The events in the Early Permian are also widely manifested to the south of the Siberian platform within the bounds of the Transbaikal segment of the Mongol–Okhotsk orogenic belt. They are the scale manifestations of granitoid magmatism in the Transbaikal area [10] and the Khamar-Daban mountain range [11], high-temperature metamorphism in the western Transbaikal [12], and the formation of tectonic nappes and olistostrome complexes in the Dzhidinskaya zone [13].

It is probable that these events and the manifestations of the Early Permian deformations revealed in the Tunka Goltsy area characterize one and the same tectonic stage, which is connected with the manifestation of the great-scale collision between the East European, Kazakhstan–Baikalian, and Siberian continents [5, 6].

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