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Tectonics and geodynamics of the Central Asian Foldbelt: the role of Late Paleozoic large-amplitude strike-slip faults

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Abstract

The following structural elements have been recognized to constitute the tectonic demarcation of Central Asian Foldbelt: (1) The Kazakhstan–Baikal composite continent, its basement formed in Vendian–Cambrian as a result of Paleoasian oceanic crust, along with Precambrian microcontinents and Gondwana-type terranes, subduction beneath the southeastern margin of the Siberian continent (western margin in present-day coordinates). The subduction and subsequent collision of microcontinents and terranes with the Kazakhstan–Tuva–Mongolia island arc led to crustal consolidation and formation of the composite-continent basement. In Late Cambrian and Early Ordovician, this continent was separated from Siberia by the Ob'–Zaisan ocean basin. (2) The Vendian and Paleozoic Siberian continental margin complexes comprising the Vendian–Cambrian Kuznetsk–Altai island arc and the rock complexes of Ordovician–Early Devonian passive margin and Devonian to Early Carboniferous active margin. Fragments of Vendian–Early Cambrian oceanic crust represented by ophiolite and paleo-oceanic mounds dominate in the accretionary wedges of island arc. The Gondwana-type continental blocks are absent in western Siberian continental margin complexes and supposedly formed at the convergent boundary of a different ocean, probably, Paleopacific. (3) The Middle–Late Paleozoic Charysh–Terekta–Ulagan–Sayan suture-shear zone separating the continental margin complexes of Siberia and Kazakhstan–Baikal. It is composed of fragments of Cambrian and Early Ordovician oceanic crust of the Ob'–Zaisan basin, Ordovician blueschists and Cambrian–Ordovician turbidites, and Middle Paleozoic metamorphic rocks of shear zones. In the suture zone, the Kazakhstan–Baikal continental masses moved westward along the southeastern margin of Siberia. In Late Devonian and Early Carboniferous, the continents amalgamated to form the North Asian continent. (4) The Late Paleozoic strike-slip faults forming an orogenic collage of terranes, which resulted from Late Devonian to Early Carboniferous collision between Kazakhstan–Baikal and Siberian continents and Late Carboniferous to Permian and Late Permian to Early Triassic collisions between East European Craton and North Asian continent. As a result, the Vendian to Middle Paleozoic accretion-collisional continental margins of Siberia and the entire Kazakhstan–Baikal composite continent became fragmented by large-amplitude (up to a few thousand kilometers) strike-slip faults and conjugate thrusts into several strike-slip terranes, which mixed with each other and thus disrupted the original geodynamic, tectonic, and paleogeographic demarcation.

Keywords: microcontinents; terranes; accretion; collision; island arcs; Late Paleozoic displacements; Central Asian Foldbelt

Introduction

The folded regions of Central Asia, among them the Eastern Kazakhstan and Southern Siberia (Altai–Sayan Region, Cis-baikalia and Transbaikalia), are generally regarded as Vendian and Paleozoic structures formed along the periphery of Siberian Craton as a result of volcanic arc and Gondwana terrane accretion accompanied by strike-slip deformation that substantially altered the style of successive accretionary growth of the Siberian continent (Berzin and Dobretsov, 1993; Berzin et al., 1994; Didenko et al., 1994; Gordienko, 2006; Parfenov et al., 2003; Sengör et al., 1993, 1994; Windley et al., 2007; Xiao et al., 2009; Yakubchuk, 2008; Zonenshain et al., 1990; and others).

The article presents a new tectonic demarcation model for Eastern Kazakhstan, Altai–Sayan and Central Asian foldbelt (Central Asian orogenic belt or Altaids) in the context of their Late Paleozoic origin as large-amplitude (hundreds to several thousands of kilometers) strike-slip terranes being fragments of Vendian and Paleozoic continental margin complexes of Siberian Craton, including the Vendian–Cambrian Kuznetsk–Altai volcanic arc and the Kazakhstan–Baikal composite continent consisting of Gondwana terranes, fragments of Vendian–Cambrian Kazakhstan–Tuva–Mongolia island arc and of late Precambrian oceanic crust of the Paleoasian Ocean.

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The discussion focuses on the problem of Central Asian Fold Belt (CAFB) formation and position of its boundaries.

Tectonic demarcation of Central Asian Foldbelt

Late Paleozoic strike-slip deformations have been shown to be a dominant feature in the structure of the Central Asia (Berzin and Dobretsov, 1993; Berzin et al., 1994; Buslov, 1998; Buslov et al., 2000, 2003, 2004; Didenko et al., 1994; Dobretsov, 2003; Dobretsov and Buslov, 2007; Sengör et al., 1993, 1994; Zonenshain et al., 1990). They form an orogenic collage of terranes originated as a result of Late Devonian to Early Carboniferous collision between the Kazakhstan (Kazakhstan–Baikal) composite continent and the Siberian Craton and of Late Carboniferous to Permian collision between the East European and Siberian cratons and the Kazakhstan–Baikal Continent (Buslov, 1998; Buslov et al., 2000, 2003, 2004; Dobretsov and Buslov, 2007). As a consequence of collisions the Vendian to Middle Paleozoic margins of the Siberian and East European cratons and the entire Kazakhstan–Baikal composite continent became fragmented by large amplitude strike-slip faults and conjugate thrust faults into several strike-slip terranes (tectonostratigraphic units) that mixed with each other and disrupted the original geodynamic, tectonic, and paleogeographic demarcation.

The tectonic demarcation of the Central Asia (Figs. 1, 2) consists of the following major structural elements (Buslov, 1998; Buslov et al., 2000, 2003, 2004; Dobretsov and Buslov, 2007):

1. The Kazakhstan–Baikal composite continent has basement formed during Vendian–Cambrian subduction of the oceanic crust of Paleoasian Ocean, together with Precambrian Gondwana-type terranes (Issyk-Kul', Karatau, Ulutau, Kokchetav, Aktau-Mointin, Tarbagatai, Central Tianshan, Altai–Mongolia, Tuva–Mongolia, etc.). The subduction and subsequent collision between the terranes and the Kazakhstan–Tuva–Mongolia island arc along the southeastern Siberian margin (present-day coordinates) led to broad manifestation of collisional metamorphism and magmatism and, eventually, crustal consolidation and formation of the basement of the composite continent (Dobretsov and Buslov, 2007). In Cambrian and Early Ordovician this continent was separated from the Siberian Craton by the Ob'–Zaisan oceanic basin. In Early Ordovician the continent started moving west relative the Siberian Craton gradually closing the oceanic ocean, which in Ordovician–Devonian subducted beneath the continent. The subduction of oceanic crust and the subsequent collision between the Kazakhstan–Baikal and Siberian continents eventually led to formation of the Charysh–Terekta–Ulagan–Sayan strike-slip suture zone. The composite continent grew from the south by accretion of Gondwana continental blocks along the active margins. In the present-day CAFB structure the Kazakhstan–Baikal composite continent is represented in eastern part of Urals, western part of West Siberian plate basement, in Tianshan, Kazakhstan, southern part of Altai–Sayan region, Tuva, Cisbaikalia and Transbaikalia, Mongolia, and northern part of China (Fig. 1). The continental blocks of Gondwana is the distinctive feature of the structure. The Charysh–Terekta–Ulagan–Sayan strike-slip suture zone separates the composite continent from western continental margin complexes of Siberian Craton (Figs. 1, 2). In northwestern direction the suture zone is heavily disturbed by Late Paleozoic strike-slip faults and hidden under Mesozoic–Cenozoic sedimentary cover of the West Siberian Basin. In the eastern direction, in the Baikal Region and Transbaikalia, the structure continues as the Ol'khon strike-slip zone (Dobretsov and Buslov, 2007), where metavolcanogenic sedimentary rocks of backarc ophiolite affinities are located (Zorin et al., 2009). The boundary between the Kazakhstan–Baikal composite continent and the East European Craton runs along the Main Ural Fault. This could be established by showing that the Paleozoic island-arc systems of the Urals formed as continental margin complexes of Kazakhstan–Baikal and then were displaced several thousand kilometers north together with the East European Craton that had a passive margin with the Uralian Ocean. The subduction of Uralian Ocean beneath the Kazakhstan–Baikal continent had culminated by the end of Carboniferous to Early Permian with deposition of Cis-Uralian foreland trough flysch. The Late Permian collision between the continents ended up in formation of molasse deposits in the Cis-Uralian Trough, emplacement of the main granite axis of the Urals, and strike-slip deformations in the Urals Orogen and Main Ural Fault (Puchkov, 2000; Savel'ev et al., 1998). The Urals Orogen formed along the East European Craton margin and both had migrated north. Paleogeographic characteristics of Late Carboniferous and Permian Pechora, Karaganda, Kuzbass coal basins (Betekhtina, 1983) and paleomagnetic data (Didenko et al., 1994; Pecherskii and Didenko, 1995) have shown that starting from Late Carboniferous the East European Craton migrated a few thousand kilometers north. The northward drift of the East European Craton led to formation of large amplitude strike-slip faults along the continental margins. The East European Craton had reached its present-day location by Early Jurassic and, eventually, joined the North Asia continent (Buslov et al., 2003). In Paleozoic the Kazakhstan–Baikal composite continent grew from the south by amalgamation with Gondwana terranes, which continued through Mesozoic.

2. The Vendian and Paleozoic continental margin complexes of the Siberian Craton (Buslov, 1998; Buslov et al., 2003, 2004; Dobretsov and Buslov, 2007; Dobretsov et al., 2004a,b; Safonova et al., 2004a,b; Yolkin et al., 1994) consist of the Vendian–Cambrian Kuznetsk–Altai island arc, Ordovician–Early Devonian passive margin complexes, and Devonian to Early Carboniferous active margin (Figs. 2, 3). The accretionary island arc wedge contain abundant fragments of Vendian–Cambrian oceanic crust consisting of ophiolite and paleoceanic mounds. Gondwana continental blocks are absent in continental margin complexes of the Siberian Craton suggesting their formation along a convergent boundary of a different ocean, most likely the Paleopacific Ocean. In the present-day structure they are confined to the western margin of the Siberian Craton and represented in northern part of

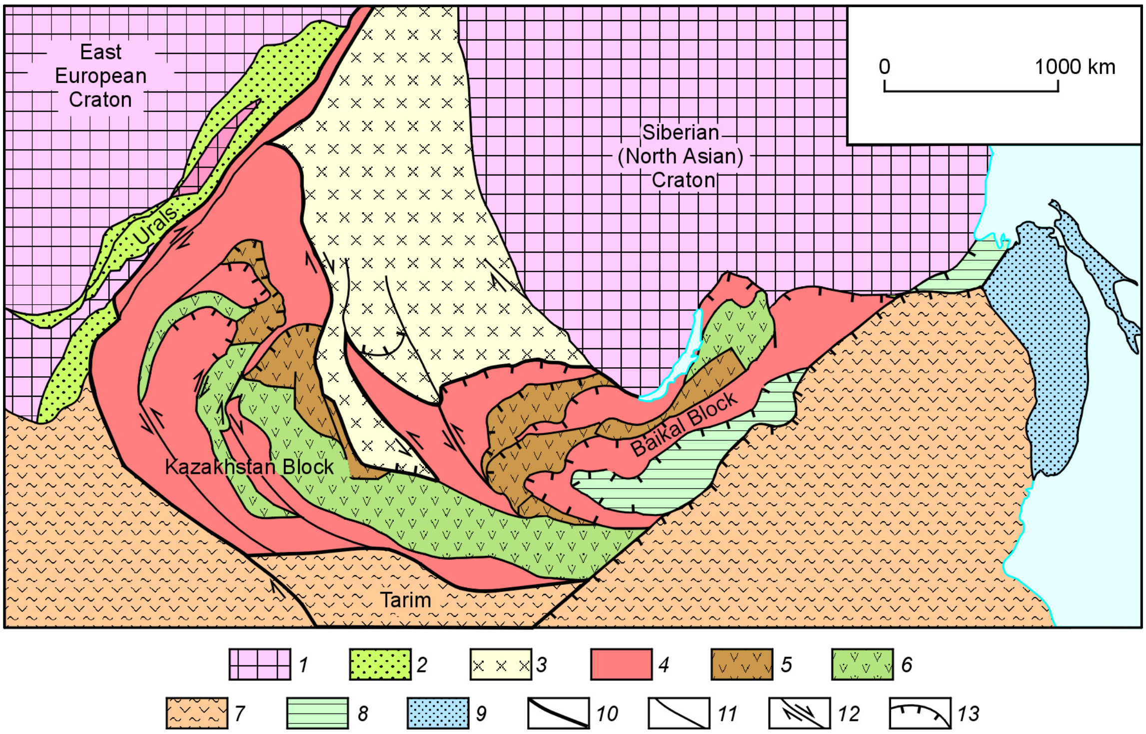

Fig. 1. Tectonic demarcation of Central Asian Foldbelt, modified from (Dobretsov and Buslov, 2007). *1*, Precambrian cratons; *2*, Paleozoic passive margin formations of the East European Craton; *3*, Vendian and Paleozoic continental margin formations of the Siberian (North Asia) Craton; *4–7*, Kazakhstan–Baikal composite continent: *4*, accretionary-collisional zones including Gondwana-type Precambrian terranes, *5–6*, Vendian and Early Cambrian Kazakhstan–Tuva–Mongolia island arc: *5*, essentially igneous rocks, *6*, accretionary prisms and fore-arc basin formation; *7*, Early Mesozoic accretionary-collisional belt with Gondwana-type terranes; *8*, Early Mesozoic Mongolia–Okhotsk strike-slip suture zone; *9*, Late Mesozoic orogenic belt; *10*, Kazakhstan–Baikal composite continent boundaries; *11*, Late Paleozoic undifferentiated faults; *12*, Late Paleozoic and Early Mesozoic strike-slip faults with direction of displacement (arrows); *13*, Late Paleozoic and Early Mesozoic thrust faults.

Altai–Sayan Mountains, eastern and central parts of West Siberian plate basement (Fig. 1).

3. The Middle Paleozoic Charysh–Terekta–Ulagan–Sayan suture-shear zone separating the continental margin complexes of the Siberian and Kazakhstan–Baikal continents consists of fragments of Cambrian to Early Ordovician oceanic crust of the Ob'–Zaisan oceanic basin and Ordovician blueschists and Cambrian to Ordovician turbidites (Figs. 4, 5) (Buslov, 1998; Buslov et al., 2003, 2004; Dobretsov and Buslov, 2007; Safonova et al., 2004a,b; Volkova and Sklyarov, 2007; Volkova et al., 2004, 2008). The suture zone is the strike-slip convergent boundary between the Siberian and Kazakhstan–Baikal continents, with closure of an oceanic basin from east to west. In Late Devonian and Early Carboniferous the continents amalgamated to form the North Asia continent.

4. The heterochronous suits of strike-slip terranes (Fig. 6) are represented by fragments of Early to Middle Paleozoic geodynamic units detached from margins of Siberian and Kazakhstan–Baikal continents. The terranes are separated by Late Paleozoic strike-slip-thrust zones. They often terminate formation of suture zones and/or develop subparallel to ophiolite sutures between colliding continental masses. The most evident are Late Devonian to Early Carboniferous and Late Carboniferous to Permian strike-slip-thrust faults in the present-day mosaic-block structure of Central Asia (Buslov et al., 2000, 2003, 2004). As a result of Late Paleozoic strike-slip movements the Kazakhstan–Baikal composite continent was divided into several strike-slip terranes, with Vendian–Paleozoic structures complicated by thrust faults and folds, including oroclinal (Berzin and Dobretsov, 1993; Berzin et al., 1994; Sengör et al., 1993, 1994). The most intensive Late Carboniferous to Permian strike-slip faults manifested themselves in Eastern Kazakhstan and divided the composite continent into two large collages of strike-slip terranes, the Kazakhstanian and Baikalian (Fig. 1). They are separated by a linear strike-slip structure more than 500 km wide (Fig. 6). The Late Carboniferous to Permian strike-slip-thrust structures in Altai–Sayan Fold Region complicate the Late Devonian and Early Carboniferous Charysh–Terekta–Ulagan–Sayan strike-slip suture zone that culminated the collision between the Kazakhstan–Baikal and Siberian continents (Buslov et al., 2000, 2003, 2004).

Position of the above listed structural elements in the West Siberian Plate is given in view of the published results of drilling and geophysical studies (Egorov and Chistyakov, 2003; Yolkin et al., 2007; Ivanov et al., 2009).

Late Carboniferous–Permian faults: a phase in collision between East European and North Asia continents

According to paleomagnetic data (Didenko et al., 1994; Pecherskii and Didenko, 1995), the East European Craton in

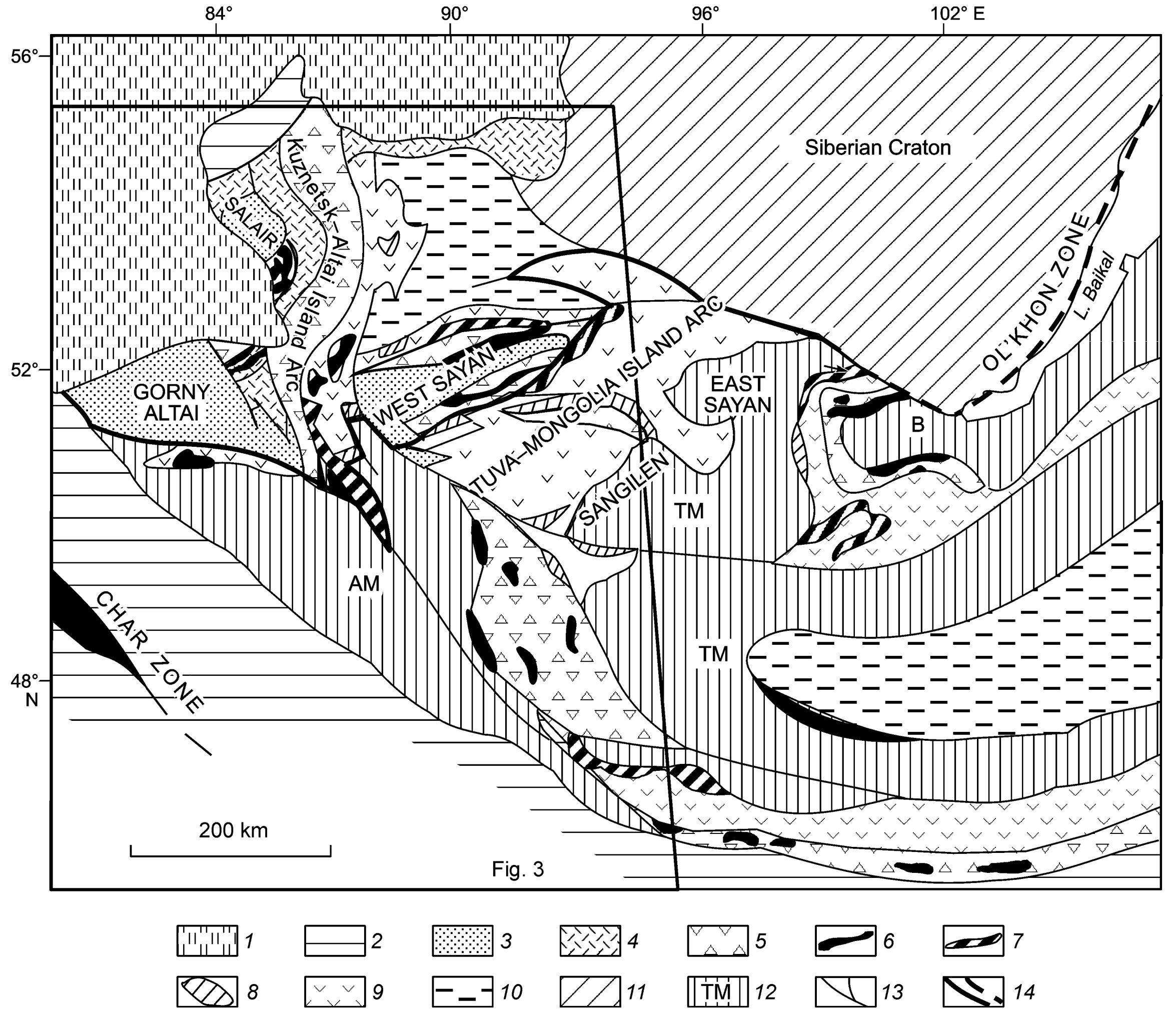

Fig. 2. Tectonic demarcation of Central Asian Foldbelt in the Altai–Sayan folded region, Mongolia, and Cisbaikalia. *1*, Neogene–Quaternary deposits of Biysk–Barnaul Depression; *2*, undifferentiated collage of Late Paleozoic strike-slip terranes of East Kazakhstan dividing the Kazakhstan–Baikal continent into western Kazakhstan and eastern Baikal blocks; *3*, undifferentiated Ordovician–Early Devonian continental passive margin and Devonian active margin formations of Siberia; *5*, Late Vendian to Early Cambrian accretionary wedges; *6*, oceanic ophiolite; *7*, primitive island arc ophiolite; *8*, backarc basin ophiolite; *9*, Vendian–Cambrian island arcs; *10*, undifferentiated Early Mesozoic formations of the Mongolia–Okhotsk suture-shear zone; *11*, Siberian Craton; *12*, Gondwana terranes: Tuva–Mongolia (TM), Barguzin (B), Altai–Mongolia (AM); *13*, undifferentiated Late Paleozoic to Early Mesozoic fault structures; *14*, Middle–Late Paleozoic Charysh–Terekta–Ulagan–Sayan suture-shear zone.

Late Carboniferous to Permian time was located near the equator and rotated counterclockwise, whereas the Siberian Craton was located at midlatitudes and turned clockwise. Located between them was the Kazakhstan–Baikal continent devoid of common thick consolidated basement. The rotation of large continental masses during their collision with the composite continent determined the strike-slip pattern of the Central Asian Foldbelt. The Char strike-slip zone is the main structure separating the western Kazakhstanian and eastern Baikalian collages of terranes (Fig. 2). The dextral Chinghiz–Tarbagatai strike-slip fault is located to the west, and the strike-slip Irtysh–Kurchum, Northeastern, and Kurai faults, the strike-slip faults of the Tunka Goltsy and the Main Sayan Fault are successively located to the east. The Char ophiolite belt is the best studied block of the Char strike-slip zone. The Tarbagatai, Zharma, and Saur terranes to the west of the Char zone formed along the margin of the Kazakhstanian block of the Kazakhstan–Baikal composite terrane. They are represented by fragments of Devonian and Early Carboniferous island arc. The terranes are displaced southward along the sinistral Chinghiz–Tarbagatai strike-slip fault towards the Junggar microcontinent, where an overthrust structure of the West Junggar formed along the margin (Chi et al., 1993; Xiao et al., 1994; Li et al., 1998).

A suite of terranes located northeast of the Char zone were displaced southward along sinistral faults and associated thrust faults relative to their original position in continental margin zones of the Siberia. These are the Kalba–Narym, Rudny Altai, Gorny Altai, Salair, and Tom'–Kolyvan' strike-slip terranes. The Kalba–Narym and Rudny Altai terranes constitute a large northeast-striking belt delineated by the most prominent shear zones of Eastern Kazakhstan, the Irtysh–Kurchum and Northeastern zones of major regional sinistral strike-slip faults.

The following tectonic units of distinct structure, age, and geodynamic affinity can be identified within the Char ophiolite

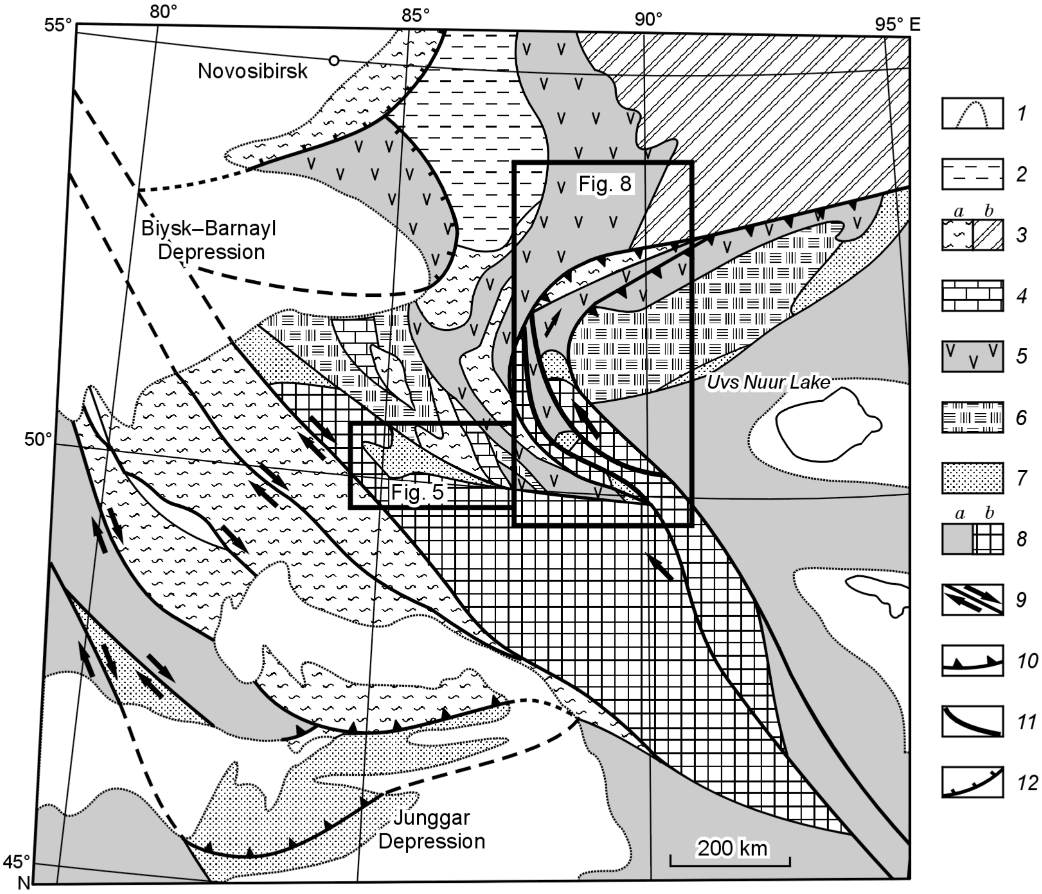

Fig. 3. Schematic structural map of the Middle–Late Paleozoic Charysh–Terekta–Ulagan–Sayan suture-shear zone in Eastern Kazakhstan, Junggar, and Altai–Sayan (Dobretsov and Buslov, 2007; Buslov et al., 2010). *1*, Cenozoic–Quaternary deposits; *2*, Permian–Mesozoic formations of the Kuznetsk Basin; *3*, Early Devonian Siberian active margin (*a*) and backarc (*b*) zones; *4*, Ordovician Siberia passive continental margin formation; *5*, Vendian–Cambrian complexes of the Kuznetsk–Altai island arc; *6*, Late Cambrian forearc turbidites; *7*, Early–Middle Paleozoic ophiolite, turbidites, and blueschists of the Charysh–Terekta–Ulagan–Sayan strike-slip suture zone and its possible analogues in Eastern Kazakhstan and Junggar; *8*, Kazakhstan–Baikal continent (*a*) and Altai–Mongolia terrane (*b*) formations; *9*, Late Carboniferous and Permian strike-slip faults and displacement directions (arrows); *10*, Late Carboniferous and Permian thrust faults; *11*, Late Devonian and Early Carboniferous Kurai and Teletskoe–Bashkaus fault zones; *12*, Mesozoic thrust faults.

belt of the eponymous 80-km thick Char shear zone (Buslov et al., 2003):

1. Type I subduction melange located in the southeastern part of the Char zone consisting of isometric, several meters across blocks of high-pressure metamorphic rocks: garnet amphibolite, eclogite, and blueschists. Geochemical characteristics of the metamorphic rocks suggest that the original protolith was tholeitic and subalkaline basalt of mid-oceanic ridges and oceanic mounds and islands (Dobretsov et al., 1979; Safonova et al., 2004b).

The K–Ar-muscovite dates obtained from eclogite, garnet amphibolite and glaucophane-crossite schists range between 445 and 429 Ma (Early Silurian) and characterize the time of over-pressured rock exhumation (Buslov et al., 2003). The over-pressured minerals phengit and barroisit from the garnet amphibolite have yielded ages of 449.3 ± 1.0 and 450.0 ± 2.7 Ma, respectively, that reflect the onset of exhumation. The age of metamorphism in the subduction zone is thought to be older, possibly Cambrian to Early Ordovician (Dobretsov and Ponomareva, 1969). The coeval over-pressured rocks are known from southwestern part of West Junggar where the tectonic slabs of Tangbale blueschists are associated with ophiolites and dates as Cambrian to Early Ordovician (Chi et al., 1993; Xiao et al., 1994; Li et al., 1998).

The Early Paleozoic over-pressured formations of the Char zone are structurally linked to the blocks and slabs of volcanic and siliceous rocks with Middle Devonian to Early Carboniferous radiolarians and conodonts (Iwata et al., 1994, 1996), as well as Silurian, Lower Devonian, and Givetian carbonates. The volcanic rocks are subalkaline and tholeitic basalt with geochemical characteristics of mid-oceanic ridges and oceanic mounds and islands (Safonova et al., 2004a,b). The Silurian and Devonian carbonate rocks probably formed on oceanic mounds and islands. The age of volcanic, siliceous and carbonate rocks suggests that the Type I melange captured the fragments of older (Cambrian to Early Ordovician) subduction, oceanic islands and ophiolite in the course of exhumation and subsequent strike-slip movements.

2. Type II ophiolite melange consists of different-sized blocks and lenses of oceanic crust, among them massive apoperidotitic serpentinite (harzburgite, lherzolite, dunite, and pyroxenite), gabbro, plagioclase amphibolite, hornblendite,

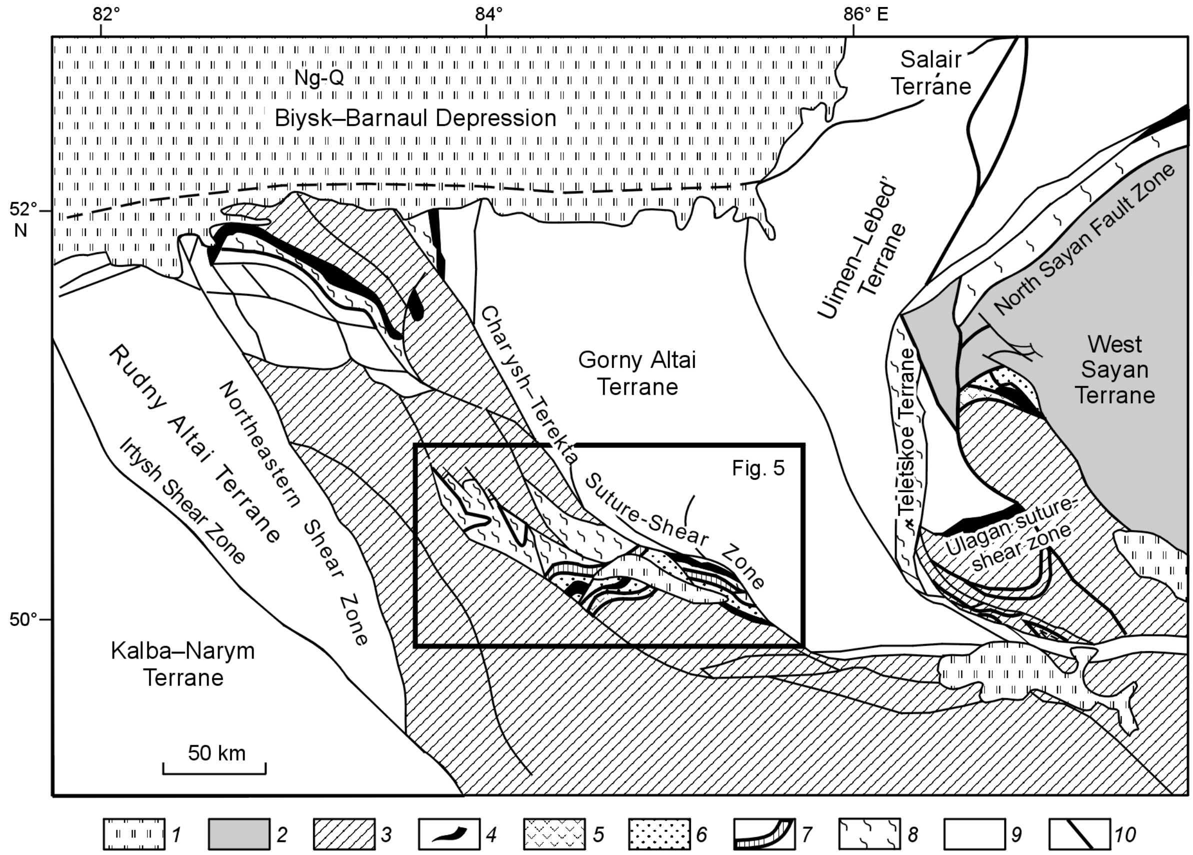

Fig. 4. Schematic geological map of the Charysh–Terekta–Ulagan–Sayan suture-shear zone. *1*, Neogene–Quaternary deposits in the Biysk–Barnaul Depression; *2*, Late Cambrian turbidites of the West Sayan terrane; *3*, Precambrian Altai–Mongolia terrane; *4*, Cambrian to Early Ordovician ophiolite (serpentine schists, gabbro-peridotite, basalt and siliceous rocks); *5*, Early Paleozoic active margin volcanogenic-sedimentary formations (the Sugash Formation and coeval strata); *6*, Ordovician blueschists; *7*, Silurian to Early Devonian granite-gneiss; *8*, Cambrian to Ordovician turbidites; *9*, terranes of Siberian continental margin origin; *10*, Late Paleozoic strike-slip-thrust faults.

amphibol-plagioclase schists, plagiogranitoid, carbonaceous, micaceous, and monomineralic quartzite, aphyric and porphyric basalt lavas interbedded with siliceous siltstones and jasperoid with Middle Devonian and Early Carbonifeous radiolarians (Iwata et al., 1994, 1996), as well as fragments of carbonate-siliceous-terrigenous sections of Early Silurian and Devonian rocks (Ermolov et al., 1981). The lavas are tholeitic and alkaline suggesting their affinity to mid-oceanic ridges and oceanic mounds and islands (Polyanskii et al., 1979; Safonova et al., 2004a,b). A similar ophiolite belt in West Junggar stretches for more than 250 km along the Naila fault and consists of several ophiolitic bodies of Ordovician age: Barlik, Khongulenk, Khebukesair (Chi et al., 1993; Li et al., 1998; Xiao et al., 1994). The carbonate-siliceous-terrigenous rocks could be slope facies of oceanic mounds and islands.

3. Type III Late Carboniferous to Early Permian polymictic melange follows the shear zones and separates tectonic thrust sheets of type I and II melanges thus outlining the Char ophiolite belt. The Late Carboniferous to Early Permian strike-slip faults dominate in the region and separate tectonic lenses and blocks incorporated into the shear zones from continental margins of Siberia and Kazakhstan–Baikal.

The Char ophiolitic belt is surrounded by tectonic slabs of Devonian to Early Carboniferous sedimentary-volcanic rocks representing fragments of island arcs, turbidites, olistostromes, and basaltic-siliceous accretionary prisms detached from continental margins of Kazakhstan–Baikal and Siberia during formation of the Char shear zone (Buslov et al., 2003, 2004).

The structural and compositional complexes of the Char zone have analogues in the West Junggar (Fig. 6), where several Paleozoic island arcs, accretionary prisms and ophiolitic zones were amalgamated in the Late Carboniferous (Briggs et al., 2007; Chi et al., 1993; Li et al., 1998; Xiao et al., 1994, 2009). The ophiolite characterizes fragments of Late Cambrian to Early Ordovician and Silurian to Early Devonian oceanic crust similarly represented by peridotite, gabbroid, lavas, and serpentinite melanges. The geochemical characteristics of basalts suggest their origin within primitive island arcs, mid-oceanic ridges, oceanic mounds and islands. The Late Cambrian to Early Ordovician (489–523 Ma) Tangbale ophiolite is associated with coeval glaucophane-crossite schists.

The correlation between the West Junggar, Tarbagatai, Zharma–Saur, and Char zones shows that they are fragments of a single Paleozoic (Ordovician–Devonian) accretion-colli-

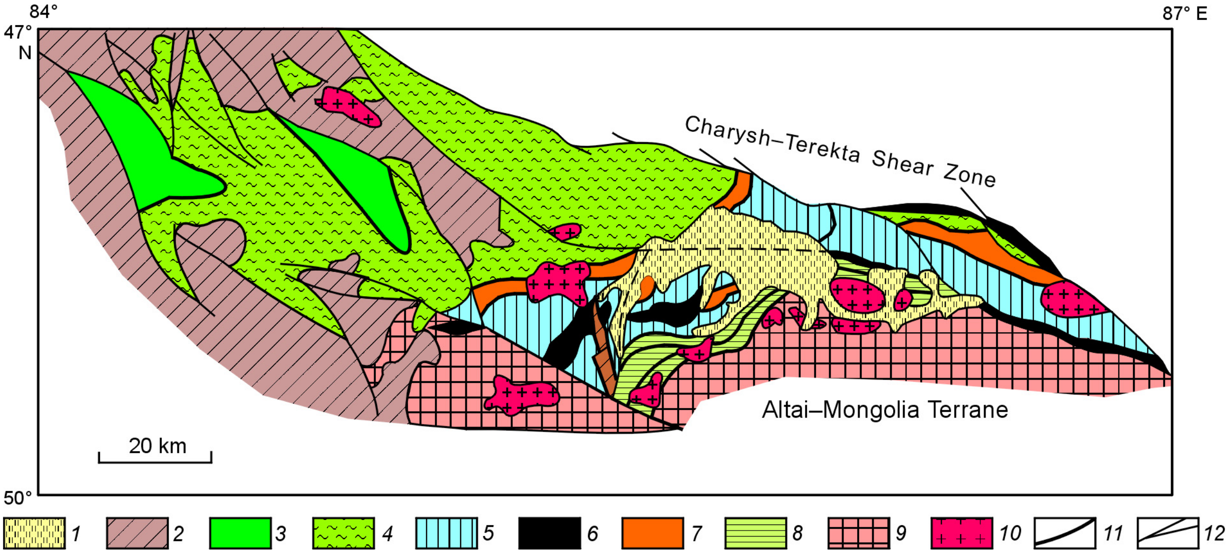

Fig. 5. Schematic geological map of the Charysh–Terekta–Ulagan–Sayan suture-shear zone in the Uimon zone of Gorny Altai. *1*, Neogene–Quaternary deposits of the Uimon Depression; *2*, Early–Middle Devonian sedimentary-volcanogenic rocks; *3*, Cambrian to Ordovician turbidites; *4*, Cambrian to Ordovician turbidites in greenschist facies (the Terekta Formation); *5*, Ordovician blueschists (the Uimon Formation); *6*, Cambrian to Late Ordovician ophiolite (serpentinite schists, gabbro-peridotite, basalt, charts); *7*, Silurian to Early Devonian granite-gneiss; *8*, Early Paleozoic active margin volcanogenic-sedimentary formations (the Sugash Formation); *9*, Precambrian sandstones and schists of the Altai–Mongolia terrane; *10*, Middle Paleozoic granitoids; *11*, Middle–Late Paleozoic thrust faults; *12*, Late Paleozoic strike-slip faults.

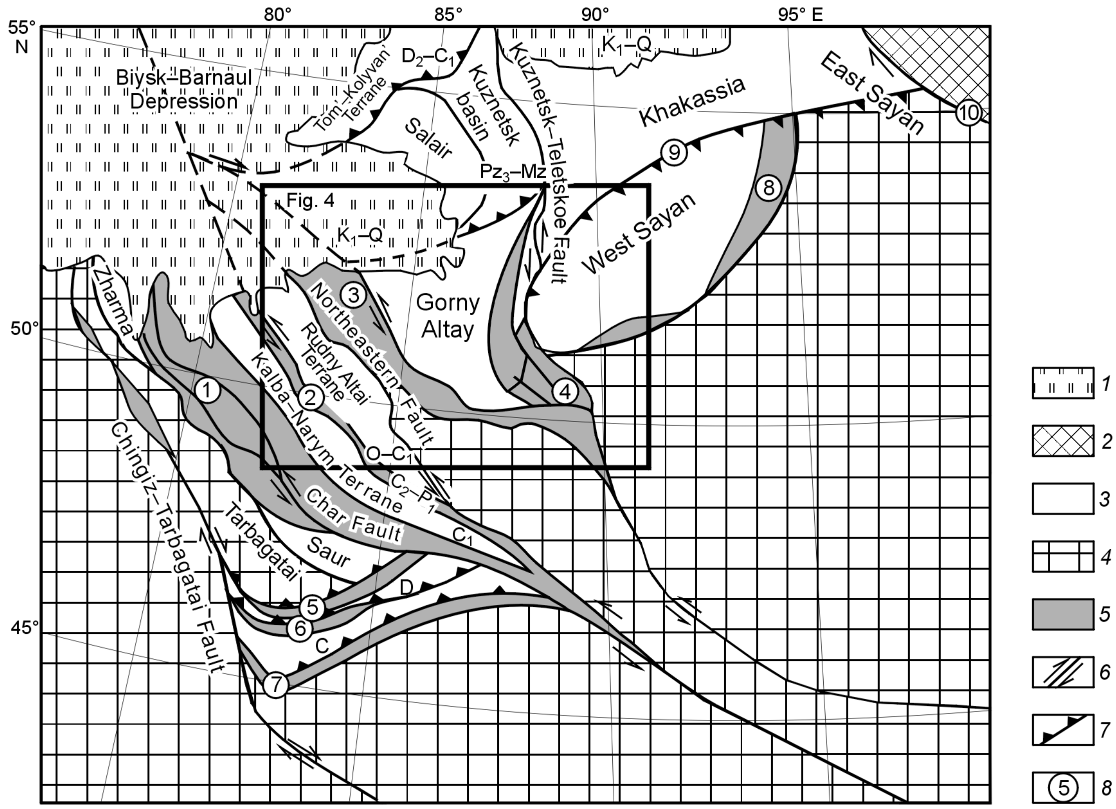

Fig. 6. Schematic terrane structure of the East Kazakhstan and Altai–Sayan regions (Buslov et al., 2003). *1*, Cenozoic–Quaternary deposits; *2*, Siberian Craton; *3*, strike-slip terranes of Siberia; *4*, Kazakhstan–Baikal composite continent; *5*, Middle–Late Paleozoic suture-shear zone reactivated in Late Carboniferous to Early Permian; *6*, strike-slip faults; *7*, thrust faults; *8*, fault zones: Char (1), Irtysh–Kurchum (2), Charysh–Terekta (3), Kurai (4), Barlik–Khongulen–Khebukesair (5), Mailskaya (6), Tangbale (7), Kurtushuba (8), North Sayan thrust fault (9), and Main Sayan Fault (10).

sion complex tectonized in Late Carboniferous to Early Permian time (Briggs et al., 2007; Xiao et al., 1994), as suggested by similarities in age and composition of Char and West Junggar ophiolites. They differ in their present-day structural position. The Char ophiolite and exotic island arcs occur as narrow sheets within the intercontinental strike-slip zone, whereas the West Junggar ophiolite together with thick sheets of island-arc and accretion complexes form a consistent north-pitching Late Paleozoic strike-slip-thrust system (Chi et al., 1993; Li et al., 1998; Xiao et al., 1994). Together the Chinghiz–Tarbagatai (Junggar) dextral fault and the West Junggar imbricates form strike-slip duplexes at the edge of Kazakhstan–Baikal composite continent (Fig. 6).

A suite of terranes of continental margin complexes of Siberia are localized to the east of Char Zone and separated by the Irtysh–Kurchum and Northeastern shear zones.

The Irtysh–Kurchum strike-slip zone (Fig. 6) 80–100 km wide separates the Kalba–Narym and Rudny Altai terranes. The zone consists of several tectonic sheets of different composition separated by serpentinite melange and schists (the Kurchum block) as well as mylonite, blastomylonite and phyllite-like greenschists. The melange-sheeted structure also comprises rocks of the adjacent Kalba–Narym and Rudny Altai terranes and of the pre-Carboniferous metamorphic rocks of the Kurchum block (tectonic sheet) that could be detached from the Altai–Mongolia microcontinent (Buslov et al., 2003, 2004).

The southwestern setting of the Kurchum Ranges, near the Zaisan Depression, is represented by a sheeted structure of strike-slip faults, with numerous evidence of sinistral displacement (Buslov et al., 2004; Melnikov et al., 1997, 1998; Vladimirov et al., 1998; Zinov'ev, 1992). The structure also includes large tectonic sheets of sheared black shales of the Takyr Formation of the Kalba–Narym Terrane separated by sheets of Early Carboniferous island-arc formations (andesite-basalt, andesite, and rhyolite lavas, lava breccia, and tuffs; volcanimictic conglomerate, sandstones, and siltstones). Locally, near the Kurchum Village, the space between the tectonic sheets is filled with serpentinite melange and schists.

The area of Bukhtarma Reservoir, at the Vasiliev Ground, consists of structural metamorphic zones characterized by directional increase in degree of stress-metamorphism of Kalba Granite on drawing near the Irtysh–Kurchum zone (Zinov'ev, 1992). The 3–4-km wide transition zone comprises brecciated granite passing to gneissed granite, with superimposed mineralization by biotite, chlorite, and sericite, to blastomylonite and mylonite of granitic composition. They are associated with biotite schists and gneiss of axial shear zone that have undergone mylonitization near the contact and transformed into dynamo-schists, with boudines of primary rocks, stratiform lenses of gneissed granite, aplite, and pegmatite of the Kalba Complex. The 270–280 My old Kalba Granites have the age of metamorphism peaking at 220–235 and 180 Ma near shear zones (Buslov et al., 2004; Melnikov et al., 1997, 1998; Vladimirov et al., 1998; Zinov'ev, 1992). The Ar–Ar dates on mica, amphibole, and K-feldspar from blastomylonite and gneiss suggest two pulses of sinistral deformation in the Irtysh–Kurchum zone at 283–276 and 273–265 Ma (Travin et al., 2001).

According to geochronological and geological data, the Irtysh–Kurchum shear zone is a Late Carboniferous to Early Permian sinistral fault. After the intrusion of the Kalba Granite, the displacement continued until Late Permian to Early Triassic, and then it was reactivated in Early Jurassic.

The Irtysh–Kurchum shear zone separates the Kalba–Narym and West Kalba terranes of forearc, accretionary prism, and island-arc complexes representing the fragments of a single island-arc Siberian system displaced several hundreds of kilometers along the faults as a result of collision between the Kazakhstan–Baikal and Siberia in Late Carboniferous to Permian (Figs. 1, 6).

The Northeastern strike-slip zone separates the Kazakhstan–Baikal continent, represented by Altai–Mongolia terrane and Charysh–Terekta–Ulagan–Sayan strike-slip suture zone, and the continental margin of Siberia (the Rudny Altai island-arc terrane) (Fig. 6). This shear zone is a few kilometers wide and is characterized by specific structural features (Chikov and Zinov'ev, 1996; Distanov, 1962; Mokhov, 1988; Zinov'ev et al., 2009). It is formed as a result sinistral strike-slip deformations and comprises tectonic blocks within phyllite-like greenschists. The Early Permian age of displacement along the faults is determined by the relationship between phyllite, substrate, and granitoids. Deformation affected Ordovician to Carboniferous sedimentary-volcanogenic rocks, as well as Late Carboniferous granitoids of the Zmeinogorsk complex. The shear deformation zone was accompanied by intrusion of Late Permian to Triassic plutons (Savvushin, Tigerek) (Vladimirov et al., 1997), which provide an upper age limit of the sinistral movements of the Rudny Altai terrane relative to adjacent Gorny Altai structure.

In southwestern part of the Northeastern strike-slip zone in Kazakhstan, within the Kedrovsko-Butakhinskaya Branch, abundant sericite-quartz schists trace the strike-slip-thrust structures and associated sulphide-polymetallic Tishin ore deposits. An ^{40}Ar–^{39}Ar age plateau of the wallrock sericite from tectonic schists suggests two episodes of deformation and metamorphism as 301–294 and 288–279 Ma (Zinov'ev et al., 2009).

The Northeastern and Irtysh–Kurchum strike-slip zones continue southeast as the structure of Chinese Altai Range and Junggar. The Late Carboniferous and Early Permian strike-slip zones include fragments of Ordovician ophiolite (Briggs et al., 2007; Windley et al., 2007; Xiao et al., 2009) (Fig. 6). To the east, the Late Carboniferous to Permian faults complicate the structure of Late Devonian to Early Carboniferous collision between Kazakhstan–Baikal and Siberia (discussed in the next section) and appear to be most vivid in the Eastern Sayan along southwestern setting of Siberia.

Late Carboniferous to Early Permian thrust and strike-slip structures of the Tunka Goltsy (Eastern Sayan) (Fig. 7) have been recently recognized as evidence of large-scale Late Paleozoic deformations over large territory, from East European to Siberia cratons (Buslov et al., 2009).

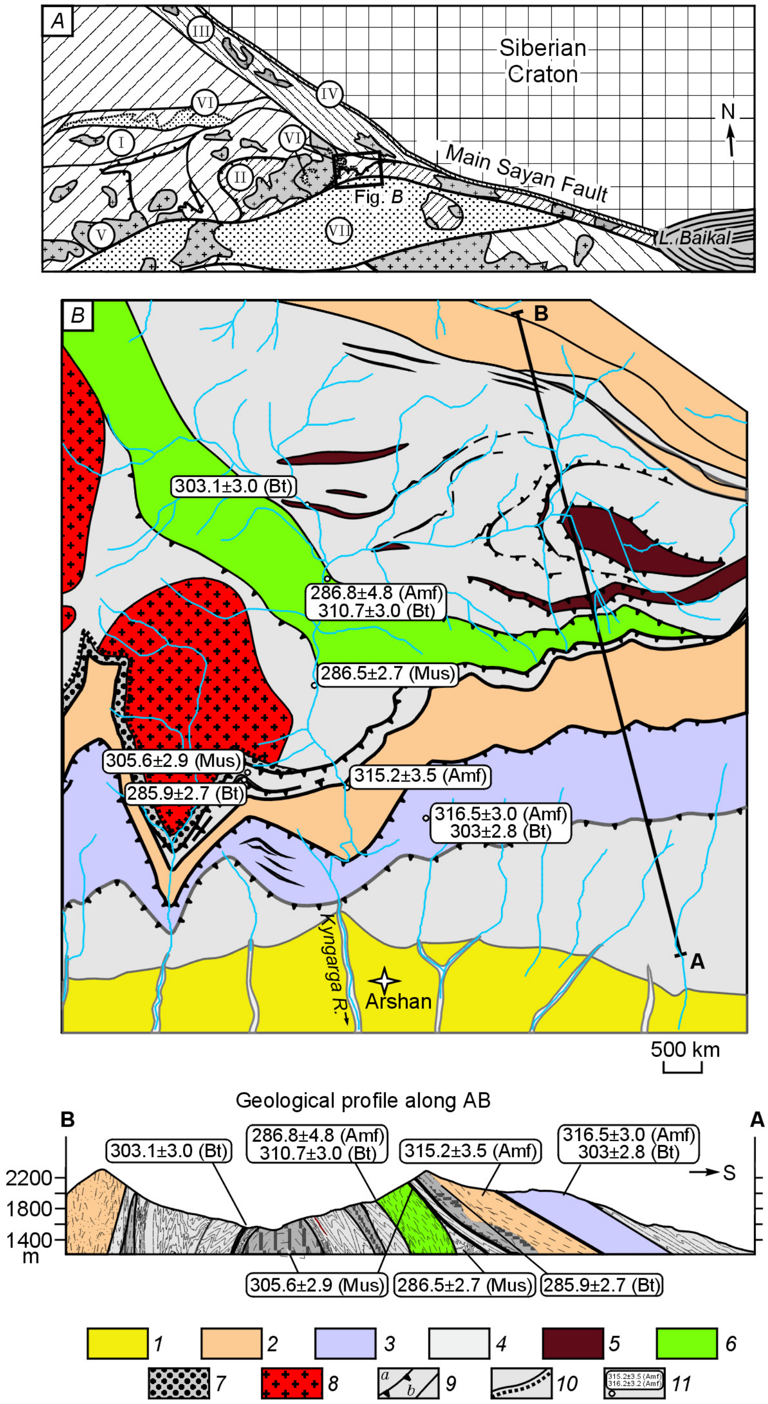

Fig. 7. Geological map of the Arshan segment (*B*) and its position in the structure of southern surrounding of Siberian Craton (*A*) (Buslov et al., 2009). *1*, Cenozoic–Quaternary deposits of the Tunka Depression; *2*, Late Paleozoic plagiogneiss, migmatite, schists and garnet amphibolite; *3*, Late Paleozoic melange zone with diaphtorized plagiogneiss, schists, garnet amphibolite, and mylonitized marble; *4*, mylonitized marble; *5*, garnet-biotite blastomylonite; *6*, Late Paleozoic greenschists; *7*, Late Devonian to Early Carboniferous molasses (the Sagansair Formation); *8*, Late Devonian microcline granite and granosyenite; *9*, Late Paleozoic faults with oblique (*a*) and steep (*b*) fault planes; *10*, stratigraphic contacts; *11*, samples for geochronology, with Ar–Ar dates.

The Late Paleozoic of Eastern Sayan is characterized by a series of Late Carboniferous and Early Permian geological events. Garnet-staurolite-bimicaceous schists in central part of the Tunka Ranges (Bogdo-Khongoldoi River) have the Rb–Sr isochrone age of 312 ± 20 Ma for (Belichenko et al., 1988). Based on geological evidence, metamorphic isogrades cut stratigraphic boundaries and the Ordovician tectonic zones that separate tectonic sheets of different composition. The Ara-Osheya granitoids intruded into the Ordovician thrust and strike-slip structure in the axis of Tunka Ranges have a K–Ar-biotite age of 320–315 Ma (Obruchev, 1964). Meso-scale geological survey in the southeastern part of Tunka Goltsy revealed a system of tectonic sheets consisting of granite-gneiss complexes thrust over Late Devonian to Carboniferous molasses of the Sagansair Formation (Boss, 1991). Furthermore, there is a geochronological evidence suggesting a Late Carboniferous age of deformations along the Main Sayan Fault located in the vicinity and north of the studied area (Savel'eva et al., 2003) (Fig. 7).

The Tunka Goltsy of Eastern Sayan consist of two packages of Late Carboniferous to Early Permian tectonic sheets (Buslov et al., 2009) that constitute an antiform structure, with south- and north-dipping thrust planes and a hinge region plunging 30° W (Fig. 7).

The lower sheet package confined to central and northern parts of the studied region consist of (1) metacarbonate rocks (mylonitized marble, with rare bodies of garnet-biotite schists) representing metamorphic analogues of the Vendian–Cambrian Gorlyk Formation; (2) gneiss, schists, and garnet amphibolite; (3) greenschists representing metamorphic analogues of terrigenous-volcanic-carbonate rocks of the Verkhny Shumak Formation.

The metacarbonate rocks are intruded by Late Devonian microcline granites, and both are covered by the molasses of Sagansair Formation (Boss, 1991). They are bordered by a greenschist tectonic sheet to the north characterized by isoclinal folds. A planar directive structure filled with biotite is formed near fault contacts. Randomly oriented late crystals of hornblende are also observed in the schists. The biotite-amphibolite schists (sample 06-94) have an Ar–Ar-biotite age of 310.7 ± 3.1 Ma and an Ar–Ar-hornblende age of 286.8 ± 4.8 Ma. The metacarbonates (sample 06-92) have an Ar–Ar-muscovite age of 286.5 ± 2.7 Ma (muscovite growing along differential sliding planes).

To the north of the greenschist section, in a core of the antiform, tectonic slabs of metacarbonates and gneiss are observed. The quartz-garnet-biotite schists (sample 06-95) within mylonitized marble have an Ar–Ar-biotite age of 303.1 ± 3.0 Ma. Garnet crystals have snowball-type structure due to entrapment of biotite flakes suggesting mineral growth during thrust-induced metamorphism.

Southern part of the studied region is characterized by a Late Carboniferous to Early Permian nappe structure built of the upper sheet package consisting of (1) gneiss, schists, garnet amphibolite, and their greenschist diaphtorite; and (2) metacarbonates. The tectonic slabs are gently (from 35° to 5°) thrust over different structural elements of the lower sheet package (Fig. 7).

The garnet amphibolite (sample 06-90-1) within gneiss have an Ar–Ar-hornblende age of 316.1 ± 3.2 Ma. The diaphtorized garnet amphibolite (sample 06-90-3) is 315.2 ± 3.5 Myr old, whereas the age of biotite from the schistosity zones superimposed on amphibolite has been determined as 303.0 ± 2.8 Ma.

A melange zone several dozens of meters wide located at the base of the upper tectonic sheet package is characterized by an alternation of biotized plagiogneiss and muscovite-carbonate mylonite. The plagiogneiss (sample 07-37-5) have an Ar–Ar-biotite age of 285.9 ± 2.7 Ma; the metacarbonate schists (sample 07-37-1) have an Ar–Ar-muscovite age of 305.6 ± 2.9 Ma.

The revealed relationships between the tectonic sheets and the age of metamorphic rocks characterize Late Carboniferous to Early Permian collision stages, superimposed on the Ordovician deformation structure (Belichenko et al., 2003; Boss, 1991; Dobretsov, 1985). In the area studied, the Late Palaeozoic faults are mainly concentrated near the Main Sayan Fault zone and the margin of Siberia. The Ordovician structure here is complicated by the Late Palaeozoic deformation and metamorphism processes of the structure.

The new geological and geochronological data suggest that the formation of tectonic nappes and strike-slip faults in the Tunka Goltsy (the southeastern part of the East Sayan) occurred in two stages: Late Carboniferous and Early Permian. In the Late Carboniferous, the Main Sayan Fault reactivation also manifested itself (Savel'eva et al., 2003). Early Permian events also dominate to the south from Siberia craton within the Transbaikalian segment of the Mongolia–Okhotsk Foldbelt represented by the granitoid magmatism in the Transbaikalia (Tsygankov et al., 2007) and Khamar-Daban (Kovalenko et al., 1999), the high-temperature metamorphism in the western Transbaikalia (Donskaya et al., 2008), and the formation of tectonic nappes and olistostrome complexes in the Dzhida zone (Ruzhentsev et al., 2005). These Late Carboniferous and Early Permian events characterize a tectonic episode of a colossal-scale collision between the East European and North Asian cratons (Buslov et al., 2003, 2004; Dobretsov and Buslov, 2007).

Late Devonian–Early Carboniferous faults: collision between Kazakhstan–Baikal and Siberia continents

The collision between Kazakhstan–Baikal and Siberia had great impact on formation of the CAFB structure. In the Altai–Sayan it manifested itself as two separate stages. The collision is marked in formation of the Late Devonian Charysh–Terekta–Ulagan–Sayan strike-slip suture zone and the Late Devonian to Early Carboniferous Kurai and Teletskoe–Bashkaus fault systems (Figs. 8, 9).

The first stage is characterized by closure of the Ob'–Zaisan oceanic basin and the an oblique collision between the Kazakhstan–Baikal composite continent and the Siberian craton. The oceanic basin started to close in Ordovician with formation of the Ol'khon fault zone in the Baikal region (Dobretsov and Buslov, 2007) and finally closed by Late Devonian with formation of the Charysh–Terekta–Ulagan suture-shear zone of the Altai–Sayan (Figs. 2–4). The second stage is characterized by the frontal collision between Kazakhstan–Baikal and Siberia that led to initiation of the system of thrust and strike-slip faults of Late Devonian and Early Carboniferous age. The second stage structure will be discusses by the example of Kurai and Teletskoe–Bashkaus fault system.

The Charysh–Terekta–Ulagan–Sayan suture-shear zone (Fig. 8) has west-northwestern trend and is divided by a system of transverse faults into a series of segments. The zone comprises fragments of Cambrian to Early Ordovician oceanic crust, Cambrian–Ordovician turbidites, Ordovician blueschists,

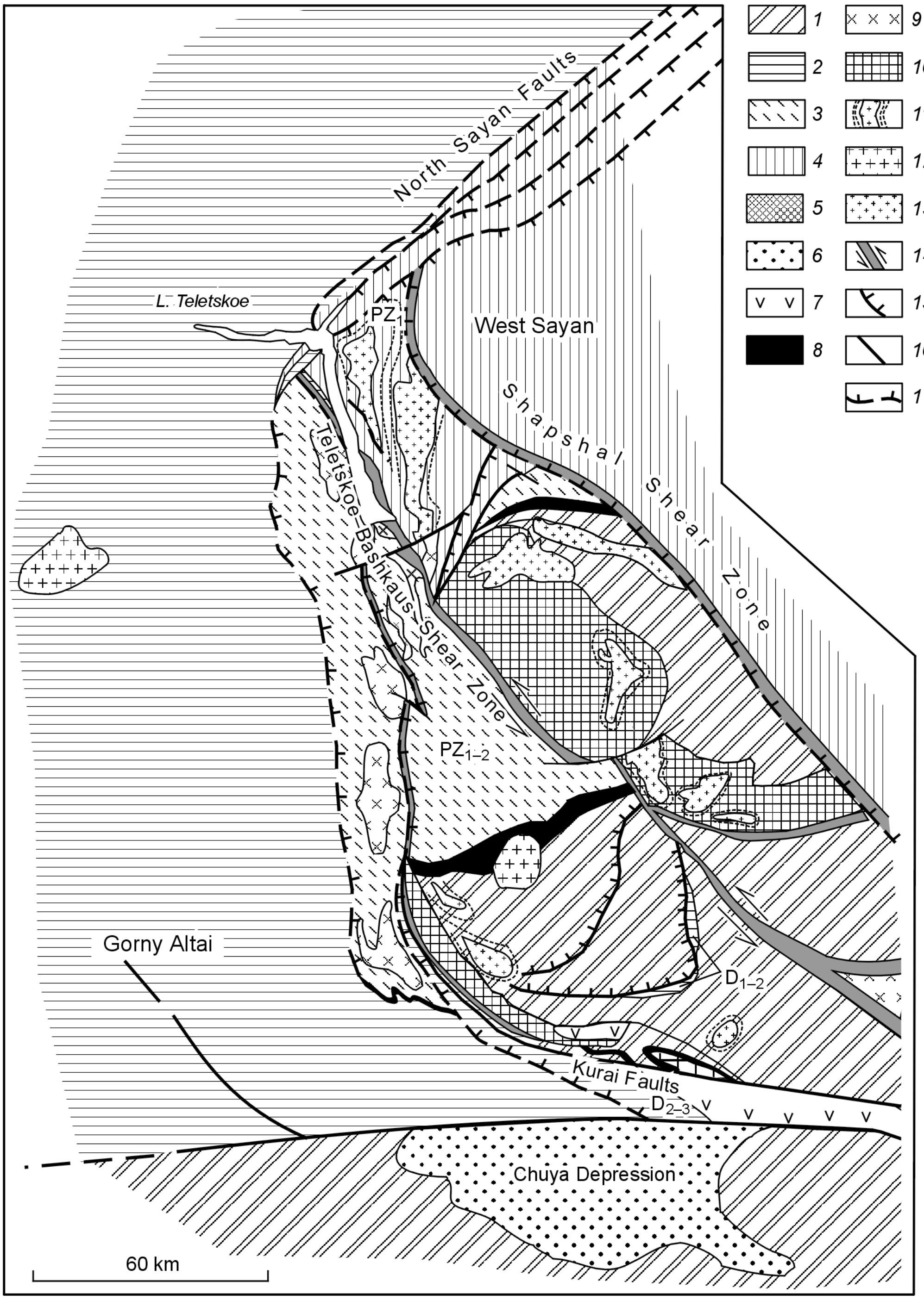

Fig. 8. Structural map of the eastern part of Gorny Altai (Buslov et al., 2003). *1*, Gondwana-type Altai-Mongolia terrane; *2–4*, tectonic units in the surrounding setting of Siberian Craton: *2*, Gorny Altai, *3*, Teletskoe, *4*, West Sayan; *5*, Permian continental molasses; *6*, Early–Middle Jurassic continental molasses; *7*, Devonian volcanogenic-sedimentary rocks; *8*, Ulagan segment of the Charysh–Terekta–Ulagan–Sayan suture-shear zone; *9*, Middle Paleozoic granitoids; *10*, Late Silurian to Middle Devonian zonal metamorphic complexes; *11*, Early Paleozoic granite-gneiss complex; *12*, Early Triassic granites; *13*, Late Devonian to Early Carboniferous granites; *14*, Late Devonian to Early Carboniferous strike-slip faults; *15*, Late Devonian to Early Carboniferous thrust faults; *16*, Charysh–Terekta Fault; *17*, Late Carboniferous to Permian thrust faults.

and over-pressured Middle Paleozoic rocks of shear zone (Buslov et al., 2003; Volkova and Sklyarov, 2007; Volkova et al., 2004). To the north the thrust sheet structure is bordered by continental margin formations of Siberia; to the south there is Altai–Mongolia terrane of Kazakhstan–Baikal composite continent. In the northwestern part of Gorny Altai the strike-slip suture reaches 120–130 km in width and comprises deformed structural units representing fragments of Siberia, Kazakhstan–Baikal, and Late Cambrian to Early Ordovician oceanic crust (Buslov et al., 2003, 2004).

The Late Devonian (post-Emsian) thrust sheet structure of the dextral Charysh–Terekta strike-slip fault is intruded by

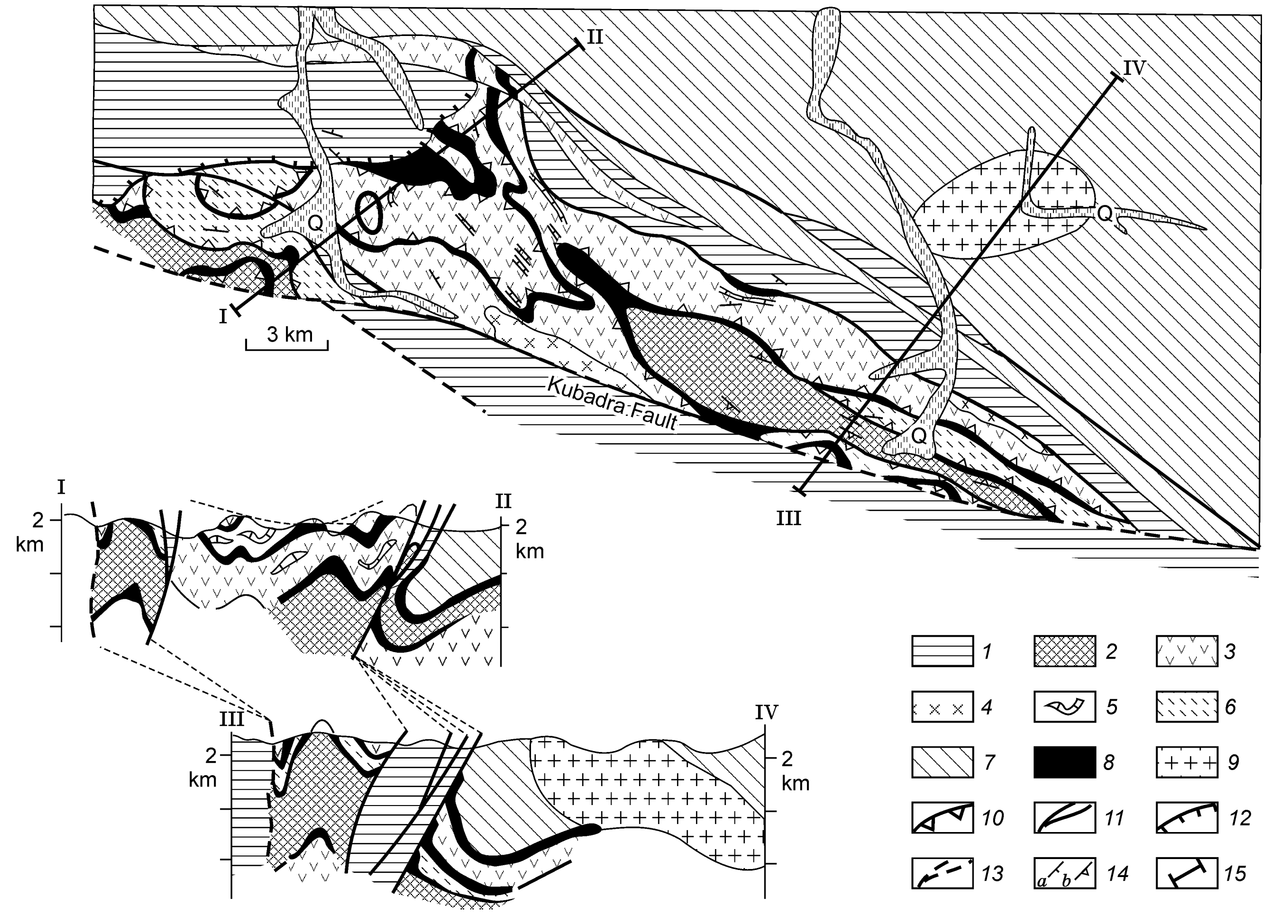

Fig. 9. Schematic geological architecture of the Verkhnii Il'dugem structure of the Kurai strike-slip-thrust zone. *1*, Devonian (D_1–D_3fm) volcanogenic-sedimentary rocks; *2*, Late Silurian to Middle Devonian Kurai granite-gneiss metamorphic complex; *3*, Vendian–Cambrian volcanogenic-sedimentary rocks of the Kuznersk–Altai Island Arc in Gorny Altai Terrane; *4*, Late Carboniferous gabbro-diorite; *5*, Vendian carbonates; *6*, Vendian black shales; *7*, Precambrian sandstones and schists in Altai–Mongolia Terrane; *8*, serpentinized melange and schists with blocks of gabbro-diabase and basalt; *9*, Late Devonian to Early Carboniferous granites; *10*, Middle to Late Devonian thrust faults; *11*, Early Carboniferous strike-slip faults; *12*, Early Carboniferous (?) thrust faults; *13*, Permian to Triassic strike-slip faults; *14*, strike and dip of bedding (*a*) and schistosity (*b*); *15*, location of geological profile.

Late Devonian to Early Carboniferous granitoids of the Talitsa pluton, and both are complicated by sinistral Late Carboniferous to Early Permian strike-slip faults of the Northeastern and Baschelak shear zones (Buslov et al., 2003; Vladimirov et al., 1997). Late Permian to Early Triassic igneous formations intruded the shear zones and associated terranes. The Triassic–Jurassic terrane structure was slightly reactivated by strike-slip faults that locally disturbed the Late Permian to Early Triassic plutons and intrusions.

The strike-slip suture structure of the Uimon zone of Gorny Altai (Fig. 5) comprises the following structural compositional units (from northwest down to southeast):

1. Middle Paleozoic sandstone-schist section unconformably overlaid by Early–Middle Devonian volcanogenic-sedimentary rocks of the Korgon Zone. The shales have yielded Middle Paleozoic pollen. It borders with the Terekta Formation through a 100–200-m wide mylonitized greenschist zone.

2. Middle Paleozoic (?) metavolcanogenic-carbonate-terrigenous Terekta Formation comprises epidote-quartz-albite-chlorite and chlorite-albite-carbonate rocks with intercalations, lenses, and packages of quartzite-schists, marble, and metabasalt.

3. Granite-gneiss and schists mostly transformed to greenschists. The lowest degree of the greenschist diaphtoresis is found in the easternmost part the tectonic slab which is known as the Turgundin metamorphic complex. The biotite-amphibole schists have an Ar–Ar-amphibole ages of 415 ± 3, 418 ± 3, and 418 ± 2 Ma (Early Silurian).

4. Different tectonic slabs of the glaucophane-greenschist Uimon Formation are characterized by ages of metamorphism ranging between 490–485 (Ar–Ar dating) and 455–400 Ma (Ar–Ar and K–Ar dating) and partly comprise the same suite of rocks as the Terekta Formation (Buslov et al,. 2003; Volkova and Sklyarov, 2007; Volkolva et al., 2004, 2005). The main difference lies in the higher content (40–60%) of metavolcanic schists, absence of carbonate (marly) schists, and presence of glaucophane, crossite, and winchit. Typical glaucophane schists occur within metabasalt (lavas and tuffs) associated with quartz schists containing piemontite, rarely riebeckite. Retrogression of the rocks has given rise to porphyroblastic albite-chlorite (phengit, quartz) schists.

5. Devonian sediments, with cleavage and shearing. In the northern part of the sheet, where the cleavage is less pronounced, fragments are preserved of a stratigraphic section comparable to that of the Eifelian Kholzun Formation of the Korgon zone.

6. Cambrian–Ordovician ophiolite represented predominantly by siliceous-volcanogenic-sedimentary rocks and ultrabasics. Almost everywhere the ultrabasic rocks are transformed into serpentinite schists, with oval bodies of massive serpentinite, occasionally serpentinized dunite, pyroxenite, gabbro, and rhodingite.

7. Early–Middle Ordovician sedimentary-tuffaceous rocks, as well as Late Cambrian to Early Ordovician siliceous (lower member of the Sugash Formation) and Early Paleozoic volcanogenic (upper member of the Sugash Formation). The sedimentary-tuffaceous section comprises often rhythmically alternating tuffaceous sandstones, siltstones, and mudstones, and gray, green and red siliceous and argillaceous rocks. The siliceous section is represented by red-colored rocks with deformed radiolarians and is analogous to the Late Cambrian to Early Ordovician Zasura Formation of northeastern Gorny Altai. The volcanogenic (andesite-basalt) section comprises interstratified diabase pyroxene-plagioclase porphyrite, variolite lavas, their tuffs, tuffites, diabase dikes and sills, diabase-porphyrite, gabbro-diabase, felsite, occasionally sandstones (mostly graywackes) and aleurolitic schists. The age of the volcanogenic section is unknown, but it supposedly could be a fragment of an Ordovician–Silurian island arc system formed within a single subduction zone together with coeval blueschists. It formed an active margin of the Kazakhstan–Baikal continent and broke up into fragments that in the Chinese Altai Ranges are well dated by paleontological and geochronological methods (Windley et al., 2002).

The entire Charysh–Terekta–Ulagan–Sayan fault zone represents a Late Devonian deformation suture affected by Late Devonian and Early Carboniferous strike-slip movements. The greenschist diaphtoresis along tectonic contacts and secondary schistosity give appearance of gradual transitions between the structural units. The diaphtorites are penetrated by gabbro-diabase dykes with K–Ar-amphibole ages of 373 ± 17 Ma thereby providing the upper age constraint for formation of the tectonic thrust sheet structure. The lower age limit is recorded by the presence of Eifelian Kholzun Formation in the structure.

The Kurai thrust and strike-slip zone is located in southeastern setting of the Altai–Mongolia terrane separating it from the Gorny Altai terrane (Figs. 8, 9). It consists of tectonic sheets, imbricate structures, mylonites and melange zones (Buslov et al., 2003, 2004). The Kurai zone is most pronounced in the axial part of the Kurai Range where it consists of two structural elements: the main body (the Kurai metamorphic complex) bordered by Late Devonian to Early Carboniferous strike-slip faults, and the imbricate structure formed by Early Carboniferous strike-slip faults and Permian–Triassic oblique thrusts. The structure includes Early–Middle Devonian metamorphic rocks of the Kurai complex, Devonian and Vendian to Early Cambrian volcanogenic-sedimentary rocks. The fault planes are marked by linear schist bodies of serpentinite and by monomictic to polymictic melange. The bodies are usually several tens of meters thick. Serpentinite has been metamorphosed to talk-quartz-carbonate rocks and listvenite.

The thrust sheet structure is dominated by the Early Devonian Kurai zonal metamorphic complex, which is in the epidote-amphibolite facies. K–Ar- and Ar–Ar-amphibole and -mica ages are within the 374–394 Ma interval (Early Devonian to Frasnian) (Buslov et al., 2003). The thrust sheet is several kilometers thick, 70 km long and 10 km wide. The complex is composed of granite-gneiss, migmatite, gneiss and schist of different composition, amphibolite, and pegmatite.

The Kurai thrust and strike-slip zone is preserved in the Verkhnii Il'dugem structure (Fig. 9) located in upper reaches of left tributaries of the Bashkaus River draining the axial part of the Kurai Range: the Verkhnii Il'dugem, Bol'shoi Salzhek, Uzunyuk, and Malaya Kokorya Rivers. The structure is the end southeastern member of the Kurai metamorphic complex and wedges out in southeastern direction along Late Paleozoic faults. The wedge-shaped block has maximum width of 10 km, its length exceeding 35 km.

The block is characterized by a relatively simple structure. It consists of five sheets up to 1.5–2 km wide deformed into large-scale northwest-striking brachiform folds. Each sheet comprises Vendian to Lower Cambrian volcanogenic-sedimentary, igneous, as well as deeply metamorphosed rocks. The internal structure of sheets in general is conformal to bounding thrust faults. The faults are traced by serpentinite melange and schists reaching 250 m in width. Folded thrust fault planes demonstrate various dip angles, down to recumbent.

Deeply metamorphosed rocks in the apparent basement of Verkhnii Il'dugem thrust sheet structure constitute an ellipsoidal body with maximum width 3 m and length 20 km. They comprise gneiss, schists, quartzite, and amphibolite. We studied the structure of southeastern termination of the metamorphic section representing an antiform fold cut by the Kubadra Fault from the south. The metamorphic rocks near the fault were affected by schistosity and diaphtoresis, with formation of numerous narrow greenschist zones parallel to the main fault. Almost everywhere the metamorphic rocks are delineated by bodies of serpentinized schists and melange forming a large antiform fold. They are overthrusted by a thick sheet of Vendian and Early Cambrian carbonate-terrigenous rocks, penetrated by gabbro-diorite-plagiogranite massifs and dykes. In northwestern part of the wedge the thrust sheet structure is complemented by additional sheets separated by serpentinite. The sheets consist of effusive-tuffaceous rocks of the Kuznetsk–Altai island arc.

The Kurai thrusts has Late Devonian to Early Carboniferous age because it contains Devonian formations disrupted by Early Carboniferous strike-slip faults.

The Early Carboniferous shear zones are most prominent in the southern and northern settings of the Kurai thrust zone, where a series of tectonic thrust sheets marked with mylonitized and cataclastic rocks of the Kurai metamorphic complex and Vendian to Middle Cambrian volcanogenic-sedimentary rocks separated by serpentinite melange. The Kurai complex is extensively mylonitized and blastomylonitized and associated with linear zones of biotite schists. K–Ar and Ar–Ar-biotite dates fall in the narrow range between 333 and 323 Ma (Early Carboniferous) (Buslov et al., 2003). Biotite lineation of the metamorphic rocks suggests dextral displacement along the Early Carboniferous shear zones.

The Kurai thrust and strike-slip zone is complicated by Permian to Triassic Kubadra Fault and other faults of northwestern strike and steep southeastern dip, with brecciated, quartzous, chlotitized mylonites along the shear surfaces. Subparallel to these faults both within the Kurai Ridge and in autochthon, there are zones, 5–10 m wide, consisting of epidote-chlorite, muscovite-quartz-chlorite, and quartz-chlorite-talk rocks with pronounced slickensides and slickenlines suggesting thrust-fault kinematics. They characterize a Mesozoic to Cenozoic reactivation of Late Paleozoic fault zones.

To summarize, numerous deformation phases manifested themselves in the thrust sheet Kurai zone. The Late Devonian to Early Cambrian phase of frontal collision between the Kazakhstan–Baikal and Siberia is represented by the thrust structure consisting of large sheets of Devonian crystalline rocks and gneiss of the Kurai complex, serpentinized schists and melange, Devonian volcanogenic-sedimentary rocks, as well as the Vendian to Early Paleozoic volcanogenic-sedimentary formations of the Gorny Altai terrane (Kuznetsk–Altai island arc) which are regarded as the Kurai autochthon overthrusted by Precambrian rocks of the Altai–Mongolia terrane of the Kazakhstan–Baikal composite continent. The Early Carboniferous sinistral faults of the Kurai zone are coeval in age, kinematics, and structural position with faults in the eastern part of Gorny Altai, of which the most obvious and best studied is the Teletskoe–Bashkaus strike-slip fault.

The Teletskoe–Bashkaus strike-slip fault zone is located in the eastern part of Gorny Altai Ranges (Fig. 8, 10) and comprises the Gorny Altai, Teletskoe, and West Sayan terranes, separated by the regional tectonic sutures of Late Carboniferous to Permian Sayan and Early Carboniferous Teletskoe–Bashkaus and Shapshal faults (Buslov and Sintubin, 1995; Smirnova et al., 2002). The Teletskoe–Bashkaus fault is Early Carboniferous because it contains sheets of Middle Devonian rocks and divides the Middle Paleozoic Ulagan thrust sheet structure into two segments, with sinistral displacement of fragments of ophiolite suture and Ordovician basin measuring almost 80 km. This is confirmed by K–Ar and Ar–Ar-mica and Ar–Ar-amphibole ages of 342–309 Ma for the metamorphic rocks of Teletskoe–Bashkaus shear zone (Buslov et al., 2003).

Structural metamorphic study of the Teletskoe–Bashkaus shear zone (Buslov and Sintubin, 1995; Smirnova et al., 2002) has identified two stages in the tectonic-metamorphic evolution: (1) Early–Middle Devonian stage, the formation of petrographic structure of the Chiri Segment representing a fragment of zonal metamorphic complexes in the eastern part of Gorny Altai; and (2) Early Carboniferous, sinistral deformations along the greenschist zone of Teletskoe–Bashkaus faults.

Three large-scale tectonic units, the Gorny Altai, West Sayan and Teletskoe separated by shear zones are recognized in the northern part of Teletskoe–Bashkaus zone near the Teletskoe Lake (Buslov and Sintubin, 1992; Smirnova et al., 2002) (Fig. 10). *The Gorny Altai tectonic unit* is located to the north of sublatitudinal part of the lake and represented by Vendian to Early Cambrian ophiolite and siliceous-terrigenous rocks, Late Riphean lavas and sedimentary rocks, and Early–Middle Cambrian effusive-tuffaceous, terrigenous, and carbonate rocks. *The Teletskoe tectonic unit* is located on the western bank of the Teletskoe Lake is comprises the Late Silurian Altyntaus Massif of bimicaceous granitoids and Early Paleozoic greenschists. *The West Sayan tectonic unit* crops out along the eastern bank of the lake and consists of metamorphosed Cambrian to Early Ordovician tuffaceous-terrigenous rocks (metaturbidites) and Middle Paleozoic zonal granite-gneiss complex. The metaturbidites (Kokshi Group) is represented by quartz-micaceous, quartz-plagioclase-micaceous, chlorite, and biotite schists, often with metadiabase and rhyolite dykes and massifs. The metamorphic zonation of granite-gneiss complex is manifested as gradual transition from cordierite rocks to sillimanite, biotite, and chlorite zones of metamorphism (Lepezin, 1978).

The tectonic units are delineated by the regional tectonic sutures of North Sayan, Teletskoe–Bashkaus, Shapshal, and other faults (Figs. 8, 10). The Teletskoe–Bashkaus shear zone formed as a result of sinistral strike-slip displacements separates the Teletskoe and West Sayan units. The schistosity strikes northwest–north-northwest and deeps subvertically (~70°–80°). The shear zone on the western bank of the Teletskoe Lake incorporated Late Silurian Altyntaus Granitoid Massif (southwestern part) and Early–Middle Devonian tuffaceous-terrigenous rocks (northeastern part). Granitoid blocks in the southwestern part are well expressed in relief as elevated areas surrounded by mylonites and blastomylonites of granitoid composition. The northeastern part of the shear zone consists of greenschists with narrow mylonite zones and lenses of primary rocks. From northeast the shear zone is delineated by young tectonic breccia traced along the boundary between the greenschists and metaturbidites delineates. The breccia contains fragments of granite, granodiorite, mylonite, greenschists, and weakly altered Devonian rocks and turbidites.

Granite-gneiss complex and metaturbidites of the West Sayan tectonic unit on eastern and southern banks are separated from the Altyntaus Granitoid Massif by the Teletskoe–Bashkaus shear zone represented by biotite-quartz schists, locally with migmatite gneiss and granites of the Chiri segment, the amphibolite, biotite-amphibole and granat-cordierite-biotite schists and gneiss from the contact zone of granite-gneiss complex (Buslov and Sintubin, 1995), along with narrow (few centimeters) zones of actinolite-biotite-chlorite quartzouse schists.

Microstructural analysis of oriented samples from the Chiri segment suggests several deformation phases (Smirnova et al., 2002):

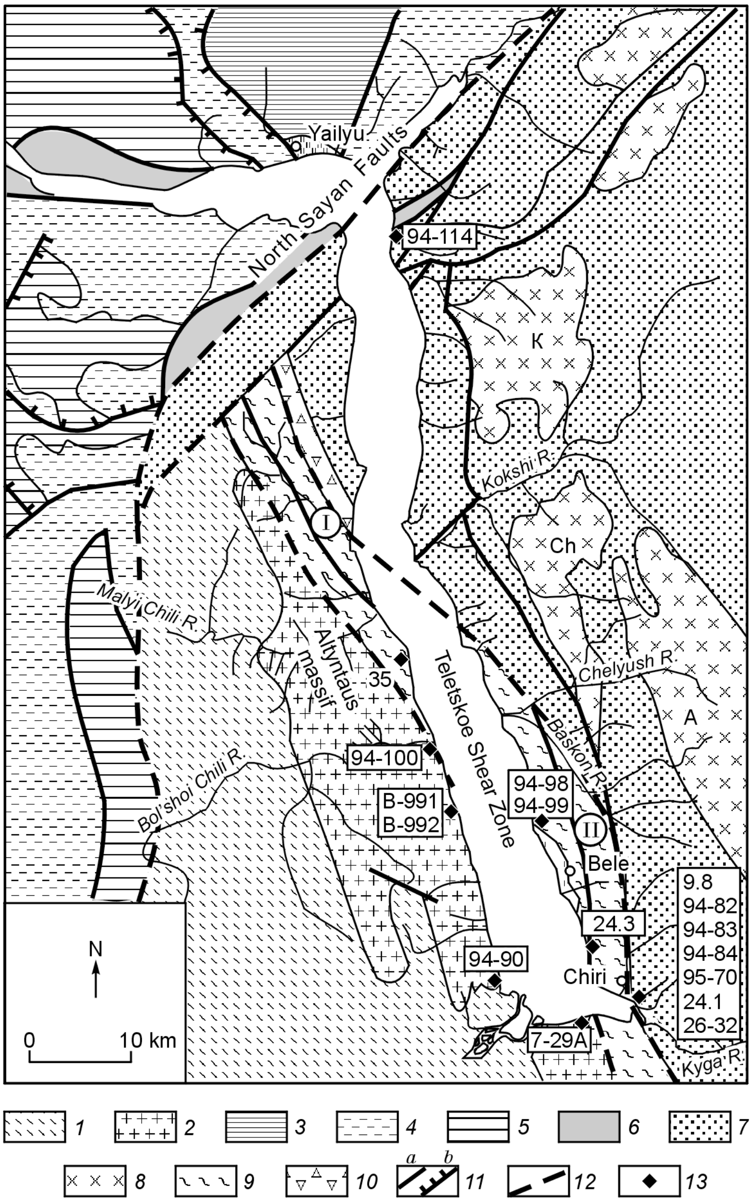

Fig. 10. Schematic geological map of the Teletskoe zone (Smirnova et al., 2002). *1–2*, Teletskoe tectonic unit: *1*, Late Precambrian greenschists, *2*, Late Silurian Altyntaus granitoids; *3–6*, Gorny Altai tectonic unit: *3*, Vendian–Cambrian ophiolite, *4*, Early–Middle Cambrian volcanogenic-sedimentary rocks, *5*, Ordovician–Silurian sedimentary rocks, *6*, Middle Devonian volcanogenic-sedimentary rocks; *7–8*, West Sayan tectonic unit: *7*, Late Cambrian to Early Ordovician turbidites, *8*, Middle Paleozoic granite-gneiss complex: Kokshi (K), Chelyushin (Ch), Abakan (A); *9*, Teletskoe shear zone: Teletskoe (I) and Chiri (II) segments; *10*, tectonic breccia; *11*, strike-slip (*a*) and thrust (*b*) faults; *12*, tectonic unit boundaries; *13*, samples for geochronology, with K–Ar and Ar–Ar dates.

D0–1—granitoid intrusion into the sedimentary succession, with relict bedding represented by an internal structure (S_i) of cordierite porphyroblasts. The originated oblique crystallization schistosity S_1 mostly coincides with the bedding, although locally it corresponds to axial planes of recumbent folds with an acute angle with S_0. Earlier folding is preserved in a form of hinge relicts, whereas the schistosity S_1 (axial plane cleavage) is probably defined by first type biotite from Chiri gneiss (porphyroblasts). The metamorphic segregation could also a result from D1 phase. The northern and central domains were represented by near-surface sections with weakly developed schistosity and abundant sedimentary structure.

D2—in the course of northwestern–southeastern compression of deep metamorphosed sheared rocks of the Chiri segment the continued deformation leads to formation of a duplex structure, with sinistral strike-slip movements along north-northwest-striking planes accompanied by thrust movements in ESE direction and generation of folds and submeridianally oriented coeval schistosity S_2 (axial plane cleavage). A sinistral Teletskoe shear zone is formed simultaneously along the boundary with the Altyntaus Massif. Weakly metamorphosed Teletskoe segment constitute a gently thrust structure with anticlinal folded zone generated in the frontal part.

Geochronological study of the Teletskoe–Bashkaus shear zone was carried out using K–Ar and Ar–Ar methods on basic rock-forming minerals (biotite, muscovite, amphibole) in laboratories of Okayama University (Japan) and Institute of Geology and Mineralogy SB RAS (Novosibirsk) (Buslov and Sintubin, 1995; Smirnova et al., 2002). The study was focused on samples from the Teletskoe–Bashkaus shear zone and Chiri Group. Several mineral associations characterizing heterochronous geological processes were identified based in outcrops and thin-sections and from microprobe analysis of minerals. K–Ar and Ar–Ar dates suggest two phases, the Early–Middle Devonian and Late Devonian to Early Carboniferous (Buslov and Sintubin, 1995; Smirnova et al., 2002).

The youngest deformation is preserved in relict rocks and minerals of the Chiri Group representing weakly altered fragments of the Altyntaus Granitoid Massif, with an amphibole (hornblende) date of 375 ± 5 Ma (sample 26-32) and muscovite dates of 370 ± 6, 378 ± 3.5, and 373 ± 5.7 Ma (samples B-991 and B-992). The amphibole and muscovite appear to be large deformed crystals not engaged in the formation of the oriented petrographic structure of the Chiri Group. A muscovite date of 367.7 ± 3.4 Ma (sample 94-98) and a biotite date of 365.7 ± 2 Ma (sample 35) from the shear zone correspond to the same event (Fig. 10).

The Late Devonian to Early Carboniferous phase is characterized by development of the Teletskoe–Bashkaus shear zone, folding, and thrust faulting accompanied by regional schistosity S_2. The cordierite-biotite and biotite-amphibole schists of the Chiri Group have yielded dates of 328.5 ± 1.7, 332.4 ± 2.3, and 344.4 ± 1.4 Ma (samples 95-70, 24.1, and 9.8). The samples are characterized by lepidoblastic biotite clearly oriented defining the rock schistosity. Geochronological study of the Teletskoe–Bashkaus shear zone corroborated the Late Devonian to Early Carboniferous phase of shear deformations.

Geodynamic nature of strike-slip terranes and their paleomagnetic characteristics: amplitude of horizontal displacement along the strike-slip faults

New paleomagnetic data on strike-slip terranes comprising continental margin formations of Siberia and Kazakhstan–Baikal together with geological and geochronological data allow an estimate to be made of the amplitude of horizontal displacement along the faults of East Kazakhstan and Altai–Sayan regions (Buslov et al., 2003, 2004).

The Gorny Altai Terrane (Fig. 6) is represented by a complex aggregate of geodynamic units formed at the margin of Siberia. The identified Late Vendian and Cambrian island arc formations are overlaid by Ordovician to Early Devonian terrigenous-carbonate passive margin shelf deposits (Yolkin et al., 1994). In Emsian to Early Givetian the geodynamic regime changed to active margin. Late Devonian and Early Carboniferous in the terrane is represented by dark-colored fine-grained shallow-water deposits (Cheremshan Formation and coeval strata) suggesting a rift setting related to strike-slip deformations along the Siberian margin. The riftogenesis is associated with intrusion of gabbro-diabase dykes and sills forming wide continuous belts in central part of Gorny Altai (Yolkin et al., 1994), as well as with intrusion of granitoid massifs (Vladimirov et al., 1997).

The Kalba–Narym Terrane is located between Char and Kurchun–Irtysh shear zones and comprises Late Vendian to Early Carboniferous sedimentary rocks of the Takyr Formation penetrated by Early Permian intrusions of the Kalba complex, which also seal the western margin of the terrane.

The Takyr Formation comprises black shales and siltstones with thin intercalations of fine-grained oligomictic sandstones, which gradually become abundant in the upper part of the 1500-m-thick section. The sediments were deposited as turbidity flows. There are disparate views on geodymanic affinities of the formation. According to Rotarash and Gredyushko (1974), the deep-water Takyr Formation formed in an abyssal trough on oceanic-type crust. Together with the Irtysh shear zone and the adjacent chaotic olistostrome to the southwest, the Takyr Formation is interpreted as a subduction complex. In our opinion, the Takyr Formation represents a passive margin and has analogues in the Tom'–Kolyvan' zone and Salair.

The Rudny Altai terrane is represented by a thick section of Devonian–Carboniferous deposits. In our view, the Emsian and Early Givetian terrigenous rocks and reefogenic limestones were deposited in a forearc trough and include tuffs, polymictic sandstones, and conglomerates. Fragments include red, purple, gray, black, green siliceous rocks, polymictic volcanics, granitoids unknown in earlier Devonian part of the Rudny Altai section and representing unroofing of an Early Devonian volcanic arc and its basement, possibly in the present-day Salair structure. The Emsian fauna and facies composition of the Rudny Altai Terrane have affinities with Salair (Yolkin et al., 1994). Late Givetian and Late Devonian volcanic and plutonic island arc complexes in Rudny Altai were coeval with backarc basins in Salair and Gorny Altai (Yolkin et al., 1994). The formation of Rudny Altai, Kalba–Narym, and West Kalba terranes are fragments of a single Salair–Altai Devonian to Early Carboniferous island-arc system displaced hundreds of kilometers relative to each other along the strike-slip faults as a result of Late Carboniferous to Permian collision between Kazakhstan–Baikal and North Asian. Based upon the thickness of metamorphic rocks, the amplitude of displacement is estimated to be as much as one thousand of kilometers for the Irtysh shear zone (Segnör et al., 1993, 1994). The Salair–Altai island-arc terranes, in turn, are separated from the coeval Devonian to Early Carboniferous island-arc formations of the Chinghiz–Tarbagatai zone of Kazakhstan–Baikal by the Char ophiolite suture (Figs. 3, 6).

If the Early Paleozoic ophiolite and glaucophane-crossite rocks of West Junggar and Charysh–Terekta–Ulagan–Sayan suture zone are to be regarded as parts of originally single active margin of Kazakhstan–Baikal, then the amplitude of strike-slip displacement along the Northeastern shear zone could be estimated as one thousand of kilometers.

In Middle–Late Devonian the Rudny Altai active margin of Siberia had NE strike and was located $32° \pm 4°$ N (Burtman et al., 1998). Paleomagnetic data suggest that the Chinghiz–

Tarbagatai island-arc of Kazakhstan–Baikal in Middle Devonian had sublatitudinal trend and originated at 21° ± 4° N. The convergence with Rudny Altai island arc along a paleomeridian is estimated to be 650–1650 km (Burtman et al., 1998). It is the minimum overall amplitude of sinistral displacement along the Char and Irtysh zones. Based in geological data, the amplitude of sinistral regional displacement along the North Sayan Fault located 500 km east of Char Fault is 80 km.

The Char, Irtysh–Kurchum, Northeastern, and North Sayan shear zones, therefore, constitute a single Late Carboniferous to Early Permian strike-slip structure 500 km wide originated along the continental margin of Siberia. Within the Kazakhstan block of the Kazakhstan–Baikal composite continent, dextral faults (e.g., Chinghiz–Tarbagatai Fault) dominate to the west of major collision zone (Char Fault), whereas sinistral displacements are prevalent to the east of Char shear zone, with their amplitude declining by an order of magnitude, from 650–1650 km to a few dozens of kilometers, over a distance of 500 km in the eastern part of Gorny Altai.

There are several North Eurasian Late Carboniferous and Permian coaliferous basins with biostratigraphic characteristics suggesting their formation in disparate paleogeographic settings, whereas their present-day location can be explained as a result of Late Permian and Triassic large horizontal displacement of continental blocks (Buslov et al., 2004). Thus, within the surrounding setting of the Siberian Craton there are Late Carboniferous to Permian Kuznetsk and Gorlovka coaliferous basins, whereas the Kazakhstan–Baikal continent is characterized by two large Late Carboniferous to Permian coaliferous basins, the Kendyrlyk and Karaganda basins. There is also the Late Carboniferous to Permian Pechora Basin on the northeastern margin of East European continent. Paleofloristic and paleofaunistic communities of the above-mentioned basins suggest that Siberia was located in temperate climatic zone, unlike the Kazakhstan–Baikal and East European continents that were positioned in tropical climate. The distribution of non-marine bivalves points to a close connection between the Pechora, Karaganda, and Kendyrlyk basins (Betekhtina, 1983).

The paleogeographic zonation is corroborated by geological and paleomagnetic data. Considering the present-day position of continents and coaliferous basins the East European Craton is assumed to have moved more than 2000 km north since the closure of Uralian Ocean, whereas Siberia is thought to have rotated clockwise while remaining at the same latitude (Didenko et al., 1994). Such kinematics of large continental mass movements led to large amplitude dextral displacement of East European Craton relative Siberia and deformation of their margins and of the Kazakhstan–Baikal composite continent. Based on paleomagnetic data, the East European Craton had reached its present-day position by Early Jurassic. Therefore, the strike-slip deformations must have manifested themselves during Late Carboniferous to Triassic. The current location of the Pechora Basin near the Arctic Circle is 20–25° farther north relative to other above mentioned basins.

The allochthonous Urals Orogen originated in the zone of frontal collision between the East European and Kazakhstan–Baikal continents during Late Carboniferous–Permian when strike-slip faults and oroclinal folds developed over much of the Central Asian Foldbelt. From the east the East European Craton together with the overthrusted Urals Orogen are separated from most of Kazakhstan–Baikal continent by a zone of large-amplitude strike-slip faults. From the west the East European Craton is bordered by the Troitsk fault system with large strike-slip deformations (Puchkov, 2000). These and other major faults in the Urals originated during Late Permian and Early Triassic and deformed the Early Paleozoic thrust sheet structure, as demonstrated for the Magnitogorsk zone (Savel'ev et al., 1998).

Discussion and conclusions

Late Paleozoic strike-slip deformations are abundant in the structure of Central Asia. They disturb younger structural and formational zones that characterize growth of continental crust, history of the oceanic basins separating East European Craton, Siberia, and Gondwana, and the accretionary and collisional processes along continental margins. Late Devonian and Early Carboniferous shear deformations produced a collage of terranes as a result of collision between the Kazakhstan–Baikal composite continent (including continental blocks of Gondwana) and Siberia and formation of North Asian continent. Late Carboniferous to Permian collision between the East European Craton and North Asia led to fragmentation of the southern part of Vendian–Paleozoic margin of Siberia and of the entire Kazakhstan–Baikal composite continent by strike-slip and associated thrust faults into a series of terranes that constitute the structure of the Central Asian Foldbelt (Fig. 1). Within the terranes of Kazakhstan–Baikal composite continent there are fragments of island arcs, Precambrian microcontinents and Gondwana terranes (Kokchetav, Issyk-Kul', Altai–Mongolia, Tuva–Mongolia, Dzabkhan, etc.), fragments of accretion and collision structures, including paleosubduction zones and accretionary prisms. The Vendian to Cambrian subduction of Precambrian microcontinents and terranes of Gondwana underneath the Kazakhstan–Tuva–Mongolia island arc and their Ordovician collision created the composite Kazakhstan–Baikal continent. The latter includes Early Caledonian structures of Kazakhstan, southern part of Altai–Sayan Region, Tuva, Baikal Region, Mongolia, and North China. The Middle to Late Paleozoic suture-shear zone separates the Kazakhstan–Baikal composite continent from Siberia continental margin. The suture-shear zone incorporated fragments of Cambrian and Early Ordovician oceanic crust, Ordovician blueschists, and Cambrian–Ordovician turbidites. The suture-shear zone delineated by transverse strike-slip faults can be traced over more than 1.5 km in the Altai–Sayan Region (Charysh–Terekta–Ulagan–Sayan zone) and are likely to have analogues in Junggar and East Kazakhstan. The sublatitudinally striking Middle to Late Paleozoic suture-shear zone casts doubt on numerous tectonic and geodynamic reconstructions in which the Vendian–Paleozoic zones in foldbelts are considered in relation to Siberia.

Such zones are preserved only in the north of Altai–Sayan region and possibly in the east of the basement of West Siberian basin.

Vendian to Paleozoic formations of Siberia western continental margin are represented by Vendian–Cambrian Kuznetsk–Altai island arc, Ordovician–Early Devonian passive margin complexes, and Devonian to Early Carboniferous active margin. The island arc accretionary wedges contain abundant fragments of Vendian to Cambrian oceanic crust consisting of ophiolite and paleooceanic plateau, mounds and islands. Gondwana continental blocks are absent in the accretionary and collisional structures of Siberia western active margin.

The structural relationship between the composite Kazakhstan–Baikal continent (including the Altai–Mongolia Terrane) and the Siberia western continental margin can be observed in the East Kazakhstan, Junggar, and Altai–Sayan regions (Figs. 3, 6). The Middle to Late Paleozoic Charysh–Terekta–Ulagan–Sayan suture-shear zone is complicated by Late Paleozoic strike-slip displacements. The best manifested strike-slip faults are related to Late Carboniferous to Permian and Late Permian to Early Triassic collisions between the East European and North Asian continents which complicated the structure of earlier tectonic events and are relatively weakly altered by later faults.

Correlation and generalizations of structural, paleomagnetic, and geochronological data from East Kazakhstan and Altai–Sayan Foldbelt reveal the importance of Late Paleozoic large-amplitude horizontal particularly strike-slip movements in the formation of the resulting structure of these regions after the closure of oceanic basins. The Early Devonian active margins of Siberia and Kazakhstan–Baikal divided by a sublatitudinal Middle to Late Paleozoic suture-shear zone are shown to had been separated by the Ob'–Zaisan oceanic basin. The suture-shear zone originated in Late Devonian to Early Carboniferous. During Late Carboniferous to Permian collision continental margins of Siberia and Kazakhstan–Baikal continent were divided by strike-slip faults and associated thrust faults into numerous terranes within a broad zone extending for 1500 km and were accompanied by sinistral displacements along the Char ophiolite zone, Irtysh, Northeastern, Teletskoe–Bashkaus, and Shapshal shear zones, and Main Sayan Fault, all characterized by NE strike. The amplitude of displacement decreases in eastern direction, from several thousands kilometers to a few hundreds or dozens of kilometers.

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