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Middle Paleozoic subduction belts: The leading factor in the formation of the Central Asian fold-and-thrust belt

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Abstract. The Paleozoic fold-and-thrust belt, confined between the European, Siberian, Tarim, and North China Precambrian continents, results from a complex evolution of the Paleo-Asian Ocean. At the end of the Ordovician, the Kazakhstan–Kyrghyz continent, originating from the accretion of island arcs and Gondwanan continental fragments, divided the Paleo-Asian Ocean into four oceanic basins, Uralian, Turkestan, Junggar–Balkhash, and Ob–Zaisan. The Middle to Late Paleozoic history of these oceanic basins, which closed completely in the terminal Carboniferous to Permian, is portrayed in eight detailed, 1:10,000,000 scale, palinspastic reconstructions for the Early Silurian (430 Ma), Early Devonian (Emsian, 390 Ma), Middle Devonian (Givetian, 380 Ma), Late Devonian (Famennian, 360 Ma), Early Carboniferous (late Visean to Serpukhovian, 330 Ma), early Late Carboniferous (305 Ma), Early Permian (280 Ma), and Late Permian (255 Ma) time slices. These reconstructions draw on 1:2,500,000 scale sedimentologic-paleogeographic maps and paleomagnetic measurements from ancient continents and Variscan orogenic zones of the Urals, Kazakhstan, Tien Shan, Junggaria, and Altay. The shrinking and collision-induced closure of the oceans were ensured by the three large and long-lived (100–130 m.y.) Urals–Tien Shan, Junggar, and Siberian subduction belts, spanning thousands of kilometers, whose polarities remained stable. The belts were represented by systems of roughly parallel and branching subduction zones, each with a 10–30 m.y. lifespan, plunging beneath the Kazakhstan–Kyrghyz and Siberian continents. Taken together, they constituted a system that diverged in a southwesterly direction and ensured differential rotations of the European, Siberian, and Kazakhstan–Kyrghyz continents. The Urals–Turkestan belt began to form at the beginning of the Silurian, and the Siberian and Junggar belts, at the beginning of the Devonian. The subduction belts ceased to exist as they were crushed between continents during a general collision that set on in the second half of the Devonian and in which the Junggar belt became involved prior to the beginning of the Permian. Geologic and paleomagnetic evidence points to oblique motions of oceanic plates being consumed in the subduction belts and, accordingly, to an oblique collision in the Urals and South Tien Shan foldbelts that propagated through time and space to finally give rise to large-scale post-collisional lengthwise strike slips. We believe the subduction belts to be surface manifestations of descending mantle convection flows that drove the long-lasting sinking of oceanic plates into the mantle.

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Introduction

The vast expanses of Eurasian fold-and-thrust domains confined between the Eastern European, Siberian, and China cratons are referred to as the Urals–Mongolia fold-and-thrust belt [*Muratov,* 1965, 1974; *Zonenshain et al.,* 1990], one of the most intricate structural assemblages worldwide. Within this area, one recognizes (i) the Uralian belt proper, restricted between the Eastern European craton and the Khanty–Mansi and Kazakhstan–North Tien Shan ancient massifs in the east, (ii) the Central Asian belt, stretching from Tien Shan in the west via central Kazakhstan, the Altay–Sayan region, Mongolia, and western Trans-Baikalia as far as the Vitim River in the east, and (iii) the Mongolia–Okhotsk belt, confined between the Siberian craton and the Khingan–Bureya massif.

This enormous area brings together fragments of pre-Paleozoic continental blocks, slices of Paleozoic oceanic crust of various formative ages, island arcs of contrasting ages, newly formed orogenic systems, and continental masses with their active and passive margins. All these entities occur in a variety of mutual relations and not infrequently share tectonic boundaries with each other as a result of large-scale horizontal displacements. It is no accident that issues pertaining to the formation of the Urals–Mongolia fold-and-thrust belt have been a focus of attention in tectonic literature ever since A. D. Arkhangelsky and N. S. Shatsky's times.

Among the latest studies, which provide the basis for the present-day geodynamic insight into the oceanic stage in the belt's evolution, which lasted from the opening to the closure of the Paleo-Asian Ocean, it suffices to mention [*Didenko et al.,* 1994; *Dobretsov et al.,* 1995; *Gordienko and Mikhaltsov,* 2001; *Kuzmin et al.,* 1995; *Mossakovsky et al.,* 1993; *Pechersky and Didenko,* 1995; *Scotese and Golonka,* 1993; *Sengör et al.,* 1993, 1994; *Zonenshain et al.,* 1990].

An issue of particular significance to the evolution of the Paleo-Asian Ocean is reconstructing locations, characters, and evolutionary peculiarities of the subduction zones responsible for the closure of oceanic tracts and convergence and subsequent collision of structural units of the Urals–Mongolia fold-and-thrust belt.

In numerous reconstructions dating from the 1970s to 1980s, paleomagnetic data [e.g., *Paleomagnetology,* 1982; *Piper,* 1983; *Scotese et al.,* 1979] were mostly used to calculate positions of continents, while leaving oceanic tracts as white spots. An exception is provided by reconstructions of [*Zonenshain et al.,* 1987, 1990], which employ paleomagnetic data not only from ancient continents, but also from Paleozoic folded areas, with the result that paleoceanic tracts are beginning to be filled with tangible entities of oceanic affinity. These geodynamic constructions invoke the idea that within the Paleo-Asian Ocean there existed a broad variety of both Gondwanan- and Laurasian-derived microcontinents, as well as island arcs, whose accretion and collision gave rise, by the end of the Paleozoic, to the Urals–Mongolia belt.

A totally different evolutionary model for the Urals–Mongolia belt was put forward by [*Sengör and Natal'in,* 1996; *Sengör et al.,* 1993, 1994]. According to these workers, the Paleo-Asian Ocean experienced a phase in its history when a continuous belt in which lithospheric plates were converging stretched along the southern margin of the Siberian paleocontinent and the eastern margin of the Eastern European paleocontinent, to use present-day reference frame. A major part of this boundary was occupied by the Kipchak arc until the mid-Silurian. Then, differential rotations of the plates just mentioned led to a complete deformation of the Kipchak arc's structure, manifest in oroclinal bends, major strike slips, and multiple repetitions of arc fragments and Precambrian microcontinents. One should note that the existing paleomagnetic measurements from both the continents and the Urals–Mongolia belt cannot be fully accommodated by a model calling for the existence in the Early Paleozoic of a continuous arc that stretched along the Uralian margin of the Eastern European paleocontinent and the Altay–Sayan margin of the Siberian paleocontinent.

Another concept, drawing on L. P. Zonenshain's work, was proposed in [*Paleogeographic Atlas...,* 1997]. It postulated that at least two subduction systems existed in the Paleo-Asian Ocean between the European and Siberian continents. The most recent scheme [*Puchkov,* 2000] reanimates the idea of a single "subduction system" changing its position over time and rimming the Siberian continent alternately from north or south.

Comparative analyses of principal paleogeodynamic schemes for the Urals–Mongolia fold-and-thrust belt were carried out by [*Klootwijk,* 1996] and [*Burtman,* 1999]. As is evident from these works, the issue of geodynamic evolution of the foldbelt is still far from being solved. Apparently, one should abandon the construction of synoptic small-scale schemes in favor of more detailed and specific ones accounting more fully for kinematic characteristics of the motions of lithospheric plates and microplates. Precisely this objective is addressed by our study.

An important step forward along this line is the research conducted in the framework of the international project entitled *Atlas of Lithologic-Paleogeographic, Structural, Palinspastic, and Geo-ecologic Maps of Central Eurasia.* This project was carried out between 1997 and 2001 jointly by the geological surveys of Azerbaijan, Kazakhstan, Kyrghyzstan, China, Russia, Tajikistan, Turkmenistan, and Uzbekistan. The Atlas includes, in particular, 1:2,500,000 scale lithologic-paleogeographic maps at 43 time slices from the Late Proterozoic to the Quaternary. They portray present-day positions of lithologic-petrographic assemblages and their paleogeographic characteristics and offer a modern base of concerted data, unique in its detail, elaborated by experts in the geological setups of specific regions in central Eurasia. With these maps and paleomagnetic data at our disposal, the Russian workers plotted 23 palinspastic paleogeographic maps on a 1:10,000,000 scale for selected stages from the Vendian to the Pliocene. The maps were constructed by a team that included V. A. Bush, Yu. A. Volozh, A. N. Didenko, V. G. Kazmin, I. B. Filippova, and T. N. Kheraskova with contributions from A. A. Belov, V. N. Puchkov, and S. P. Shokalsky (Russia), V. A. Bykadorov, V. Ya. Koshkin, L. I. Skrinnik, and A. V. Smirnov (Kazakhstan), A. V. Dzhenchuraeva and R. A. Maksumova (Kyrghyzstan), and A. K. Bukharin (Uzbekistan). The reconstructions do not cover the entire area of the Urals–Mongolia fold-and-thrust belt, but rather only its Uralian and Central Asian parts, including the Altay–Sayan area, i.e., tracts that occur between the Eastern European, Siberian, and Tarim paleocontinents. We have named this entire area "the Central Asian foldbelt."

This paper draws on the analysis of the eight palinspastic maps just mentioned: 430 Ma (S_1), 390 Ma (D_1em), 380 Ma (D_2gv), 360 Ma (D_3fm), 330 Ma (C_1v_1), 305 Ma (C_3), 280 Ma (P_1), and 255 Ma (P_2), presented in a scaled-down and schematized form here.

Methods Used in Our Paleoreconstructions

To draw the palinspastic maps, we used the work of *Zonenshain et al.* [1990] as a conceptual base, which was corrected and modified to conform to C. Scotese's data while compiling the *Paleogeographic Atlas of Northern Eurasia* [1997]. The latter presents virtually the whole set of geological and paleomagnetic raw data used in our constructions, except for those acquired after the Atlas had been published, and which are referred to in the text. Latitude positions of the continents and their orientations relative to cardinal points provided decisive constraints on the Paleo-Asian Ocean tracts, without, however, defining the continents' longitude positions relative to each other, which cannot be pinpointed by paleomagnetic techniques. Due account was taken not only of paleolatitudes, but also of paleomagnetic declinations, which describe differential rotations of blocks with respect each other in geographic reference frame. It should be kept in mind that available paleomagnetic data are not extensive and by no means cover all the structural units (terranes). Where such data are lacking, terranes are positioned arbitrarily.

Paleogeographic settings, depositional environments, and the character of magmatism were copied to the palinspastic drawing base from lithologic-paleogeographic base maps. In constructing the maps, the palinspastic base was, where necessary, corrected to account for geologic assemblages indicative of specific geodynamic settings and in cases where oceanic crustal tracts between continents failed to accommodate the known terranes. Where no direct paleomagnetic data to quantify the width of oceanic tracts were available, this width was estimated rather tentatively from spreading rates, as deduced from TiO_2 abundances of MORB-like basalts [*Matveenkov,* 1983], and from subduction rates, as inferred from Fe/Mg ratios in calcalkaline effusive suites [*Miyashiro,* 1974] from the fossil oceanic basins in point. Palinspastic maps were constructed in descending order through the geological record so as to remove later deformations.

A painstaking problem, which was not always soluble in a unique way, was the restoration of the original positions, transport directions, and rotations of numerous minor microcontinents and island arcs, for which no paleomagnetic data of any validity are available. To this end, we relied primarily on geologic evidence indicative of geodynamic settings, such as locations of passive and active margins of continental blocks and their transform boundaries. Collisions of blocks were timed from deformation ages, changes in paleogeographic environments, and emplacement of collisional granites. Subduction polarities were deduced using thoroughly described techniques [e.g., *Khain and Lomize,* 1995], from across-arc increase in volcanite alkalinity, the presence of boninitic series in rock successions, and the location of accretionary prisms synchronous to subduction-related magmatism. Positions of seafloor spreading zones are shown only where defined by paleomagnetic measurements constraining latitude and absolute strike of a paleorift [*Pechersky and Didenko,* 1995]. Otherwise, spreading zones were shown as inferred.

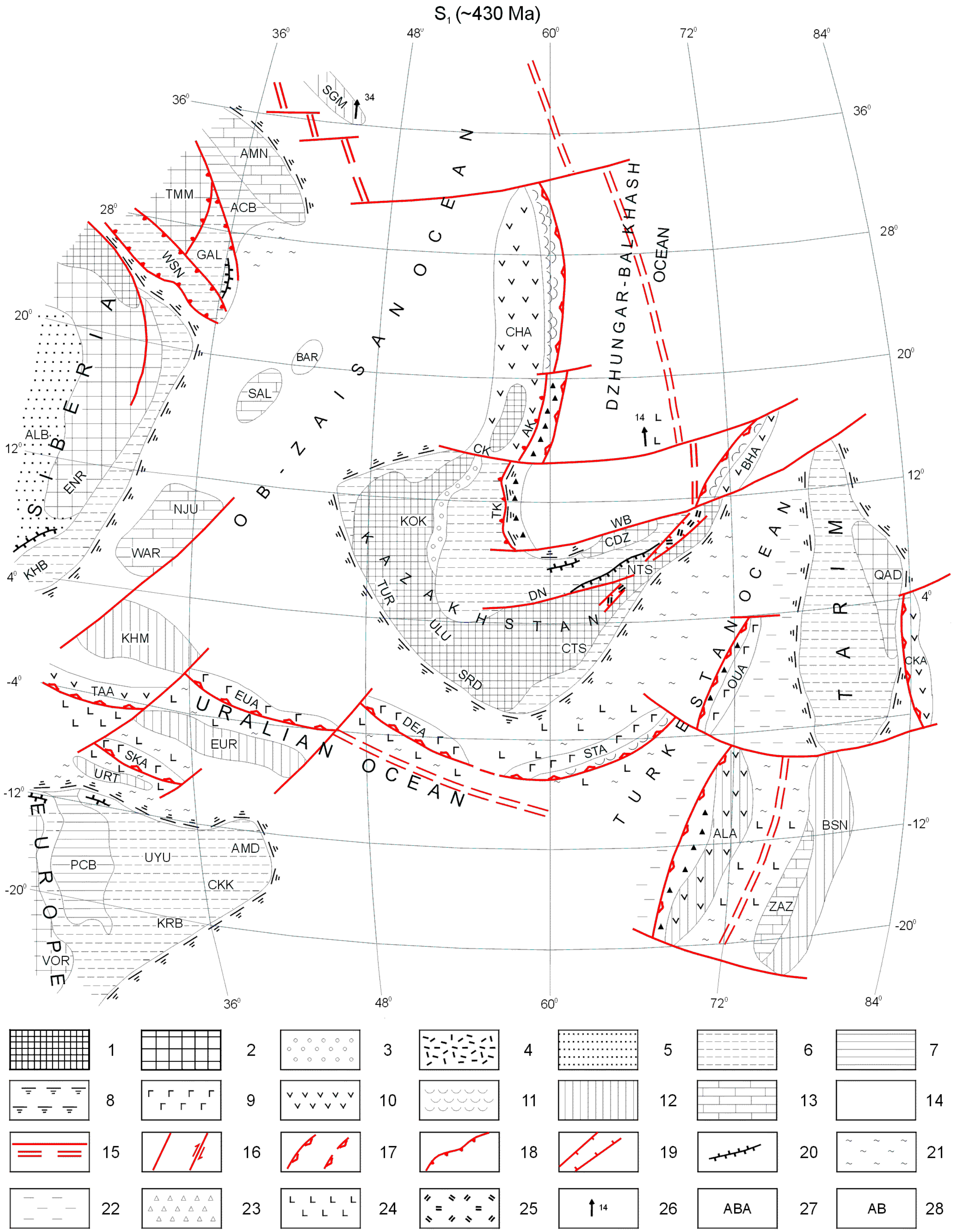
In appraising our palinspastic maps, allowance should be made for the fact that their confidence level is greatest as regards location of large continental masses at one or another paleolatitude and their rotation angles, as deduced from a set of paleomagnetic measurements. The maps are less reliable as regards the width of oceanic tracts between continents, especially from west to east, restored largely from geologic evidence. The positioning of oceanic tracts of minor terranes that currently lack paleomagnetic characteristics is largely arbitrary.

Middle to Late Paleozoic History of the Paleo-Asian Ocean and Central Asian Foldbelt

The Paleo-Asian Ocean, a basin between Siberia and Eastern Europe on the one hand and eastern Gondwana on the other [*Dergunov,* 1989; *Zonenshain et al.,* 1987], is firmly established to have existed since as early as Vendian time, based on at least three reliable radiometric ages from ophiolites in western Mongolia. These include the 569 Ma Bayan-Khongor ophiolite [*Kepezhinskas et al.,* 1991] and the 568 Ma Khan-Taishiri and 573 Ma Daribi ophiolites [*Khain et al.,* 1999]. The beginning of the Cambrian was characterized by vigorous generation of new oceanic crust in the Paleo-Asian Ocean and by a number of Central Asian microcontinents, Syr-Darya–North Tien Shan, Aktau–Mointy, Tarim–Tsaidam, etc., splitting off eastern Gondwana. In that time, two large roughly N–S trending island-arc systems formed along the Siberian and eastern Gondwanan margins of the paleocean plunging under Siberia and Gondwana, respectively.

On the Siberian margin, intense accretionary buildup of the Siberian continent proceeded in the Early Paleozoic [*Didenko et al.,* 1994; *Mossakovsky et al.,* 1993]. At the eastern Gondwana margin, in the Cambrian and through most of the Ordovician, the subduction system provided the site for accretion of intraoceanic rises arriving from the west and for fragments of pre-Paleozoic microcontinents that had split off eastern Gondwana. The second subduction zone likely diverged gradually from Gondwana and converged with Siberia and Eastern Europe. In the terminal Late Ordovician, this process culminated in the Kazakhstan and Tien Shan island arcs colliding with microcontinents, giving rise to the newly formed Kazakhstan–Tien Shan, or Kazakhstan–Kyrghyz, continental mass, marked by voluminous collisional granite plutonism.

For Vendian and Early Paleozoic times, reliable paleomagnetic measurements are scanty not only from units involved in the foldbelt, but also from the paleocontinents sur-



S1 (~430 Ma)
36°
48°
60°
72°
84°
28°
20°
12°
4°
-4°
-12°
-20°
SGM
34
AMN
TMM
ACB
GAL
WSN
SIBERIA
ALB
ENR
NJU
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Figure 1. Palinspastic map for the Early Silurian (Llandoverian, 430 Ma). Symbols apply to Figures 1–7. A. Continental paleogeographic and paleotectonic settings: 1 – orogenic edifice, 2 – denudation plain, 3 – intermontane basin or foredeep with continental sedimentation, 4 – active margin volcano-plutonic chain, 5 – epicontinental nearshore or marine basin, 6 – marginal shelf, 7 – deep water (bathyal) intracontinental basin, 8 – continental slope and rise of a passive margin.
B. Oceanic and backarc basinal paleogeographic and paleotectonic settings: 9 – primitive deeply submerged volcanic arc, 10 – mature volcanic island arc, 11 – accretionary prism, 12 – microcontinent, 13 – carbonate platform, 14 – ocean and backarc basin floor and abyssal plain.
C. Active tectonic structures: 15 – spreading axis, proven or inferred, 16 – principal strike slip or transform fault, 17 – subduction zone, proven or inferred, 18 – overthrust, 19 – rift.
D. Other features: 20 – barrier reef, 21 – ocean-floor siliceous sediments, 22 – clay and carbonate sediments, 23 – flysch/olistostrome apron, 24 – ocean-floor tholeiitic basalts, 25 – within-plate subalkaline and alkaline volcanics, 26 – paleomagnetic vectors and mean paleolatitudes, 27 – names of structural units (see list), 28 – names of principal faults (see list).
Names of structural units: A. Massifs, microcontinents, blocks, and tectonic zones: ALM = Alay microcontinent, AMD = Amu-Darya block, AMN = Altay–Mongolia block, BAR = Barnaul massif, BDM = Baydaratsky massif, BEC = Bechasyn zone, BEL = Beltau zone, BES = Beishan, BOR = Borkoldoy block, BSN = Baisun massif, CAT = Chatkal, CDZ = Central Junggar Alatau, CHI = Chinghiz, CKK = Central Karakum, CKL = Central Kunlun, CTS = Central Tien Shan, DZF = Junggar foldbelt, ENR = Yenisei Range, EUF = East Urals folded zone, EUR = East Urals, GAL = Gorny Altay, GCM = Greater Caucasus massif, GKT = Greater Karatau, KHM = Khanty–Mansi massif, KHR = Kharbey microcontinent, KOK = Kokchetav massif, KRB = Karabogaz massif, MGZ = Magnitogorsk zone, NDZ = Northern Junggar Alatau, NJU = Nyurolka massif, NKL = North Kunlun, NPM = North Pamir, NTS = North Tien Shan, NUF = North Urals, OUR = Osh–Uratyube block, OZF = Ob–Zaisan foldbelt, PAR = Parapamiz, QAD = Tsaidam massif, RAL = Rudny Altay, SAL = Salair, SDZ = Southern Junggar Alatau, SGM = Southern Gobi massif, SLZ = Salym zone, SRD = Syr-Darya block, STS = South Tien Shan, SUF = South Urals, TAR = Tarbagatay, TIM = Timan, TKO = Tom–Kolyvan zone, TMM = Tuva–Mongolia massif, TUR = Turgay block, UKM =Ukrainian massif, ULN = Ulan block, ULU = Ulutau, URT = Ural-Tau, UYU =Ustyurt, VOR = Voronezh massif, VUR = Volga–Urals arch, WAR = Vartovsk massif, WSN = Western Sayan, ZAZ = Zeravshan–Alay zone.
B. Sedimentation basins: ACB = Anuy–Chu, AGB = Angara–Lena, ALB = Almantaisky, BOB = Borotalinsky, CSB = Chu–Sarysu, DBB = Junggar–Balkhash, DDB = Dneper–Donets, DZB = Junggar, KAB = Karpinsky Range, KHB = Khatanga, KUB = Kuznetsk, LEB = Lemva, MIB = Minusinsk, MNB = Mangyshlak, MSB = Moscow, NCB = North Caucasus, ORB = Ortosuisky, OZB = Ob–Zaisan, PCB = Peri-Caspian, RYB = Rybinsk, SAB = Sakmara, SDB = Syr-Darya, TGB = Tunguska, TNB = Teniz, TPB = Timan–Pechora, TUB = Tuarkyr, UFB = Uralian foredeep, WKB = Vashan–Kalmakasuisky, WMB = Western Mugodzhary.
C. Island arcs and volcano-plutonic belts: ALA = Alay, BEA = Beltau, BGA = Bogdoshan, BHA = Barunkhuray, BKA = Barlyk, BSA = Baisun, CFA = Caucasus Frontal Range, CHA = Chinghiz, CKA = Central Kazakhstan, CKL = Central Kunlun, CTA = Chinese Tien Shan, DEA = Denisovsky, EDA = Eastern Junggar, EUA = East Urals, ILA = Ili, IRA = Irendyk, JOA = Zholotag, JSA = Zharma–Saur, KUA = Kurama, MGA = Magnitogorsk, NBA = Northern Barunkhuray, NUA = North Urals, OUA = Osh–Uratyube, PBA = Balkhash, RAA = Rudny Altay, SAA = Salym, SDA = Southern Junggar, SKA = Sakmara, SLA = Salair, STA = South Tien Shan, SUA = Sultan-Uizdag, TAA = Tagil, TKA = Tom–Kolyvan, UBA = Ubagan, VAA = Valeryanovsky.
D. Principal faults: AK = Akbastau, AB = Altay face, BH = Boro-Horo, CC = Central Chinghiz, CK = Central Kazakhstan, DA = Darbut, DN = Dzhalair–Naiman, ES = Eastern Sayan, EU = East Urals, IR = Irtysh, KA = Kuznetsky Alatau, KK = Karakunlun, KO = Kobda, NE = Northeastern Altay, TF = Talas–Fergana, TK = Tekturmas, WB = Western Balkhash.

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rounding this belt. A likely exception is the Siberian paleocontinent, covered by an acceptable set of paleomagnetic poles dating as far back as the Cambrian [*Smethurst et al.,* 1998]; as for the Eastern European and Tarim paleocontinents, their Vendian, Cambrian, and Ordovician strata each yielded as few as two or three reliable paleomagnetic poles [*Didenko et al.,* 2001; *Li et al.,* 1995]. Beginning with the Middle Paleozoic, the situation changed, enabling us to propose the palinspastic constructions below.

At the beginning of the Silurian (Llandoverian, 430 Ma), the following pattern is reconstructible from the Central Asian space (Figure 1). The European continent, welded by the Norwegian–British Caledonides into a continuous mass with the North American continent (Euroamerica), lay at low latitudes in the Southern Hemisphere, with its passive Uralian margin trending WNW. The continent was rotating counterclockwise. Siberia, with its current northern margin facing south, occurred at low latitudes in the Northern Hemisphere, after having rotated 20° clockwise relative to its N–S position in the Vendian to Arenigian. Tarim and the Kazakh continent, the latter having formed in the end of the Ordovician, drifted rapidly 2000 km northward into subequatorial and subtropical latitudes of the Northern Hemisphere [*Li et al,* 1995; *Pechersky and Didenko,* 1995]. Meanwhile, Tarim maintained its N–S orientation. Kazakhstan occupied a central position in the Paleo-Asian space, dividing it into four oceanic basins: (i) Ob–Zaisan, which opened in Ordovician time, (ii) Turkestan [*Biske,* 1996; *Kurenkov and Aristov,* 1999], (iii) Junggar–Balkhash, and (iv) Uralian, which reached its maximum development in the Late Ordovician to Early Silurian [*Didenko et al.,* 2001; *Puchkov,* 2000]. The spreading axis of the last one was situated a considerable distance north of the Eastern European continent, at 10°N–15°N latitude, trending NNW [*Didenko et al.,* 2001].

Along the European continent's passive Uralian margin, filled in with carbonate deposits, a deep Lemva–Sakmara marginal basin began forming in the Middle Ordovician, separated from the Uralian oceanic floor by submerged microcontinents (borderlands) of Ural-Tau, Kharbey, and Central Urals. The marginal sea exhibits condensed successions of shale and cherty shale [*Puchkov,* 2000; *Ruzhentsev et al.,* 1996].

The Uralian Ocean, over 2000 km wide, separated Eastern Europe from the Kazakhstan–Kyrghyz paleocontinent. The ocean was floored by siliceous sediments with oceanic-type tholeiitic basalts exposed in successions of the Sakmara allochthon and Voznesensk–Sakmara, Tagil, and Denisovsky zones [*Puchkov,* 2000; *Seravkin,* 1997]. Ophiolites of the Voikary–Syninsky, Kempirsai, etc., massifs [*Didenko et al.,* 2001; *Puchkov,* 2000] must have formed in a spreading zone. On either side of this zone, ensimatic island arcs were formed. Near the Eastern European continent, the Sakmara arc was situated, while further north and some distance toward the SW margin of Kazakhstan, the Tagil–East Urals–Denisovsky island arc system stretched [*Didenko et al.,* 2001]. Subduction zones of all these island arc systems plunged toward Kazakhstan [*Puchkov,* 2000; *Seravkin,* 1997; *Yazeva and Bochkarev,* 1993]. Stratigraphic sections of these arcs are dominated by basaltic suites resembling those composing present-day intraoceanic island arcs. The Tagil arc occurs in tight spatial association with the Uralian ultramafic platiniferous assemblage with island-arc petrologic and geochemical affinities [*Puchkov,* 2000].

The Turkestan Ocean, trending roughly EW [*Burtman,* 1999; *Didenko and Pechersky,* 1986], was rimmed by Kazakhstan passive margins on one side and by those of Tarim and Baisun microcontinents on the other. The beginning of the Silurian is marked by a change in bottom sediments in the Turkestan Ocean. Its greater part was covered by a bituminous graptolite shale succession deposited on Ordovician oceanic crust [*Biske,* 1996]. Near the Kazakhstan margin, black shale facies give way to chert and basalt ocean-floor successions, occurring at lower stratigraphic levels of the upper greenschist thrust sheets [*Biske,* 1996]. The upper stratigraphic levels of the same thrust sheets (cherty shales with differentiated tholeiitic basalts) likely mark the South Tien Shan ensimatic arc, formed above a subduction zone plunging beneath Kazakhstan and possibly linked with the similarly dipping subduction zone of the Denisovsky arc.

Within the Turkestan Ocean, two island arcs, Osh–Uratyube–Ulan and Alay, formed with their subduction zones dipping toward Tarim and Baisun. They are restored from Silurian calcalkaline volcanics composing thrust sheets beneath carbonate nappes of Devonian to Carboniferous age [*Biske,* 1996]. The Alay arc, which was situated 900–1000 km off the Kazakhstan margin, formed on sialic basement of a microcontinent of the same name. Apparently, volcanomictic flysch, occurring on top of graptolite shales of lower Llandoverian age on the arc's west margin, corresponds to island-arc slope and accretionary prism settings [*Biske,* 1996].

Along a system of roughly EW trending transform faults, the Turkestan Ocean was connected to the Junggar–Balkhash Ocean, where spreading continued into the Early Silurian. Margins of this ocean stretched roughly N–S and were marked by the Chinghiz and Boro-Horo ensialic island arcs [*Gao et al.,* 1998].

On the Siberian margin of the Ob–Zaisan Ocean, the collision of the western Sayan and Chulyshman–Kharkharinsky Ordovician island arcs with the Tuva–Mongolia massif began. On top of the partly accreted edifice of the Altay–Sayan area, a terrigenous–carbonate passive margin with reef structures along its shelf break was formed [*Elkin et al.,* 1994]. In the ocean, the submerged Altay–Mongolia microcontinent remained separated from the passive margin by the Anyui–Chu (Kobdinsky) deep-water trough with its condensed bituminous graptolite shale fill [*Rozman and Tsukernik,* 1988; *Ruzhentsev et al.,* 1991]. It was not until the end of the Silurian that structures of the Altay–Sayan area docked onto Siberia.

By the end of the Early Devonian (Emsian, 390 Ma), all the continents shifted 6°–10° northward (Figure 2). Euroamerica, while remaining in the subequatorial zone of the Southern Hemisphere, rotated to bring its Uralian margin roughly parallel to the equator. Carbonate shelf with barrier reefal limestones, which makes up this margin, features the Uralian Ocean's passive margin.

Kazakhstan and Tarim migrated into the subtropical belt of the Northern Hemisphere [*Didenko,* 1997; *Li et al.,* 1995]. The current Kazakhstan margin adjoining the Urals stretched WNW, while Caledonian structures of North Tien Shan stretched nearly N–S. Tarim, while remaining oriented roughly N–S between 10°N and 28°N, formed a continental barrier between the Turkestan Ocean's features and the Paleo-Tethys. The Siberian continent with the Altay–Sayan area accreted onto it prior to the Devonian shifted northward while rotating up to 6° clockwise, to acquire a NE orientation. The southwestern passive margin of the craton, adjacent to the present Yenisei River, was situated at 10°N, whereas the Altay–Sayan area remained at moderate latitudes. In the Uralian, Turkestan, and Ob–Zaisan oceans,

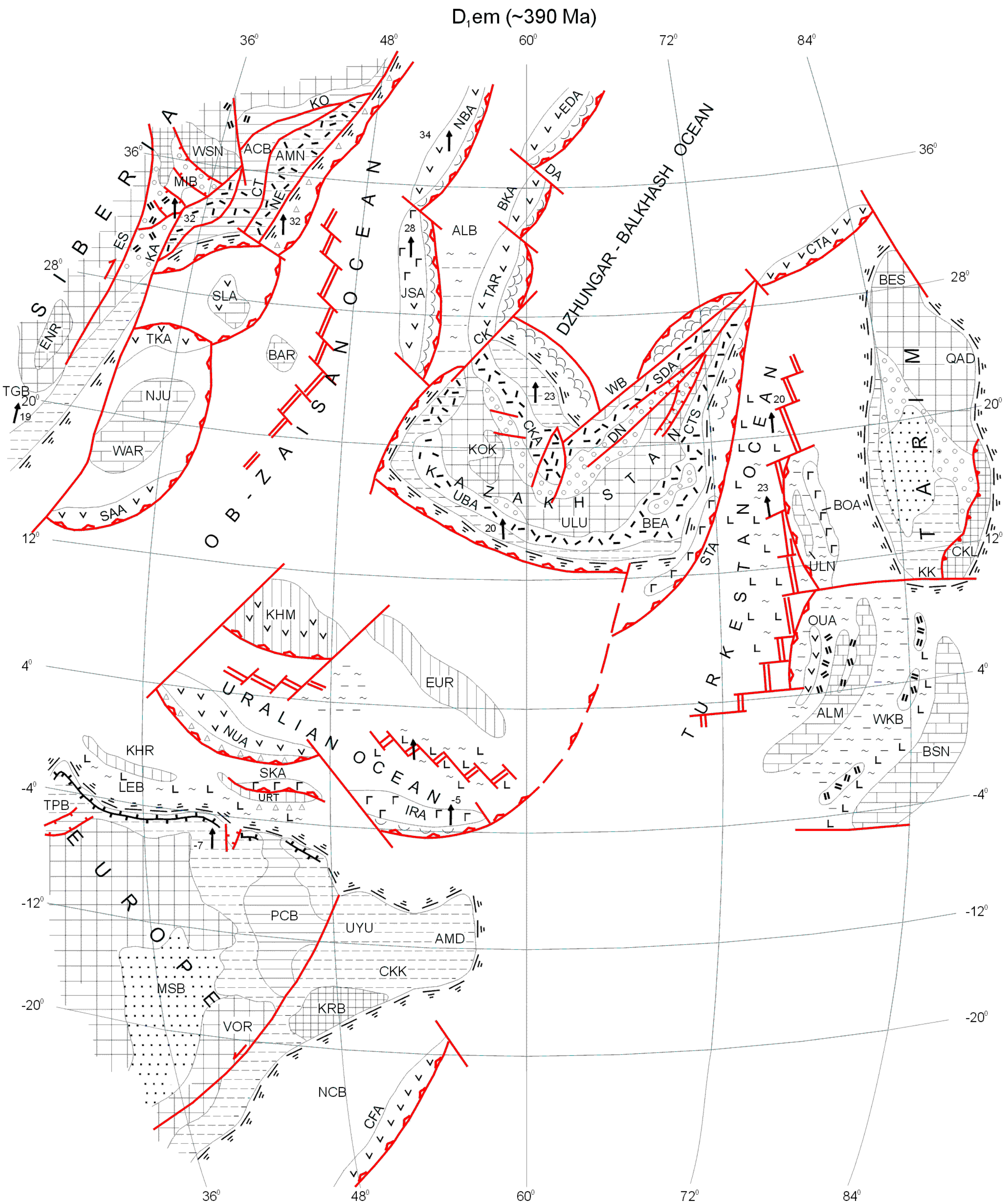

Figure 2. Palinspastic map for the Early Devonian (Emsian, 390 Ma). Symbols, as in Figure 1.

spreading resumed, but, at the same time, the lithosphere of all four oceans was being vigorously consumed under the Kazakhstan–Kyrghyz and Siberian paleocontinents.

The Uralian Ocean stretched roughly EW along the equator [*Didenko and Pechersky,* 1986], and, from paleomagnetic evidence [*Burtman et al.,* 2000], it may have been as wide as 2400 km. The ocean was separated by the Lemva–Sakmara marginal basin from the passive margin of Eastern Europe, to which this basin was parallel. At both margins of the ocean, accretionary processes set on. The Sakmara volcanic arc collided with the submerged Ural-Tau borderland, which led to the first thrusting event in the South Urals, recorded by the Shandinsky olistostrome [*Puchkov,* 2000; *Ruzhentsev et al.,* 2001]. Silurian island arcs accreting to microcontinents (East Uralian, etc.) at the southeastern margin of Kazakhstan [*Mizens,* 2001; *Yazeva and Bochkarev,* 1993] caused an oceanward jump in subduction, which maintained its plunge toward Kazakhstan. The new setup of the magmatic front included the North Urals ensialic arc (Voikary–Krasnoturinsky andesite–tonalite belt; [*Yazeva and Bochkarev,* 2001]), surmounting the accreted Silurian basement, in the west, and the Irendyk ensimatic arc with its basaltic volcanism in the southeast. On their south side, the island arcs were accompanied by accretionary prisms of the Maksytutovsky complex and by sliced-up siliceous sediments with tectonic lenses of serpentinite and MORB-like oceanic basalts [*Puchkov,* 2000; *Yazeva and Bochkarev,* 2001].

Based on paleomagnetic data [*Burtman et al.,* 2000], the Irendyk arc stretched in a northwesterly direction and was situated not far from the Eastern European margin and southeast of its present-day location. The entire island arc system ran aslant to the continental margin and presumably occurred southeast of Eastern Europe in the equatorial zone. In the backarc of the Irendyk arc, the western Mugodzhary backarc basin opened with a roughly EW trending spreading zone at a rate of up to 5 cm/yr [*Zonenshain and Matveenkov,* 1984; *Zonenshain et al.,* 1990]. On the other side of the spreading zone, in the oceanic interior, the East Uralian and Khanty–Mansi microcontinents remained submerged. The latter, with calcalkaline and shoshonitic volcanism developed on it [*Kurchavov,* 2001], represented an ensialic island arc that formed above a subduction zone that most likely plunged northward, toward Kazakhstan.

Along all the Kazakhstan margins, under which oceanic crust was subducting, the voluminous supra-subduction volcanism gave rise to a gigantic "ring of fire." It is comprised of four volcanic belts, central Kazakhstan, Ili, North Tien Shan, and Ubagan. Their common feature is that in their frontal parts, on continental margins, low-K calcalkaline rocks are spread, which give way inward across the belts, in the continental interiors, to high-K shoshonite–latite suites [*Kurchavov,* 2001; *Kurchavov et al.,* 1998; *Skrinnik and Senkevich,* 1996].

The formation of the central Kazakhstan volcanic belt was related to the continent thrusting over the Junggar–Balkhash and Ob–Zaisan oceanic beds. In Emsian time, the present-day roughly EW trending branch of the belt had a NNW strike and was situated at 23°N latitude [*Pechersky and Didenko,* 1995], being linked via the central Kazakhstan transform to the Irtysh branch. Volcanics of the belt were dominated by rhyolite and rhyodacite with alkalinity increasing inland [*Kurchavov et al.,* 2000]. Nearshore shoals and shelf of the Tekturmas and Spassk zones make up a forearc terrace that passes into the northern Junggar accretionary assemblage.

The Ili belt in southern Kazakhstan is also related to the Junggar–Balkhash Ocean. It is featured by a calcalkaline basaltic andesite series alternating with marine and continental terrigenous rocks [*Skrinnik and Senkevich,* 1996]. On the inner side of the belt, subalkaline olivine basalts filling out a system of grabens in North Tien Shan were manifest. The accretionary prism of the Ili belt is represented by the chaotic assemblage of central and southern Junggaria.

The Ubagan volcanic belt, stretching along the margins of the Uralian Ocean from northern Kazakhstan to the eastern part of Lake Aral, displays an asymmetric volcanic zonation. In the frontal part of the belt, drillholes in the Turgay depression penetrated subaquatic calcalkaline volcanics, giving way on the inner side of the belt to continental and subalkaline suites in the Tobol River basin and Aksuatsky District [*Bekzhanov et al.,* 2000; *Kurchavov,* 2001]. The belt's forearc terrace is formed by terrigenous successions of the Denisovsky zone of the East Urals.

The North Tien Shan volcanic belt stretches along the western margin of the Turkestan Ocean within central and North Tien Shan and is comprised of a subalkaline suite ranging from basalt to rhyodacite. Further south, in Syr-Darya District, the belt extends into a double volcanic arc, whose frontal zone is referred to as the Sultan-Uizdag ensimatic island arc composed of tholeiitic volcanics and cherts, and which is separated from the inner arc by an interarc basin. The North Tien Shan volcanic belt was likely linked to the intraoceanic island arc system of the Uralian Ocean by a continuous subduction zone plunging beneath Kazakhstan. On the northeastern extension of the North Tien Shan subduction zone, the Chinese Tien Shan island arc came into being [*Chengzao et al.,* 1997] to separate the Turkestan Ocean from the Junggar–Balkhash Ocean.

In plan view, the roughly N–S trending Turkestan Ocean was a southward widening triangle up to 2000 km across where it adjoined the Uralian Ocean. Devonian ophiolites of the Alay Mtns. and northeastern Fergana depression mark a spreading ridge that trended roughly EW (340°), as inferred from paleomagnetic measurements [*Didenko and Pechersky,* 1988; *Pechersky and Didenko,* 1995]. Along the ocean's periphery, marginal oceanic basins floored by basalts and cherts existed [*Biske,* 1996], namely, the Kyrghyz basin with a spreading zone and the Vashan–Kalmakasuisky basin. Between them were situated the Osh–Uratyube–Ulan island arc, which was nearing extinction and under which spreading ridge was likely subducting, and the Alay microcontinent, transformed into a carbonate platform. The ocean's southern and eastern passive margins were made up of carbonate platforms of the Zeravshan–Gissar zone, Baisun microcontinent, and Tarim [*Biske,* 1996].

The Ob–Zaisan Ocean stretched in a northeasterly direction, widening southwestward up to 1800–2000 km. Judging by the presence of Early Devonian ophiolitic slices in the Charsky melange [*Berzin et al.,* 1994], the ocean contained a spreading zone. At the ocean's northwestern margin, above the freshly reinstated subduction system dipping under Siberia, an ensemble of island arcs (Salym, Tom–Kolyvan, Salair) and the Altay active volcanic margin [*Shokalsky et al.,* 1996] emerged. The architecture of this active margin is modified by dextral strike slips formed along Caledonian structures during the oblique subduction of the oceanic plate [*Buslov,* 1998].

In the northeast, the Ob–Zaisan and Junggar–Balkhash oceans were separated by two roughly parallel NE-trending intraoceanic island arc systems, the Zharma–Saur–northern Barunkhuray and Bairlyk–Kainda–eastern Junggar, with their subduction zones plunging toward the Siberian continent [*Ruzhentsev et al.,* 1992; *Samygin et al.,* 1997; *Zonenshain et al.,* 1990]. Based on paleomagnetic evidence [*Didenko,* 1997; *Didenko and Morozov,* 1999; *Li et al.,* 1992], both systems were situated at medium latitudes (28°N to 40°N). Most volcanic arcs were ensimatic, with basalt-dominated volcanism, and only the Zharma and Bairlyk–Kainda arcs were ensialic, with volcanism in shelf environments. Frontal zones of the island arcs display olistostromal accretionary prisms [*Samygin et al.,* 1997]. On the inner side of the Bairlyk–Kainda arc, Chinghiz and Tarbagatay continental volcanics occur, interpreted by [*Kurchavov et al.,* 2000] to be of island-arc affinity and apparently involved in a triple junction with the two branches of the central Kazakhstan volcanic belt. This pattern resembles the Philippine Sea triple junction setup of Late Cenozoic arcs. Island arc systems were separated by the Almantaisky interarc oceanic basin with E-MORB–like tholeiites, passing southeastward into a deep water trough with prevailing siliceous sedimentation [*Samygin et al.,* 1997].

The volcanic belts and arcs were linked to each other either by transform faults (western Balkhash, central Kazakhstan, Darbut) or by triple junction.

The Junggar–Balkhash Ocean, up to 1200–1900 km wide, is restored from basalt and chert sequences and ophiolites exposed in northern Junggaria [*Bekzhanov et al.,* 2000; *Zonenshain et al.,* 1990]. The ocean was shrinking rapidly due to the convergence of Kazakhstan's active margins and island arcs with oppositely dipping subduction zones.

In the mid-Devonian (Givetian, 380 Ma), all the continents shifted 700–900 km northward (Figure 3) while rotating clockwise, with Tarim alone remaining in place. Euroamerica shifted 8°, or some 900 km, north, its northern roughly EW-trending Uralian margin reaching 4°N latitude. The Siberian continent rotated clockwise almost in place about a rotation center in the Altay–Sayan area. The continent's Khatanga–Yenisei portion shifted from 16°N to 26°N, traveling almost 1000 km. Along the boundaries of both continents with the Uralian and Ob–Zaisan oceans, carbonate passive margins stretched. Based on paleomagnetic data [*Burtman et al.,* 1998b], the Kazakhstan continent, while remaining virtually in place at subtropical latitudes, rotated almost 40° clockwise relative to its Emsian position.

Spreading ceased in the oceans, which kept shrinking vigorously owing to ongoing consumption of oceanic crust under Kazakhstan and Siberia in subduction zones inherited from the Early Devonian. The geodynamic setup had generally persisted since Emsian time. Volcanic belts kept functioning at Kazakhstan margins, island arcs were forming in the Uralian Ocean, island arc systems between Kazakhstan and the Siberian continent were maintained, and the Altay margin of the Siberian continent kept evolving as an active margin. However, the principal Emsian subduction zones underwent a considerable rearrangement due to their oceanward shift with polarities remaining unchanged, and accretionary processes at continental margins intensified.

Based on paleomagnetic data, in the Uralian Ocean, all the paleogeographic features shifted in a northwesterly direction into the tropical zone of the Northern Hemisphere, coming to rest aslant to the Eastern European margin, likely due to an oblique subduction with a sinistral slip component [*Kovalenko,* 2001; *Puchkov,* 1997; *Zonenshain et al.,* 1990]. In the South Urals, accretionary processes went on, and the Irendyk island arc, after having arrived from southern latitudes with a sinistral rotation, docked onto the submerged Ural-Tau borderland. Sea-floor spreading ceased in the western Mugodzhary oceanic basin.

A jump of the subduction zone further into the ocean took place. Above the subduction zone, there formed a double ensialic island arc, Magnitogorsk and East Uralian, with island-arc tholeiites in the frontal part of the former [*Puchkov,* 2000; *Seravkin,* 1997]. However, in the terminal Givetian, through oblique subduction, these arcs collided with one another at their eastern ends with ensuing temporary cessation in their volcanic activity. In the North Urals, the North Urals and Khanty–Mansi island arcs, following their mutual convergence, turned into carbonate platforms.

The Turkestan Ocean maintained its roughly N–S trend [*Burtman et al.,* 1998a] with a maximum opening of up to 1400 km in the south. In the west, just as in the Emsian, it remained bounded by a large subduction zone, which shifted further into the ocean. Above it formed a system of ensimatic island arcs (Sultan-Uizdag–South Tien Shan) and the ensialic arc of the Chinese South Tien Shan [*Biske,* 1996; *Chengzao et al.,* 1997]. These were separated from the Kazakhstan carbonate passive margin by a deep water backarc basin, the trapped part of the Emsian Kyrghyz sea. The South Tien Shan subduction zone represented a conceivable extension of the Magnitogorsk one into the South Urals. The inner structure of the Givetian ocean was inherited from the Emsian one [*Biske,* 1996]. The two oceanic margin basins with chert-dominated sediment fills are divided by closely spaced carbonate platforms. The latter drifted in a northerly direction, with the Alay platform reaching 8°N latitude [*Burtman et al.,* 1998a], which indicates oblique subduction of the underthrusting plate.

The Ob–Zaisan Ocean, which maintained its northeastern trend, shrank dramatically through the convergence of Kazakhstan and Siberia. The system of subduction zones plunging beneath the Siberian continent kept operating persistently. Above it, ensembles of island arcs and microcontinents were converging with each other and with the active margin of the Altay–Sayan area. However, the front of the Altay volcano-plutonic belt shifted oceanward, overlapping the former forearc terrace of Emsian time, likely due to the subduction zone shifting further oceanward [*Shokalsky et al.,* 1996]. In the Altay–Sayan area and on the Siberian margin, dextral slips kept operating vigorously. This was

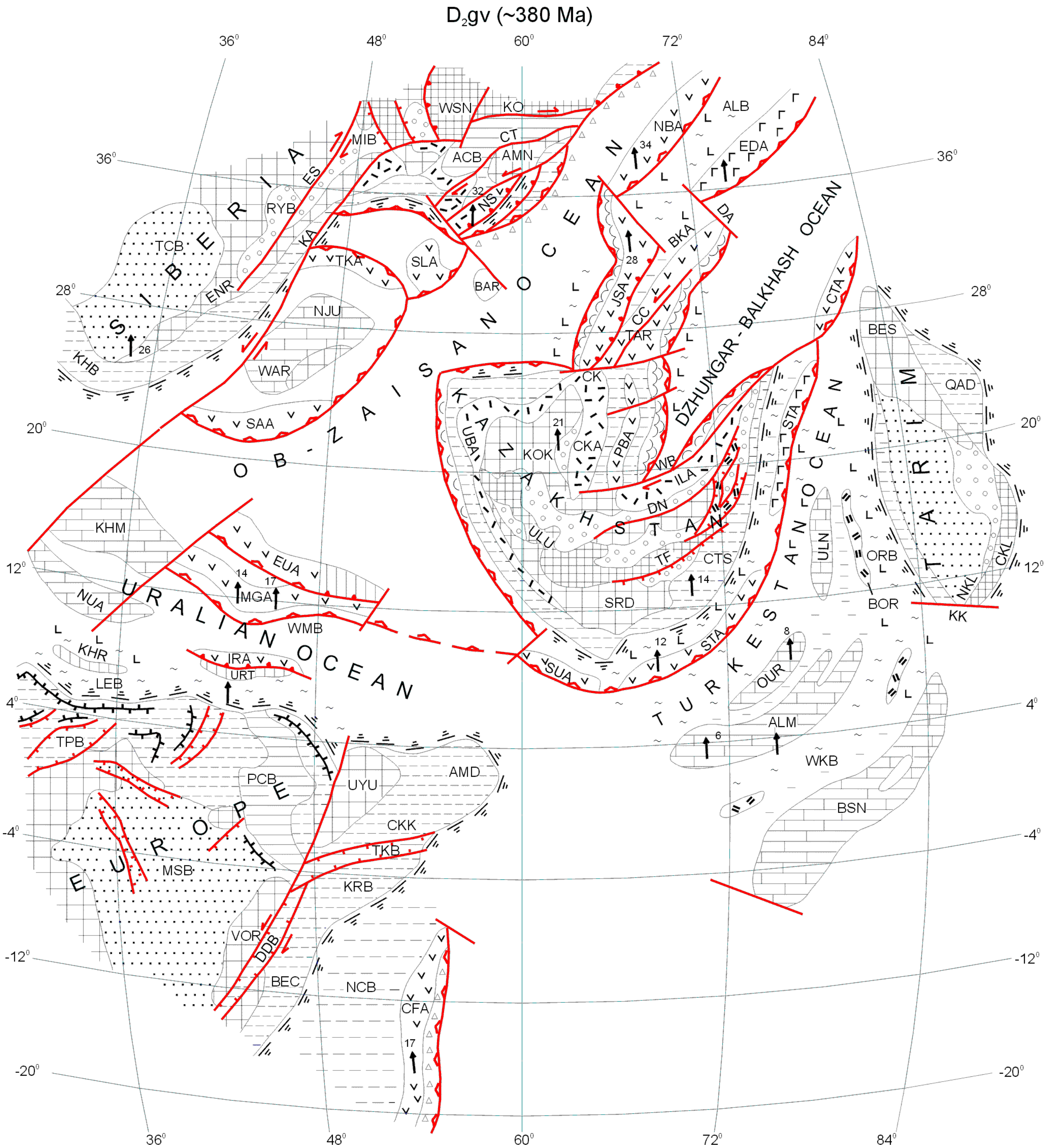

Figure 3. Palinspastic map for the Middle Devonian (Givetian, 380 Ma). Symbols, as in Figure 1.

most likely due to the Siberian continent rotating clockwise and to increasing compression between the Siberian craton and the Altay–Sayan structures [*Buslov,* 1998; *Buslov and Travkin,* 1997]. This kinematic pattern is evidently responsible for the opening of the Anyui–Chu (Delyun–Yustyd) backarc black shale trough, which temporarily separated the Altay–Mongolia block from the continent [*Berzin et al.,* 1994; *Zonenshain et al.,* 1990].

In the northeastern, Sino-Mongolian, part of the ocean, two roughly parallel island arc systems, whose subduction zones (except that of the Zharma–Saur arc) had maintained their southern vergence, kept converging with the Siberian margin and with one another. Both systems migrated into moderate northern latitudes [*Didenko and Morozov,* 1999; *Pechersky and Didenko,* 1995]. Most arcs entered their maturity phase.

The island arc systems began accreting onto Kazakhstan. The Bairlyk–Kainda arc alongside Chinghiz and Tarbagatay docked along strike-slip faults onto central Kazakhstan. The Zharma–Saur arc nearly collided with Tarbagatay, owing to which the subduction zone flipped to its back-arc side.

Kazakhstan volcanic belts associated with the subducting Junggar–Balkhash oceanic plate underwent a rearrangement. The subduction zone jumping oceanward caused the volcanic front in the Ili belt to shift into central and southern Junggaria [*Skrinnik and Senkevich,* 1996]. In the Emsian forearc region, deformed during the Telbes orogenic phase, the Balkhash ensialic volcanic arc emerged. The latite–shoshonite volcanism in the roughly N–S trending branch of the central Kazakhstan belt terminated [*Kurchavov et al.,* 2000]. The Balkhash arc alongside the Bairlyk–Kainda arc, with the latter having accreted onto Kazakhstan, were incorporated into a single island arc system that formed over the subduction zone, which had flipped into the ocean, into northern Junggaria [*Zonenshain et al.,* 1990]. Rapidly converging active margins of central, southern, and eastern Kazakhstan brought about a dramatic narrowing of the Junggar–Balkhash Ocean to as little as 700–900 km.

At the end of the Devonian (Famennian, 360 Ma), the oceans shrank dramatically and the continents, nearly all of them rotating steadily clockwise, clustered at 60°E, 20°N, where Kazakhstan was located (Figure 4). An oblique continent-continent collision involving all the continents set on, while oceanic crust kept subducting beneath Kazakhstan and Siberia in all the remnant basins.

Euroamerica shifted 400–500 km northeastward. The Uralian margin, which stretched WNW between 8°N and 16°N, maintained its environment of a vast carbonate platform modified by the relatively deep water Kama–Kinel rift-related trough filled by the Domanik facies sediments [*Puchkov,* 2000]. The continent's southeastern margin (Bechasyn–Karabogaz block) was gradually splitting off the mainland along the NW-propagating Dneper–Donets rift [*Zonenshain et al.,* 1990].

Siberia kept rotating clockwise about a pole located virtually at the center of the paleocontinent. Its Khatanga–Yenisei passive margin migrated from 26°N to 30°N, into the vicinity of Norilsk.

The Kazakhstan continent, judging from paleomagnetic data [*Burtman et al.,* 1988b], maintained its orientation and position at subtropical latitudes but converged with South Uralian oceanic-margin structures. The continent's margins, except for the Junggar–Balkhash one, turned into passive carbonate platforms. Tarim drifted as far as 19°N into the subtropical zone of the Northern Hemisphere [*Burtman et al.,* 1998a; *Li et al.,* 1995] and rotated somewhat clockwise due to its collision with the Chinese Tien Shan island arc, which involved closure of the northernmost part of the Turkestan Ocean [*Li et al.,* 1995].

Eastern Europe converging with Kazakhstan caused a "soft" collision of South Uralian ocean-margin structures with the continent, which did not manifest itself in the North Urals. This resulted from an oblique collision of Uralian and European structures, which propagated over time from the South to North Urals [*Puchkov,* 2000; *Zonenshain et al.,* 1990].

In the Late Devonian, the Polar Urals (the Nauntin–Nyrdvomenshor zone) provided a locus for new oceanic crust generation in the Uralian–Arctic basin, incepted at the junction of the Eastern European continent and the Tagil accretionary system [*Ruzhentsev and Didenko,* 1998]. The basin was insignificant, ca. 500–700 km in width. The principal formative cause of the basin's opening was differential rotations of the paleocontinents that had converged by that time, the Polar Uralian margin of the Eastern European continent rotating counterclockwise relative to Siberia.

In the west, between Euroamerica and Siberia, an oceanic crust–floored basin called the Angayucham Ocean existed [*Parfenov et al.,* 1999]. Rift-related structures of this basin probably extended eastward, bifurcating into the Ob–Zaisan and Uralian–Arctic arms (Figure 4). The latter pinched out in an easterly direction, passing into the embryonic South Uralian rift structure, and opened westward, where the Novaya Zemlya bathyal suites have Late Paleozoic age, whereas fold deformations are Cymmerian.

In the South Urals, the Magnitogorsk arc accreting onto the Eastern Uralian one and Ural-Tau structures gave rise to a fold-and-thrust edifice with landward propagating thrust sheets. The growing Ural-Tau uplift supplied turbidites forming flysch sequences (Zilair Formation and correlatives thereof) on both its sides. These sequences overlapped a major northern part of the Sakmara marginal sea, and Devonian structures accreted onto Ural-Tau [*Pavlenko et al.,* 2001]. Apparently, in the terminal Famennian to initial Carboniferous, the West Uralian zone of the Eastern European continental margin was overthrust by the first allochthons (Sakmara, Kraka), composed of juxtaposed ophiolitic nappes, various Ordovician–Silurian assemblages, and Devonian olistostromes [*Puchkov,* 2000; *Ruzhentsev et al.,* 2001]. The northwestern part of the Magnitogorsk volcanic arc kept operating with relict oceanic crust subducting under it. In the North Urals, the Lemva marginal sea continued to exist, and the North Urals arc, which had converged with the carbonate platform of the Khanty–Mansi massif, resumed its activity.

The Turkestan Ocean underwent a structural rearrangement as well. Its northern part closed, and the southern part was shrinking scissors-wise to 700 km at its widest point owing to the oblique subduction of the oceanic plate. The oceanic crust remaining at the Kazakhstan margin was being consumed under the South Tien Shan ensimatic arc, apparently linked with South Urals structures. The rest of the oceanic tract developed into a deep sea (bathyal) basin with clay, chert, and carbonate fill. Carbonate platforms in this basin drifted northward with the obliquely subducting oceanic plate.

A considerable rearrangement occurred in the Altay–Sayan area, where island arcs that had converged with the continent came into a tectonic contact with Altay Caledonian structures. The Salym arc alone kept converging rapidly with Kazakhstan.

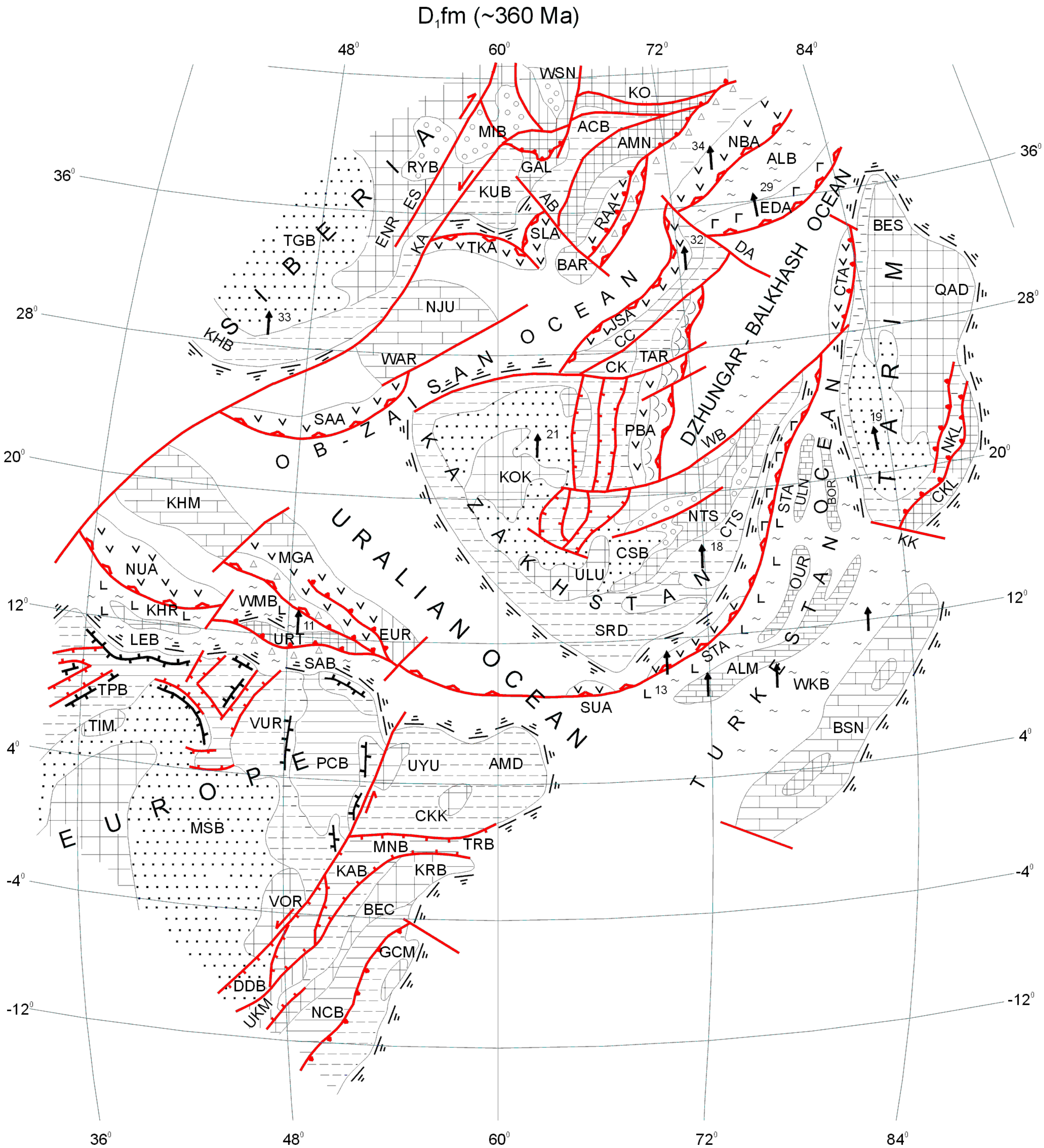

Figure 4. Palinspastic map for the Late Devonian (Famennian, 360 Ma). Symbols, as in Figure 1.

In the northeast, the beginning of collision between island arcs and the Mongolian margin of the Siberian continent led to the trapping of the Ob–Zaisan Ocean, which turned into a narrow gulf up to 300 km across linked with the Uralian Ocean. Its oceanic crust was subducting under the oppositely dipping Rudny Altay and Zharma–Saur island arcs.

Oceanic crust kept subducting under Kazakhstan on the side of the Junggar–Balkhash Ocean as well. The calcalkaline volcanic front (Balkhash arc) once again shifted oceanward into the Givetian accretionary prism [*Samygin et al.*, 1997] as the subduction zone jumped to a new position. In the backarc of this arc, along the Spassk and Uspensky zones, rift troughs, or a backarc spreading zone, formed that were marked by deep-water siliceous sediments and alkaline basalts. The eastern Junggar volcanic arc with its contiguous Junggar block was converging rapidly with the northern Barunkhuray arc, which had already docked onto the continent. In this manner, eastern Kazakhstan, via a system of island arcs, became all but amalgamated with Siberia. The Junggar Ocean declined in size to 400–600 km.

In the Early Carboniferous (Visean–Serpukhovian, 330 Ma), all the continents continued migrating northward while converging with each other and rotating clockwise (Figure 5). An oblique collision went on in the Urals, in the Turkestan Ocean, and along the south margin of Siberia, and suprasubduction volcanism resumed at Kazakhstan and Tarim margins.

The Eastern European continent drifted 400–600 km northeast and rotated 20° clockwise. Its Uralian passive carbonate margin stretched in a northwestern direction. The Siberian continent, while resting in place, continued rotating clockwise as before. Its Khatanga–Yenisei margin occurred between 32°N and 36°N. Kazakhstan, with a small amount of clockwise rotation, shifted in a northwesterly direction, heading into the reentrant between Siberia and Uralian structures. Tarim, which stayed in place at subtropical latitudes, kept rotating clockwise.

Due to an oblique collision, accretionary processes propagated into the North and Polar Urals, where flysch/turbidite sediments are reported to have been supplied from the Khanty–Mansi microcontinent with island arcs accreted onto it [*Puchkov,* 2000]. In the South Urals, the subduction zone flipped with a polarity reversal to the inner, ocean-margin, side of the accretionary massif that formed in Tournaisian time. Above the subduction zone, a calcalkaline andesitic suite of the East Uralian zone was accumulating, and on its inner side, in the Magnitogorsk zone, grabens with bimodal and alkali-basalt volcanism were formed in an oblique collision environment [*Seravkin,* 1997]. Once again, an extensive subduction zone came into being, dipping beneath Kazakhstan and marked by the Valeryanovsky volcanic belt, which ensured a rapid shrinking of the Uralian Ocean to 300–500 km through subduction on its two sides under the Urals and Kazakhstan.

The Ob–Zaisan Ocean also kept shrinking rapidly due to remnant island arcs and terranes accreting onto the Yenisei margin of Siberia. These enlarged the passive margin of the craton. In the median segment of the ocean, which kept shrinking through subduction on its two sides, volcanic margins of Siberia and Kazakhstan (the Rudny Altay and Zharma–Saur arcs) with oppositely dipping subduction zones kept converging. In the northeast, the continent's Mongolian margin, according to [*Samygin et al.,* 1997], collided with the partially accreted northern Barunkhuray and eastern Junggar island arcs and with the Almantaisky interarc basin. This nascent accretionary edifice, via the Darbut transform fault, linked eastern Kazakhstan with the Siberian continent and completed the trapping of the Ob–Zaisan basin on the east. Then, as the Salym arc collided with Kazakhstan, the Ob–Zaisan Ocean became fenced off in the west as well, turning into a trapped remnant oceanic basin. Its oceanic nature is corroborated by Visean red cherts, basalts, and limestones of Charsky District [*Bekzhanov et al.,* 2000; *Geological...,* 1979].

At Kazakhstan's active margins, a voluminous volcanism resumed. At the Uralian margin of the continent, the Andean-type Valeryanovsky volcanic belt was created [*Bekzhanov et al.,* 2000]. Above the oppositely dipping subduction zones of the Junggar–Balkhash Ocean, volcanic belts took shape on the Balkhash, southern Kazakhstan, and northwestern margins of Tarim [*Bekzhanov et al.,* 2000; *Chengzao et al.,* 1997]. The Balkhash volcanic belt, which overprinted all the structures of the Middle Paleozoic forearc, was composed of a differentiated calcalkaline suite with felsic rocks increasing in proportion toward the inner part of the belt. It extends northeastward into the newly formed Bogdoshan intraoceanic island arc with its subduction zone directed southeast, into the ocean [*Carrol et al.,* 1990]. This arc cut the Junggar deep water basin proper off the Junggar–Balkhash Ocean.

The Turkestan Ocean was closing time-transgressively in a southerly direction. Its northern segment between the converging Tarim and North Tien Shan was transformed into a remnant deep water trough with a condensed cover of cherts, clays, and carbonates [*Biske,* 1996; *Chengzao et al.,* 1997]. Oceanic crustal vestiges were being consumed under the South Tien Shan ensimatic arc, separated from Kazakhstan by a deep-water backarc basin. Carbonate shoals, such as the Alay microcontinent, shifted 500–600 km northeast from their Givetian locations to 13°N latitude. The first overthrusting event, accompanied by flysch forming along the thrust front, occurred at the ocean's southern margin, in the Zeravshan–eastern Alay zone [*Biske,* 1996]. In the inner part of the latter, along the Gissar suture, which separated the Zeravshan–eastern Alay zone from the Baisun microcontinent, the southern Gissar oceanic rift opened. Based on paleomagnetic evidence, its spreading axis occurred at 12°N, and the rift was no wider than 500 km [*Rzhevsky,* 1986]. The southern Gissar basin presumably extended into the Mangyshlak–Tuarkyr rift, the oceanic-margin portion of the Dneper–Donets aulacogen [*Popkov et al.,* 1985].

The terminal Middle to initial Late Carboniferous (305 Ma) was the epoch of principal continent–continent collisions (Figure 6) and formation of integrated Laurasia, one of the two supercontinents that were to constitute Pangea in Early Permian time [*Didenko et al.,* 1994; *Zonenshain et al.,* 1990]. The general collision of the Euroamerican, Kazakhstan, and Siberian continents began. A continuous roughly EW-trending continent came into being at subtropical and moderate latitudes in the Northern Hemisphere. The Uralian and Ob–Zaisan oceans underwent a complete closure. In their lieu, fold-and-thrust belts were created.

In the Urals, two oppositely vergent fold-and-thrust belts, West Uralian (comprised of its North and South Uralian parts) and East Uralian, were formed. These were separated by the undeformed Magnitogorsk zone [*Puchkov,* 2000]. In the South Urals, in front of the fold-and-thrust stack propagating onto the continent, the Uralian foredeep with typical flysch lithofacies that overlapped the continental shelf came

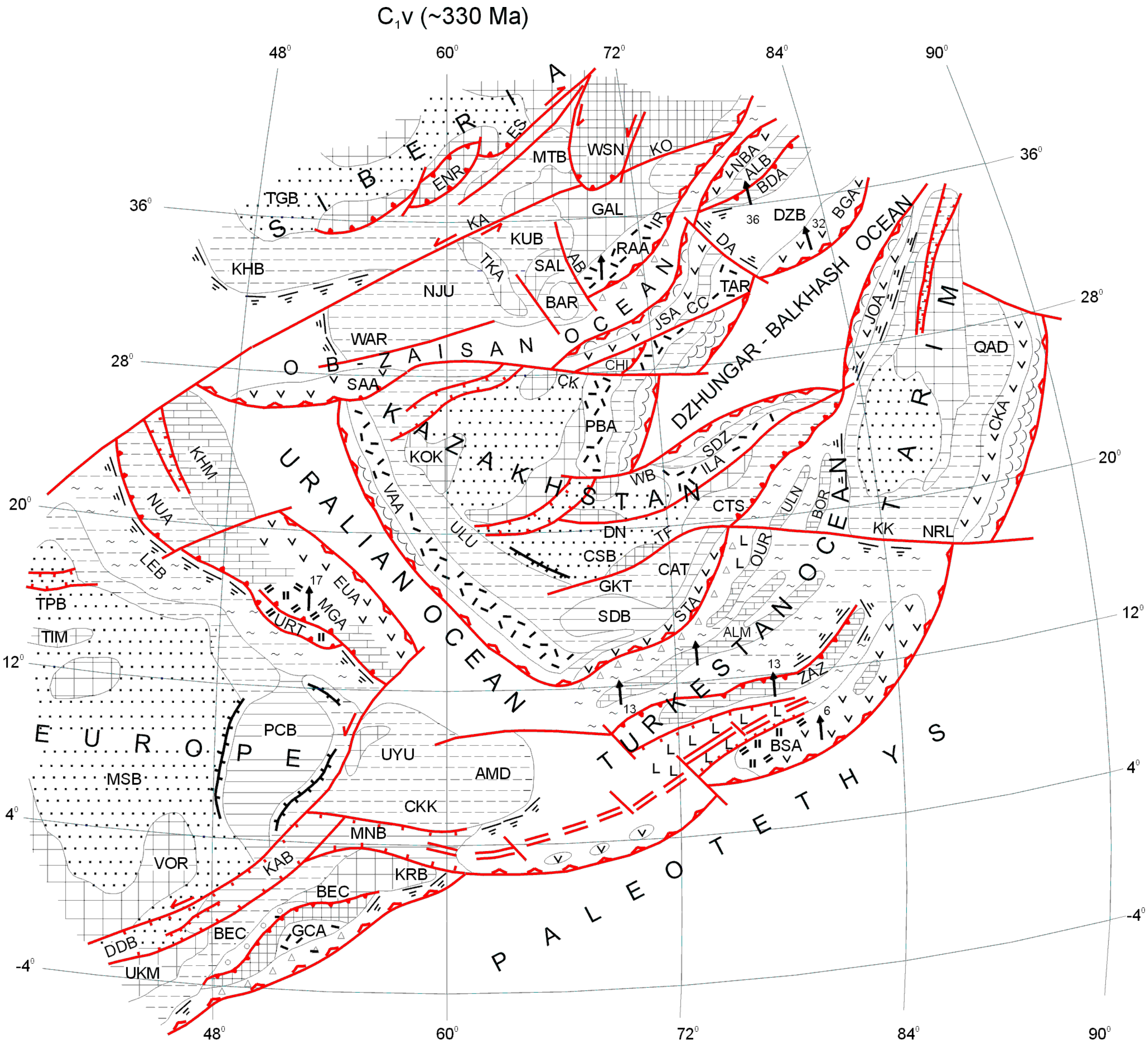

Figure 5. Palinspastic map for the Early Carboniferous (terminal Visean, 330 Ma). Symbols, as in Figure 1.

into being. In the North Urals, in the oblique collisional environment, the Lemva deep water basin still existed, being fed by flysch sediments supplied from the North Urals orogenic edifice.

The Magnitogorsk zone represented a median trough between two oppositely vergent thrust belts. Terrigenous flysch accumulated in its interior, giving way marginward to molasse and carbonate facies [*Puchkov,* 2000]. The flysch trough, which persisted until the terminal Carboniferous, in all likelihood extended into flysch/olistostrome filled troughs in the northern part of South Tien Shan.

Collision processes between Siberia and Kazakhstan varied in their particulars from locality to locality along the junction of the two continents. The Salym fold-and-thrust belt came into existence due to the crushing of its homonymous island arc between the Vartovsk-Nyurolka microcontinent and Kazakhstan. Simultaneously, Kazakhstan docked along a strike slip to structures of the Khanty–Mansi block, which was located northeast of the Polar Urals. Nappes were generated in frontal parts of the Salair and Barnaul blocks as these were overthrusting the Kuzbass basin. Further east, the Mongolian margin of the Siberian continent was growing by accretion onto it of deformed island arcs and interarc basins, with a general southward thrusting of structures toward the Junggar oceanic gulf [*Ruzhentsev et al.,* 1992]. On top of the accretionary basement, continental calcalkaline volcanism resumed along the western terminus of the southern Mongolian continental-margin volcanic belt, above the

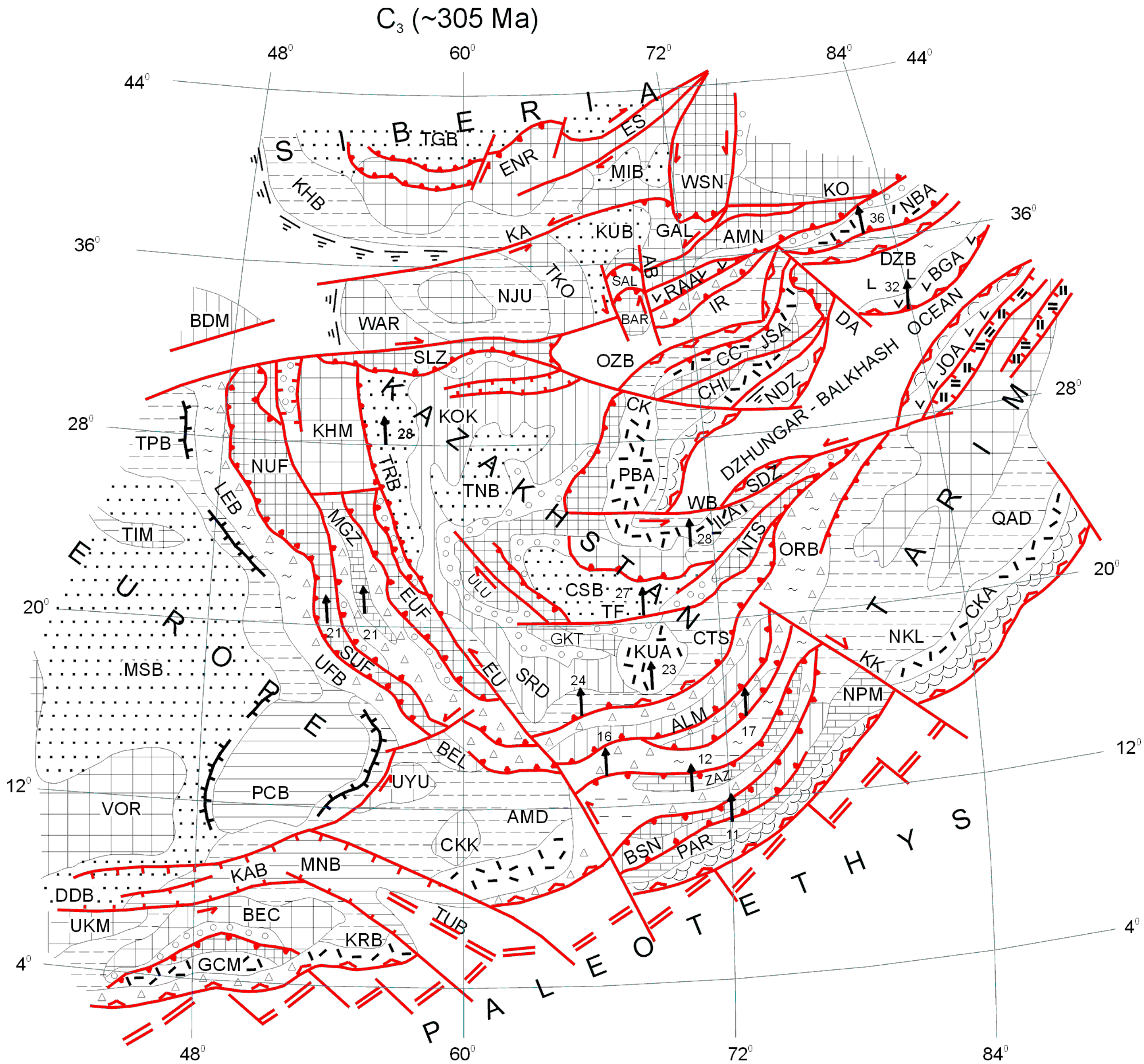

Figure 6. Palinspastic map for the beginning of the Late Carboniferous (305 Ma). Symbols, as in Figure 1.

subduction zone that had flipped into the Junggar basin. It was only in the vicinity of Lake Zaisan that a remnant trough with Taubinsky Fm. flysch and olistostrome survived temporarily between the converging continental margins [*Geological...,* 1979].

In Moscovian time, as Kazakhstan collided with Tarim and the accretionary Afghan–Tajik continent, closure affected virtually the entire Turkestan Ocean [*Ruzhentsev et al.,* 1977]. In South Tien Shan, a system of foredeeps and inner troughs with flysch/olistostrome fills formed in connection with converging thrusts that propagated southward near Kazakhstan and northward near the Afghan–Tajik microcontinent [*Biske,* 1996]. It was due to the oblique collision that the nappes are younging southward [*Chen et al.,* 1999]. The earliest, northern, nappes originated in Bashkirian time owing to the Baubashata–Ulan carbonate platform thrusting under ophiolitic and greenschist assemblages. The youngest, southern, nappes were generated in late Moscovian time as an outcome of Alay microcontinent crust underthrusting Kazakhstan [*Biske,* 1996]. Northward vergent nappes in the southern South Tien Shan, originating as early as Visean time, are characterized by large displacements. Where the converging thrust fronts met, bathyal troughs (Vashan–Kalmakasuisky and Ortosuisky) remained as vestiges of the past ocean. South Tien Shan thrust piles converged along a sinistral strike slip with the East Urals foldbelt.

Subduction processes went on throughout the margins of

Figure 7. Palinspastic map for the Early Permian (280 Ma). Symbols, as in Figure 1.

the rapidly closing Junggar–Balkhash oceanic gulf. Volcanism continued almost incessantly on the Kazakhstan and Tarim margins and in the Bogdoshan island arc [*Bekzhanov et al.,* 2000; *Carrol et al.,* 1990; *Chengzao et al.,* 1997]. As before, volcanic belts and arcs remained linked by transform strike slips (western Balkhash, central Kazakhstan, and Darbut).

At the beginning of the Early Permian (Asselian–Sakmarian, 280 Ma), all the continents were joined together to complete the formation of the Laurasian supercontinent, which then became incorporated into Pangea [*Zonenshain et al.,* 1990]. Central Eurasia provided a stage for the aggregation of the Eastern European, Siberian, Kazakhstan, Tarim, and Afghan–Tajik continents (Figure 7), with paleomagnetic data [*Didenko,* 1997] indicating a sharp decline in the rate of their northward drift and clockwise rotation. All the continents were situated in the subtropical to moderate belt of the Northern Hemisphere. Coeval paleomagnetic data from Late Paleozoic rocks offer further evidence that in Early Permian time the formation of the enormous Urals–South Tien Shan, Salym–Ob–Zaisan, and Junggar orogenic arcs achieved its completion [*Didenko,* 1997; *Didenko and Morozov,* 1999; *Klishevich and Khramov,* 1995].

The Urals–South Tien Shan belt in the shape of a wide southwest-convex arc separated Kazakhstan from the Eastern European, Afghan–Tajik, and Tarim continents. In the Urals, manifestations of the collision included the stacking of thrust sheets with a predominant western vergence, mountain building, generation of anatectic granites and granite–gneiss domes along the Main Granite Axis of the Urals, and the foredeep propagating into the North and Polar Urals [*Puchkov,* 2000]. In the south of the foredeep, flysch sequences overlapped the continental carbonate shelf, while in the north, a narrow bathyal area still existed between flysch sequences and a barrier reef.

Based on paleomagnetic evidence, the South Tien Shan fold-and-thrust belt and Kazakhstan jointly made up a tectonically coherent block with paleolatitudes changing in a systematic manner from south to north [*Burtman et al.,* 1998a; *Klishevich and Khramov,* 1995; *Pechersky and Didenko,* 1995]. The belt maintained a converging pattern of its fold-and-thrust structures, vergent southward in its northern part and northward in its southern part, or the Bukantau–Kokshaal and Gissar–eastern Alay thrust belts, respectively [*Biske,* 1996]. Through the oblique collision of Kazakhstan and Tarim, the foldbelt narrowed abruptly from 400 to 100 km in a northeasterly direction. Along its median transect, the South Tien Shan belt was cut by the Talas–Fergana and Kara-Kunlun dextral strike slips, along which a sinistral horizontal flexure was formed [*Burtman et al.,* 1998a], whereas the Suluterek block, a portion of Tarim, was displaced northward. The Vashan–Kalmakasuisky remnant trough was transformed into a foredeep with its molasse fill giving way to slope flysch sequences of the Tarim foreland [*Biske,* 1996]. In various parts of the South Tien Shan foldbelt, minor collisional granite massifs were emplaced.

The collision of the Siberian continent with Kazakhstan reached completion, and the Ob–Zaisan remnant basin finally vanished. The trace of the extinct ocean is currently marked by the Charsky ophiolite belt and by ophiolites on its northwestern extension into the basement of the Western Siberian basin. Along the boundary of the two continents, the Ob–Zaisan foldbelt took shape with its fold-and-thrust structures propagating from north to south [*Zonenshain et al.,* 1990]. Its western extension is the Salym foldbelt, incepted in Late Carboniferous time. At margins of the continents, especially of Siberia, collision brought about the thrusting of Salair and Kuznetsky Alatau onto the Kuzbass basin, of the Vartovsk–Nyurolka block onto the Tom–Kolyvan zone, and of the Western Sayan onto the Gorny Altay. The termination of collision processes was marked by collisional granites on both continental margins, in particular, by the emplacement of batholiths of the Kalabinsky complex in the Ob–Zaisan belt, Rudny Altay, and the Altay–Mongolia block.

Differential movements and rotations of continents combined with preceding oblique collision phenomena resulted in extensive lengthwise strike slip displacements, dextral in the Urals and sinistral in South Tien Shan and along Siberian margins [*Biske,* 1996; *Burtman et al.,* 1998a; *Klishevich and Khramov,* 1995].

The counterclockwise rotation of southern Kazakhstan and its collision with northern Balkhash and northern Junggar structures caused a complete obliteration of the Junggar–Balkhash and Junggar oceanic basins and jamming of the subduction zones. The Junggar foldbelt came into being. Collision-disrupted fragments of oceanic plates sinking into the upper mantle still kept producing calcalkaline volcanism in southern Kazakhstan and the northern Barunkhuray and Bogdoshan remnant island arcs and bimodal alkalic magmatism in the volcanic belts of eastern Kazakhstan [*Carroll et al.,* 1990; *Kurchavov,* 1994; *Kurchavov and Yarmolyuk,* 1984]. There, ancient transform faults were turned into major strike slip faults, such as the western Balkhash, central Kazakhstan, Chinghiz, and Darbut ones. From paleomagnetic data [*Li et al.,* 1992, 1995], complete trapping of basins had not yet occurred. They were turned into molasse-filled and remnant nearshore basins [*Carroll et al.,* 1990].

In Late Permian time, the consolidation of structures of the Central Asian foldbelt culminated in the formation of major strike slips. The rotation of Siberia relative to Euroamerica and Kazakhstan terminated, to be followed at the beginning of Triassic time by Siberia's passive Kuzbass margin colliding with the Nyurolka microcontinent to give rise to the Tom–Kolyvan fold-and-thrust arc, whose ends joined with the Irtysh–Salym and Paikhoi–Kuznetsky strike slips. The latter merges in the northwest with its coeval Novaya Zemlya fold-and-thrust arc with an opposite vergence. After collision processes in the East Urals, northern Kazakhstan, and West and East Siberia had terminated, Early Triassic within-plate flood magmatism set on, heralding the Mesozoic scenario for the northern part of Asia.

Convergent Boundaries Within the Paleo-Asian Ocean

Our study shows that the shrinking and subsequent extinction of the oceans followed by collision was controlled by the three extensive and long-lived (100–130 m.y.) Urals–Turkestan, Junggar, and Siberian subduction belts thousands of kilometers long, whose polarities remained stable (Figure 8). These belts were comprised of systems of roughly parallel or branching, relatively short-lived (10–30 m.y.) subduction zones plunging dominantly north or northwest, to use stratigraphic reference frame, under intraoceanic island arcs and continental margins. Within the Urals–Turkestan and Junggar belts, both intraoceanic and continental-margin subduction zones plunged toward the Kazakhstan continent. Subduction zones of the Siberian belt plunged beneath Siberia. A characteristic feature of the subduction belts is that, over time, particular subduction zones shifted systematically toward the ocean. Nearing the instant of a collision or accretion, subduction zones reversed their polarity and flipped to the inner side of island arcs that had docked to or approached the continent. Characteristically, just prior to collision, short-lived subduction occurred on two sides of the ocean, plunging under the continents that had approached one another.

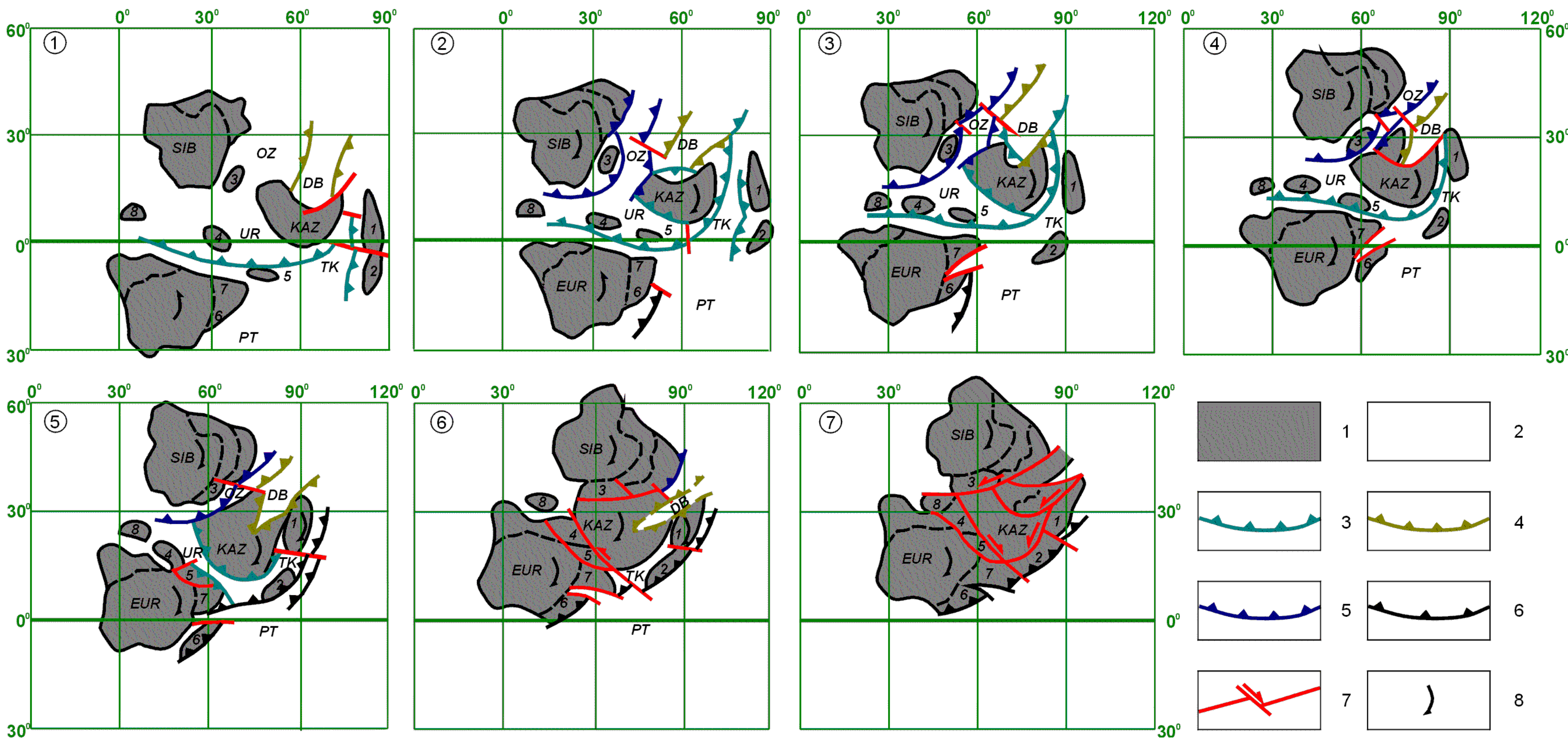

Figure 8. Schemes showing geodynamic evolution of the Central Asian foldbelt (omitting contiguous areas): 1-Early Silurian, 2-Early Devonian, 3-Middle Devonian, 4 - Late Devonian, 5 - Early Carboniferous, 6 - Late Carboniferous, 7 - Early Permian. Symbols: 1 - continents and microcontinents, 2 - oceans and backarc basins, 3 - Urals-Turkestan subduction belt, 4 - Junggar-Balkhash subduction belt, 5 - Siberian subduction belt, 6 - Paleo-Tethyan subduction zones, 7 - other structural sutures and principal strike slip faults, 8 - sense of rotation of continental blocks. Acronyms denote continents (EUR = European, SIB = Siberian, KAZ = Kazakhstan) and oceans (UR = Uralian, TK = Turkestan, DB = Junggar-Balkhash, OZ = Ob-Zaisan, PT = Paleo-Tethys). Numerals mark microcontinents and continental blocks: 1 - Tarim, 2 - Baisun, 3 - Vartovsk-Nyurolka, 4 - Khanty-Mansi, 6 - Bechasyn-Karabogaz, 7 - Ustyurt-Karakum-Amu-Darya, 8 - Baydaratsky.

Taken together, the subduction belts formed a pattern diverging to the southwest. In the southwest, they were separated by the Kazakhstan continent and in the northeast, within the Sino-Mongolian space, they merged into a single belt. This diverging pattern allowed for differential, slow for Europe and fast for Siberia, rotations of the neighboring Precambrian cratons. The Urals–Turkestan belt took shape at the beginning of the Silurian, and the Siberian and Junggar belts, at the beginning of the Devonian. The subduction belts died out through crushing between continents during the general collision in the mid-Carboniferous; the Junggar belt alone ceased to exist as late as the beginning of the Permian.

The Urals–Turkestan subduction belt was a long-lived feature. It was incepted in the Middle to terminal Ordovician, with its subduction zones advanced far into the ocean and accompanied by the Tagil, East Urals, and South Tien Shan ensimatic island arcs. In Silurian time, the belt became as long as 3000 km, and its activity culminated in the Early to Middle Devonian with the formation of a large, up to 8,000 km long, branching system of subduction zones that succeeded each other through time and space toward, and plunged under, Kazakhstan. Above them, the intraoceanic Irendyk, Magnitogorsk, East Urals, Sultan-Uizdag, South Tien Shan, and Chinese Tien Shan island arcs emerged, which were responsible for the suprasubduction volcanism on the Uralian and North Tien Shan margins of Kazakhstan. By the Early Carboniferous, the activity of the Urals–Turkestan belt began to decline: subduction continued only along Kazakhstan margins (Valeryanovsky, Kurama, and South Tien Shan volcanic arcs), while in the South Urals a new subduction zone dipping under Europe came into being with a resultant rapid closure of the ocean through subduction on its two sides and a complete jamming of the belt by the terminal mid-Carboniferous.

The Junggar subduction belt resulted from subduction of the Junggar–Balkhash oceanic plate under Kazakhstan. Within this belt, subduction zones were relatively short-lived and shifted systematically oceanward. The belt was incepted in the Silurian and existed until the terminal Carboniferous, reaching its maximum activity and size, up to 2000 km, in the Early Devonian and Early to Middle Carboniferous, when the Kazakhstan and NW Tarim active margins and the Bairlyk–Kainda–eastern Junggar and Bogdoshan intraoceanic island arcs were formed. A considerable part in this belt's architecture belonged to the western Balkhash, central Kazakhstan, and Darbut transform faults, which predetermined the tectonic boundaries between many of the island arcs. The jamming of the Junggar subduction belt had occurred by the beginning of the Permian, when the Junggar–Balkhash oceanic basin had vanished completely through subduction on its two sides, and structures of its northern and southern rims collided.

The Siberian subduction belt was almost 4000 km long. In terms of its position, this belt was largely inherited from the Early Paleozoic subduction belt located at the present southern margin of Siberia. It started developing in the Early Devonian, following the collision in Late Silurian time between the Altay–Sayan structures and the Siberian craton, as the Ob–Zaisan oceanic plate was subducting under the newly formed continental margin and the system of intraoceanic island arcs that kept migrating oceanward. In southern Mongolia and NW China, the Siberian and Junggar subduction belts merged together, forming a system of parallel intraoceanic subduction zones: Zharma, Saur–northern Barunkhuray, and Bairlyk–Kainda–eastern Junggar. In the mid-Carboniferous, the onset of collision between Kazakhstan and Siberia completed the annihilation of the Siberian subduction belt. Its eastern part remained inherited, through Late Carboniferous to Permian time, by the southern Mongolian subduction belt, which plunged under the Laurasian continent, formed in Permian time, and underwent jamming as late as Triassic time.

Conclusions

Available geologic and paleomagnetic evidence suggests that the Urals and South Tien Shan were the site of an oblique collision that propagated through time and space. Within the Uralian belt, the collision set on in the Middle Carboniferous in the South Urals and terminated by the end of the Early Permian in the North and Polar Urals, the formation of the orogen reaching its completion at the beginning of the Triassic on Novaya Zemlya. Within South Tien Shan, the oblique collision [*Chen et al.,* 1999] began in the Late Devonian as the northwest margin of Tarim collided with Chinese North Tien Shan structures. In Middle to Late Carboniferous time, collision propagated to the southwest, and in Early Permian time, South Tien Shan structures suffered a general crushing between Kazakhstan and the Tarim–Baisun continent. In both belts, collision processes spanned 45–50 m.y.

The oblique mode of the collision and previous differential rotations of the colliding continents resulted in syn- and post-collisional lengthwise strike slips, dextral in the Urals and sinistral in South Tien Shan and along the Siberian margin. Strike slip systems like this are an innate feature of oblique collision, as observed, e.g., along the Meso-Cenozoic margin of Eastern Asia [*Paleogeographic Atlas...,* 1997].

The extensive, over 8000 km long, and long-lived (up to 130 m.y.) Middle to Late Paleozoic subduction belts of the Central Asian foldbelt with their subduction zones plunging persistently under continents and an oblique mode of subduction are similar in terms of their particulars to the Meso-Cenozoic subduction belts of the Tethys Ocean [*Kazmin,* 1999] and Circum-Pacific belt running along Asia's eastern margin [*Paleogeographic Atlas...,* 1997]. Such belts are likely surface expressions of descending mantle convection flows that ensure long-lasting sinking of oceanic plates into the mantle [*Kazmin,* 1999]. Taken together, they are a counterpart of the Mediterranean mobile belt, beneath which seismic tomography evidence reveals a vast, roughly EW-trending high-velocity anomaly at depths of 700–1700 km in the mantle, suggestive of a huge mass of high-density, relatively low-temperature material existing below the belt [*Mossakovsky et al.,* 2001]. These workers attribute the formation of this anomaly to long-lasting processes of sinking of large volumes of cold lithospheric plates in the mantle, which took place in subduction belts as oceans were closing.

In light of the above, another intriguing issue is worth notice, namely, central Eurasian subduction belts changing their location across the earth's surface. Absolute motions of island arcs within the northwestern segment of the Pacific Ocean in Meso-Cenozoic times have already been discussed [*Shapiro et al.,* 1997], and we focus on such motions as regards Paleozoic subduction belts. The reconstructions clearly show that these deep-seated structures migrated systematically northward, probably ensuring the migration of continents in the same direction. Thus, over a period of 130 m.y. from the Early Silurian, the Urals–Turkestan belt drifted 25° (from 10°S to 15°N latitude) with Euroamerica and Tarim following passively together with it while rotating clockwise. The Siberian subduction belt, jointly with the Siberian continent, rotated 60°–70° clockwise, changing its strike from NE to almost EW, whereas its western part also traveled 25° northward, from 10°N to 35°N latitude. Kazakhstan, which mimicked strike changes experienced by the subduction belt, converged with this belt while rotating, like Siberia, ca. 60° clockwise, the principal phase of Kazakhstan's rotation spanning ca. 10 m.y. (Emsian–Eifelian).

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References

Bekzhanov, G., V. Koshkin, I. Nikitchenko, et al., *Geologic Structure of Kazakhstan* (in Russian), 394 pp., Gylym, Almaty, 2000.

Berzin, N., R. G. Coleman, N. Dobretsov, et al., Geodynamic map of the western part of the Paleo-Asian Ocean (in Russian), *Geol. Geofiz., 35,* (7–8), 8–29, 1994.

Biske, Yu., *Paleozoic Structure and History of South Tien Shan* (in Russian), 189 pp., St. Petersburg University, St. Petersburg, 1996.

Burtman, V., Some problems of the Paleozoic tectonic reconstructions in Central Asia, *Geotectonics, 3,* 262–270, 1999.

Burtman, V., G. Gurary, A. Belenky, A. Ignatiev, and M. Audibert, Turkestan Ocean in the Middle Paleozoic: A reconstruction using paleomagnetic data from the Tien Shan, *Geotectonics, 1,* 11–22, 1998a.

Burtman, V., G. Gurary, A. Belenky, and I. Kudasheva, Kazakhstan and the Altai in the Devonian: Paleomagnetic evidence, *Geotectonics, 6,* 479–487, 1998b.

Burtman, V., G. Gurary, A. Dvorova, N. Kuznetsov, and S. Shipunov, The Uralian paleocean in Devonian time (As Inferred from Paleomagnetic Data), *Geotectonics, 5,* 397–406, 2000.

Buslov, M., *Terrane tectonics and geodynamics of mosaic/block type folded areas: A case study in the Altay–Sayan and eastern Kazakhstan regions* (in Russian), Ph. D. thesis, Novosibirsk, 1998.

Buslov, M., and V. Travin, *Terrane tectonics and geodynamics of mosaic/block type folded areas: A case study in Central Asia* (in Russian), program and abstract presented at the Tectonics of Asia meeting, Moscow, 1997.

Carroll, A. R., Y. Liang, S. A. Graham, et al., Junggar basin, northwest China: Trapped Late Paleozoic ocean, *Tectonophysics, 181,* 1–4, 1990.

Chen Chuming, Huafu Lu, Dong Jia, Dongsheng Cai, and Shimin Wu, Closing history of the southern Tianshan oceanic basin, Western China: An oblique collisional orogeny, *Tectonophysics, 302,* 23–40, 1999.

Chengzao, J., et al., *Tectonic characteristics and petroleum of Tarim basin, China,* 295 pp., Retz. Ind. Press, Beijing, 1997.

Dergunov, A., Caledonides of the Central Asian, 192 pp., Nauka, Moscow, 1989.

Didenko, A., *Paleomagnetism and geodynamic evolution of the Urals–Mongolia foldbelt* (in Russian), abstract of Ph. D. thesis, Moscow, 1997.

Didenko, A., and O. Morozov, Geology and paleomagnetism of Middle–Upper Paleozoic rocks from the Saur range (Eastern Kazakhstan), *Geotektonika, 4,* 64–80, 1999.

Didenko, A., and D. Pechersky, Paleomagnetism of the Shuldak sheeted dikes complex (in Russian), *Izv. Akad. Nauk SSSR, Fiz. Zemli, 9,* 75–80, 1986.

Didenko A.N., Pechersky D.M., Paleomagnetism of the Middle Paleozoic ophiolite complexes from Alay range, *Geotectonika,* (4), 56–68, 1988.

Didenko, A., A. Mossakovsky, D. Pechersky, et al., Geodynamics of Paleozoic oceans of Central Asia (in Russian), *Geol. Geofiz., 35,* (7–8), 59–76, 1994.

Didenko, A., S. Kurenkov, S. Ruzhentsev, et al., *Tectonic History of the Polar Urals* (in Russian), 191 pp., Nauka, Moscow, 2001.

Dobretsov, N., N. Berzin, and M. Buslov, Opening and tectonic evolution of the Paleo-Asian Ocean, *Inter. Geol. Rev., 37,* 335–360, 1995.

Gao J., Li M., Xiao X., et al., Paleozoic tectonic evolution of the Tianshan Orogen, Northwestern China, *Tectonics, 287,* 213–234, 1998.

Elkin, E., N. Sennikov, M. Buslov, et al., Paleogeographic reconstructions for the western part of the Altay–Sayan area in the Ordovician, Silurian, and Devonian and their geodynamic interpretation (in Russian), *Geol. Geofiz., 35,* (7–8), 118–140, 1994.

Geological map of the Kazakh Soviet Socialist Republic, scale 1:500,000, Eastern Kazakhstan series, Explanatory Note (in Russian), Alma-Ata, 1979.

Gordienko, I. V., and N. E. Mikhaltsov, Position of the Vendian Early Cambrian ophiolites and Island arc complex of Dzhidinsky zones of the Caledonides in structure of the Paleoasia Ocean according to paleomagnetic data (in Russian), *Dokl. Ross. Akad. Nauk, 379,* (4), 508–513, 2001.

Kazmin, V., Mobility of subduction zones and of a subduction belt (in Russian), *Dokl. Ross. Akad. Nauk, 366,* (4), 526–529, 1999.

Kepezhinskas, P., K. Kepezhinskas, and I. Pukhtel, Lower Paleozoic oceanic crust in Mongolian Caledonides: Sm-Nd isotope and trace element data, *Geophys. Res. Lett., 18,* (7), 1301–1304, 1991.

Khain, V., and V. Lomize, *Geotectonics with Fundamentals of Geodynamics* (in Russian), 480 pp., Moscow State University, Moscow, 1995.

Khain, E., E. Bibikova, K. Degtyarev, et al., Paleo-Asian Ocean in the Neo-Proterozoic and Early Paleozoic: New isotope geochemical evidence, in *Geologic Development of Proterozoic Pericratonic and Paleoceanic Structures of Northern Eurasia* (in Russian), pp. 175–181, Tema, St. Petersburg, 1999.

Klishevich, V., and A. Khramov, A paleogeodynamic model for the Urals–Tien Shan folded system for the Early Permian (in Russian), *Dokl. Ross. Akad. Nauk, 341,* (3), 381–385, 1995.

Klootwijk, C., Phanerozoic configurations of Greater Australia: Evolution of the North-West Shelf, Pt. One: Review of reconstruction models, 105 pp., Austral. Geol. Surv. Organis. Record 1996/51.

Kovalenko, D., Tectonic implications of horizontal-plane rotations of geologic blocks during island arc–continent collision, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 294–297, Geos, I, Moscow, 2001.

Kurchavov, A., Lateral variability in the evolution of orogenic volcanism in foldbelts (in Russian), *Geotektonika, 2,* 3–11, 1994.

Kurchavov, A., The issue of original geodynamic setting of Devonian continental magmatism in Kazakhstan, Central Asia, and Western Siberia, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 351–354, Geos, I, Moscow, 2001.

Kurchavov, A., and V. Yarmolyuk, Distribution of Permian continental volcanics in Central Asia: A tectonic interpretation (in Russian), *Geotektonika, 4,* 75–89, 1984.

Kurchavov, A., M. Grankin, E. Malchenko, et al., New data on the structure of the Devonian volcanic belt of northeastern central Kazakhstan (in Russian), *Dokl. Ross. Akad. Nauk, 358,* (1), 83–86, 1998.

Kurchavov, A., M. Grankin, E. Malchenko, V. Zhukovskii, B. Khamzin, A. Mazurov, and S. Khamza, Zoning, segmentation, and paleogeodynamics of the Devonian volcanic belt in central Kazakhstan, *Geotectonics, 4,* 284–293, 2000.

Kurenkov, S., and V. Aristov, Timing the formation of the crust of the Turkestan paleocean (in Russian), *Geotektonika, 6,* 22–31, 1999.

Kuzmin, M. I., I. V. Gordienko, and A. I. Akmukhamedov, History of the Paleoasia Ocean, *Geology and Geophysics, 36,* (1), 3–18, 1995.

Li Yongan, Li Yanping, M. Williams, et al., Paleomagnetic study of the Northern Xinjiang, *Xinjiang Geology, 10,* (4), 237–327, 1992.

Li Yongan, Li Qicang, Zhang Hui, et al., Paleomagnetic study of Tarim and its adjacent area as well as the formation and evolution of Tarim basin, *Xinjiang Geology, 13,* (4), 293–376, 1995.

Matveenkov, V., Lava morphology and basalt petrology from mid-oceanic ridges with different spreading rates (in Russian), *Geotektonika, 3,* 47–59, 1983.

Miyashiro, A., Volcanic rock series in island arcs and active continental margins, *Amer. J. Sci., 274,* (4), 321–355, 1974.

Mizens, G., Sedimentation basins and paleotectonics of the South Urals in the Middle Devonian to Early Permian, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 32–35, Geos, 2, Moscow, 2001.

Mossakovsky, A., S. Ruzhentsev, S. Samygin, et al., Central Asian belt: Geodynamic evolution and history of formation (in Russian), *Geotektonika, 6,* 3–32, 1993.

Mossakovsky, A., Yu. Pushcharovsky, and S. Ruzhentsev, The Indo-Atlantic segment of the earth, in *Tectonics and Geodynamics of the Continents* (in Russian), 2001.

Muratov, M., Geosynclinal foldbelts of Eurasia (in Russian), *Geotektonika, 6,* 4–19, 1965.

Muratov, M., *The Urals–Mongolia belt, in Tectonics of the Urals–Mongolia foldbelt* (Proc. of a conference) (in Russian), pp. 5–11, Nauka, Moscow, 1974.

Paleogeographic Atlas of Northern Eurasia, Eds.: Kazmin V., and L. Natapov, 26 sheets, Institute of Plate Tectonics, Moscow, 1997.

Paleomagnitology, Ed. Khramov A. N., 312 pp., Nedra, Leningrad, 1982.

Parfenov, L., W. J. Nokleberg, J. W. H. Monger, et al., Terrane collage formation in orogenic belts of the North Pacific margin (in Russian), *Geol. Geofiz., 40,* (11), 1563–1574, 1999.

Pavlenko, T., O. Anikeeva, B. Golionko, et al., Modern structural setting and paleogeography of the Late Devonian–Tournaisian rock complexes of the South Urals, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 91–94, Geos, 2, Moscow, 2001.

Pechersky, D., and A. Didenko, *Paleo-Asian Ocean: Petromagnetic and Paleomagnetic Information on Its Lithosphere* (in Russian), 296 pp., Moscow, 1995.

Piper J.D.A., Proterozoic paleomagnetism and single continental plate, *Geophysical Journal, 74,* (1), 163–197, 1983.

Popkov, V., O. Yapaskurt, and A. Demidov, Basement rocks of the southwestern Turan plate (in Russian), *Sov. Geol., 9,* 110–113, 1985.

Puchkov, V., Structure and geodynamics of Uralian orogen, *Geolog. Soc. Spec. Publ., 121,* 201–236, 1997.

Puchkov, V., *Paleogeodynamics of the South and Central Urals* (in Russian), 144 pp., Dauriya, Ufa, 2000.

Rozman, Kh., and A. Tsukernik, A find of Early to Middle Ordovician brachiopods in the Gobi Altay, southern Mongolia (in Russian), *Dokl. Ross. Akad. Nauk, 301,* (5), 1180–1182, 1988.

Ruzhentsev, S., and A. Didenko, Tectonics and geodynamics of the Polar Urals, in *Tectonics and Geodynamics: General and Regional Aspects* (in Russian), pp. 133–135, Geos, 2, Moscow, 1998.

Ruzhentsev, S., I. Pospelov, and A. Sukhov, Tectonics of the Kalaykhumb–Sauksai zone, northern Pamir (in Russian), *Geotektonika, 4,* 68–81, 1977.

Ruzhentsev, S., I. Pospelov, and G. Badarch, Tectonics of the Barunkhuray basin, Mongolia (in Russian), *Geotektonika, 1,* 94–110, 1992.

Ruzhentsev, S., Kh. Rotman, and N. Minzhin, Timing the formation of the Southern Mongolian Ocean (in Russian), *Dokl. Ross. Akad. Nauk, 319,* (2), 451–455, 1991.

Ruzhentsev, S., M. Gaptulkadyrov, and V. Aristov, On the age of chert and chert/volcanic sequences in the Lemva zone, Polar Urals, *Dokl. Ross. Akad. Nauk, 349,* (1), 78–80, 1996.

Ruzhentsev, S., V. Aristov, K. Degtyarev, et al., Thrust sheets and the olistostrome assemblage of the Kuvandyk-Mednogorsky area, Sakmara zone, South Urals, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 159–163, Geos, 2, Moscow, 2001.

Rzhevsky Yu.S., Paleomagnetism of the igneous and sedimentary rocks from Gissar range (South Tyanshan), *Magnitostratigrapy and paleomagnetism,* pp. 64–78, VNIGRI, Leningrad, 1986.

Samygin, S., S. Ruzhentsev, I. Pospelov, et al., The Variscan transform zone in Junggaria: An attempt of delineation, in *Tectonic and Geodynamic Phenomena* (in Russian), pp. 196–220, Nauka, Moscow, 1997.

Scotese, C. R., and J. Golonka, *Paleogeographic Atlas,* PALEOMAP Project. Dept. of Geol., 32 pp., Univ. of Texas, Arlington, 1993.

Scotese C.R., Bambach R.K., Barton C. et al., Paleozoic Base Maps, *Geology, 87,* 217–277, 1979.

Sengör A.M.C., Natal'in B.A. Turkic-type orogeny and its role in the making of the continental crust, *Annu. Rev. Earth Planet. Sci., 24,* 263–337, 1996.

Sengör, A. M. C., B. Natal'in, and V. Burtman, Evolution of the Altaide tectonic collage and Paleozoic crustal growth in Eurasia, *Nature, 34,* (6435), 299–307, 1993.

Sengör, A. M. J., B. Natalin, and V. Burtman, Tectonic evolution of the Altaids (in Russian), *Geol. Geofiz., 35,* (7/8), 41–58, 1994.

Seravkin, I., Southern Urals: Tectono-Magmatic zoning and position among orogenic systems of the Urals–Mongolia belt, *Geotectonics, 1,* 27–42, 1997.

Shapiro N.M., Pechersky D.M., and Lander A.V., About rate and direction absolute muvoments of the subduction zones in geological time, *Geotectonika,* (2), 3–13, 1997.

Shokalsky, S., A. Vladimirov, and A. Izokh, Correlating Middle Paleozoic magmatic events with the issue of geodynamics of the Gorny Altay (in Russian), *Dokl. Ross. Akad. Nauk, 349,* (6), 808–810, 1996.

Skrinnik, L., and M. Senkevich, Rock associations and zonation of the southern segment of the Devonian volcanic belt in Kazakhstan (in Russian), *Geologiya Kazakhstana, 4,* (346), 28–43, 1996.

Smethurst, M. A., A. Khramov, and T. H. Torsvik, The Neoproterozoic and Paleozoic paleomagnetic data for the Siberian platform: From Rodinia to Pangea, *Earth Sci. Rev., 43,* (1), 1–24, 1998.

Yazeva, R., and B. Bochkarev, Post-collisional Devonian magmatism in the North Urals, *Geotektonika, 4,* 56–65, 1993.

Yazeva, R., and B. Bochkarev, Reconstructing fossil subduction and collisional systems in the structure of the Urals, in *Tectonics of the Neogean: General and Regional Aspects* (in Russian), pp. 337–341, Geos, 2, Moscow, 2001.

Zonenshain, L., and V. Matveenkov (Eds.), *History of Develop-*

ment of the Uralian Paleocean (in Russian), 164 pp., Institute of Oceanology, USSR Academy of Sciences, Moscow, 1984.

Zonenshain, L., M. Kuzmin, and M. Kononov, Reconstructing positions of the continents in the Paleozoic and Mesozoic (in Russian), *Geotektonika, 3,* 16–27, 1987.

Zonenshain, L., M. Kuzmin, and L. Natapov, *Plate tectonics of the USSR* (in Russian), Book 1, 326 pp., Book 2, 334 pp., Nedra, Moscow, 1990.

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