ACCRETIONARY HISTORY OF NORTHEAST ASIA

Leonid M. Parfenov, Yakutian Institute of Geological Sciences, Siberian Branch, Russian Academy of Sciences, 39 Lenin Prospekt, Yakutsk 677891, Russia

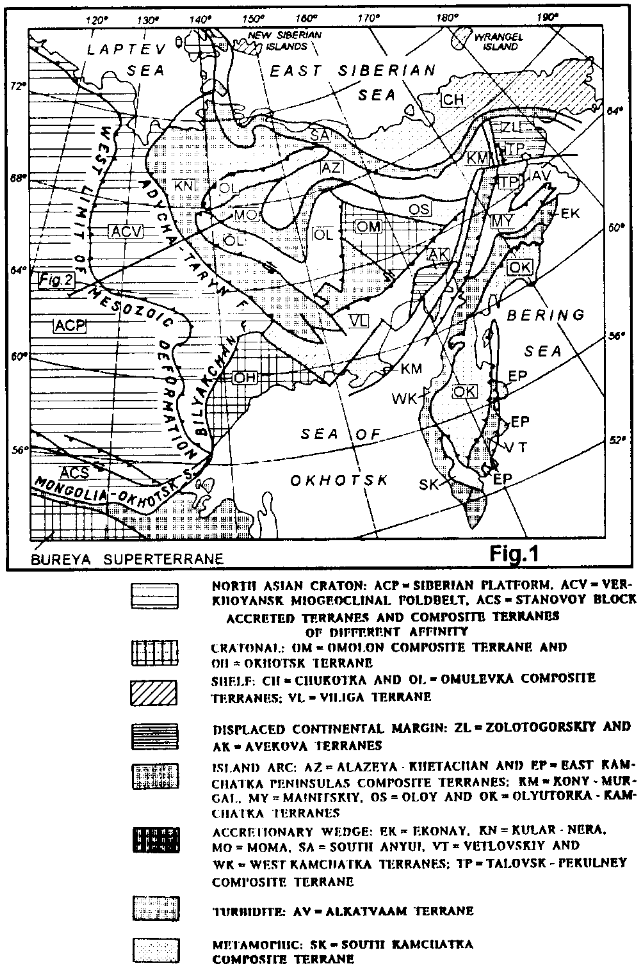
ABSTRACT

Middle-Late Devonian rifting resulted in detachment of a number of large blocks from the eastern margin of the North Asian craton. These blocks, which now form the Omulevka and Omolon composite terranes, were displaced southward towards the Paleo-Pacific in late Paleozoic time. Paleomagnetic data indicate that they were farthest away from the craton (up to 35°) in Late Permian to Early Triassic time. In Late Triassic time, they reversed their movement back towards the craton. At that time, the Alazeya-Khetachan, Koni-Murgal, and other island arcs were formed. In late Middle Jurassic time, the collision of the Omulevka and Omolon composite terranes with the Alazeya-Khetachan arc led to the formation of the Kolyma-Omolon superterrane. The superterrane and the North Asian craton collided between 134 and 144 Ma. Accretion of the Chukotka composite terrane to the craton occurred in pre-Albian time and was related to the opening of the Canada basin. The Albian to Late Cretaceous Okhotsk-Chukotsk volcano-plutonic belt defines the position of the active margin of Asia at that time. In late Late Cretaceous to Paleocene, Middle Eocene, and Pliocene times, the active margin of Asia was progressively displaced towards the Pacific, its position being defined by the Kamchatka-Koryak, Central Kamchatka, and East Kamchatka volcano-plutonic belts, respectively. Toward the Pacific, these belts are associated with forearc basins and accretionary wedges to which a number of large terranes representing mainly island arc and accretionary wedge fragments have been accreted.

INTRODUCTION

Northeast Asia includes part of a giant Mesozoic-Cenozoic orogenic belt that extends from the Siberian platform to the North American craton and from the Pacific to the Arctic Oceans. Mesozoic orogenic belts are located to the east of the Siberian platform and extend from the Sea of Okhotsk in the south and east, to the Arctic Ocean in the north. They have a mosaic-like structure (Fig.1). Typical of the area are isometric rigid blocks with a Precambrian basement surrounded by linear zones with variable trends. Along the periphery of the Pacific Ocean, within the area of the Koryak Highlands and Kamchatka Peninsula, the Mesozoic orogenic belts are replaced by linear Cenozoic foldbelts. Northeast Asia, like Alaska and the North American Cordillera, is made of terranes of different types and ages that were accreted to the North Asian craton in Mesozoic and Cenozoic time (Fujita, 1978; Fujita and Newberry, 1982, 1983; Parfenov and Natal'in, 1985; Parfenov, 1984, 1991; Watson and Fujita, 1985; Stavsky et al., 1988; Khramov and Ustritsky, 1990; Zonenshain et al., 1990). A preliminary terrane map of northeast Asia shows the distribution of these terranes as well as the post-amalgamation and post-accretionary assemblages (Parfenov et al., 1993a, 1993b).

This paper represents an effort to delineate the most general patterns in the accretionary history of northeast Asia based on terrane analysis. The ideas presented here will undoubtedly be refined as reliable and detailed paleomagnetic and paleobiogeographical data increase.



Major terranes and composite terranes in northeast Asia (modified from Parfenov et al. 1993). Post-amalgamation and post-accretionary assemblages are omitted. The straight line shows the location of the paleotectonic cross-sections shown in Fig.2.

NORTH ASIAN CRATON

The term "North Asian craton" was introduced by Kosygin et al. (1964) but has not been extensively utilized. It is more general than the term "Siberian platform" and its revival seems to be very important now, because it is relative to the North Asian craton that we estimate the displacements of terranes that make up the surrounding orogenic belts.

The North Asian craton is the stable rigid core of northern Asia. Paleomagnetic data (summarized by A. N. Khramov and V. P. Rodinov in Parfenov, 1991) suggest that it resulted from the amalgamation of some major early Precambrian blocks about 850-600 Ma. The craton includes the eastern part of the Siberian platform, the Verkhoyansk miogeoclinal foldbelt on the buried craton margin to the east, and the uplifted Stanovoi blocks south of the platform (Fig.1).

The Siberian platform consists of an early Precambrian metamorphic basement and a late Precambrian to Phanerozoic cover with local thicknesses of up to 14 km (Gusev et al., 1985). The platformal cover consists of late Precambrian and early Paleozoic limestone, dolomite, marl, shale, siltstone, and sandstone. Middle to Upper Devonian and Lower Carboniferous red-colored sandstone, dolomite, conglomerate, gypsum, rock salt, and alkali basalt fill in several major rift basins (Gaiduk, 1988). Late Paleozoic and Mesozoic deposits include alluvial, marine-littoral, and shallow-water sandstone, siltstone, shale, and conglomerate. Cenozoic formations are represented by weathering crusts and alluvial and lacustrine accumulations.

The Verkhoyansk miogeoclinal foldbelt is separated from the Siberian platform by a Late Cenozoic frontal thrust belt (Parfenov and Prokopiev, 1993). The Vendian (750-800 Ma) to Early Devonian was marked by the formation of a carbonate platform on the eastern margin of the craton, the result of the preceding Riphean rifting (800-1600 Ma) (Fig.2). Middle to Late Devonian rifting substantially modified the carbonate platform. At that time, several triple rift systems were formed (Fig.3). Their failed branches are traced in the eastern parts of the Siberian platform (Gusev et al., 1985; Gaiduk, 1988; Parfenov, 1984, 1991). Devonian rifting brought about the formation of the Verkhoyansk passive margin of the Siberian continent, which consists of thick Carboniferous, Permian, Triassic, and Jurassic marine-littoral, deltaic, and shelf clastic sequences that are replaced eastward by deep-water black shale deposits (Bulgakova et al., 1976, and Parfenov, 1984, 1991).

The Stanovoi block is an uplifted and deeply eroded margin of the craton. It consists of Archean and Early Proterozoic gneiss and schist and is separated from the platform by a set of Early Cretaceous east-west thrusts and left-lateral strike-slip faults.

The southern boundary of the North Asian craton is the Mongol-Okhotsk suture made of late Precambrian to early Paleozoic ophiolites and complexly deformed volcanic-siliceous and graywacke sequences of Paleozoic, Triassic, and Lower to Middle Jurassic age (Parfenov, 1984; Natal'in and Borukaev, 1991). The southeastern boundary of the craton is located along the Bilyakchan fault, which separates the craton from the Okhotsk terrane. According to paleomagnetic data, the Okhotsk terrane was part of the craton in Riphean time (Pavlov et al., 1991) but was located at a distance of 30° southward from the craton in the Middle to Late Triassic (Zonenshain et al., 1990).

The northeastern boundary of the craton is defined differently by different authors. 1) The boundary is defined by the Chersky Range ophiolites, which occur near the eastern margin of the Omulevka composite terrane made of early to middle Paleozoic, mainly carbonate deposits, similar to carbonate platform formations of the craton. In this case, the composite terrane is regarded as part of the craton (Fujita and Newberry, 1982; Natapov and Stavsky, 1985). Paleomagnetic data indicate that in the Riphean (Komissarova, 1991), Ordovician, Silurian, Devonian, and Early Carboniferous, the Omulevka composite terrane was at the same latitude as the craton, while in middle Late Jurassic time it was 1500-2000 km to the south (Neustroev et al., 1993). 2) Blocks combined in the Omulevka composite terrane are thought to be exotic and accreted to the craton during the second half of the Mesozoic (Zonenshain et al., 1990). In this case, the boundary of the craton is drawn along thrusts and strike-slip faults that separate the composite terrane from Mesozoic

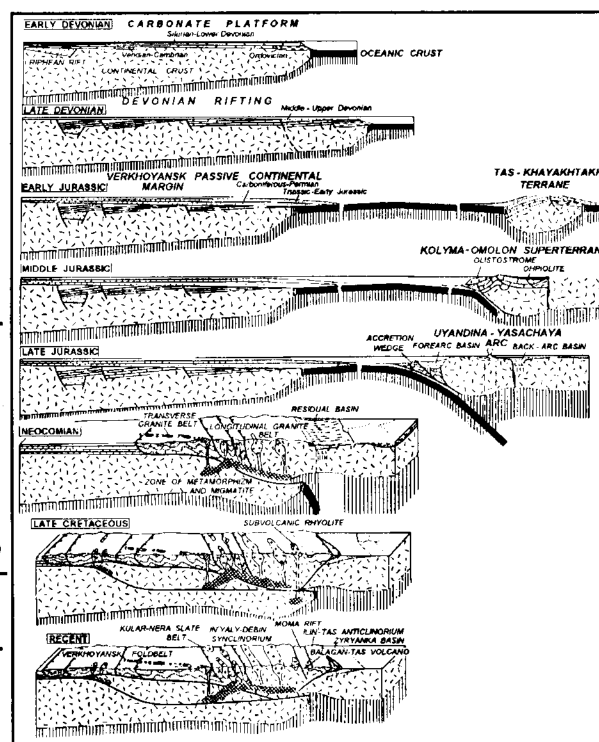


Fig.2. Speculative paleotectonic cross-sections showing the history of the eastern margin of the North Asia craton and its collision with the Kolyma-Omolon superterrane. See Fig. 1 for location. Vendian (750-800 Ma) to Early Devonian: formation of a carbonate platform on the eastern margin of the craton formed by prior Riphean rifting (800-1600 Ma). Middle to Late Devonian: rifting substantially modified the carbonate platform and detached from it a number of blocks. Devonian rifting brought about the formation of the Verkhoyansk passive margin. Pre-Bathonian (Middle Jurassic): formation of the Kolyma-Omolon superterrane accompanied by obduction of ophiolites and formation of a Bathonian to Callovian olistostrome with fragments of Paleozoic carbonate rocks, metamorphic schists, and ophiolites. Late Jurassic: subduction of oceanic crust adjacent to the Verkhoyansk margin beneath the superterrane led to the formation of the Uyandina-Yasachnaya volcanic arc. Permian and Triassic sediments were scraped off the ocean crust to form an accretionary wedge. The forearc basin is composed of Middle to Late Jurassic turbidites. The backarc basin formed as a result of secondary extension and is composed of Kimmeridgian alkaline basalt and Kimmeridgian to Tithonian turbidites which are succeeded by Neocomian coal-bearing deposits of the Zyryanka basin. Late Jurassic to Early Neocomian: collision of the Kolyma-Omolon superterrane and the Verkhoyansk passive margin caused the formation of extensive longitudinal and transverse granite belts. Latest Cretaceous: folding started on the margin of the Kolyma-Omolon superterrane and terminated in the formation of frontal thrusts along the boundary of the Siberian platform. Late Cenozoic: isostatic uplift and formation of the modern mountainous relief. Maximum uplift took place in the Chersky Range along the suture between the Kolyma-Omolon superterrane and the Verkhoyansk passive margin. Miocene time was marked by the formation of the Moma rift with the Balagan-Tas volcano forming as a result of local extension.

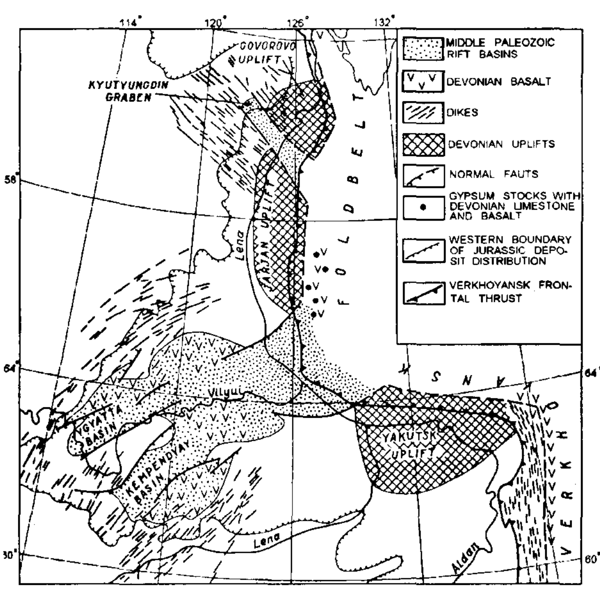


Fig.3 Middle Paleozoic rift structures east of the Siberian platform, which are identified on the basis of drilling and geophysical data.

formations to the west. 3) West of the Omulevka composite terrane, there are Triassic, Lower Jurassic, and locally Permian deep-water black shales of the Kular-Nera slate belt (Parfenov, 1991). These deposits are regarded as the most distal accumulations of the Verkhoyansk passive margin, which formed at the continental rise and in a basin floored with oceanic crust (Parfenov, 1984; Zonenshain et al., 1990). During the collision of the Verkhoyansk passive margin with the Kolyma-Omolon superterrane in Late Jurassic time (see below), the deposits were scraped off the oceanic crust to form the accretionary wedge of the Uyandina-Yasachnaya volcanic arc that existed on the margin of the superterrane (Fig.2). According to this interpretation the cratonic boundary is drawn along the Adycha-Taryn fault (Fig.1), which shows evidence of large thrust and subsequent left-lateral strike-slip motions that separate the superterrane from the Kular-Nera slate belt (Parfenov, 1991).

ACCRETED TERRANES, COMPOSITE TERRANES, AND SUPERTERRANES

A tectonostratigraphic terrane (terrane) is a fault-bounded geologic entity of regional extent that is characterized by a unique geologic history different from that of neighboring terranes (Jones et al., 1983; Howell et al., 1985). All terranes to the east of the North Asian craton suffered some displacement and/or rotation with respect to it and to each other (Fig.4). Within the Mesozoic orogenic belts of northeast Asia, the available paleomagnetic data, thought rather limited and sometimes controversial, indicate that some terranes have undergone translations relative to the craton of up to 2500-4000 km and rotations up to 150° (Khramov, 1984, 1986, 1991; Rodionov, 1991; Neustroev et al., 1993). There are also rare discoveries of Tethian fauna, for example, in the Upper Triassic of the Yarakvaam terrane (Afitsky, 1970), while neighboring terranes contain contemporaneous complexes of typical boreal faunas. Discoveries of Tethian fauna are more common in the Cenozoic orogenic belts of the Koryak Highlands and Kamchatka (Bychkov and Dagis, 1984; Ustritskiy and Khramov, 1987; Sokolov, 1988; Bragin, 1991). Paleomagnetic data show larger translations of terranes of this eastern region than those in the Mesozoic orogenic belts. Some of them moved 6000-7000 km during Late Jurassic to Late Cretaceous time (Didenko et al., 1990) and 4000 km during the Late Cretaceous to Middle Eocene (Savostin and Kheifets, 1988; Gurevich and Surkis, 1991).

In order to simplify paleotectonic reconstructions, some adjacent terranes of close affinity (Parfenov et al., 1993a, 1993b) are combined into composite terranes as defined by Plafker (1990). Within these terranes and composite terranes of the Mesozoic orogenic belts, there are fragments of the North Asian craton (Okhotsk cratonal terrane, Omolon cratonal composite terrane, and Omulevka shelf composite terrane), which were detached from the craton as a result of Devonian rifting and reattached to it in the second half of the Mesozoic. The Chukotka composite terrane, which forms a single unit with the North Slope composite terrane of Alaska, represents a fragment of the North American craton that was detached as a result of the opening of the Canada Basin of the Arctic Ocean (Plafker, 1990). There are also terranes that consist of fragments of island arcs (Alazeya-Khetachan composite terrane, Koni-Murgal terrane), continental margin arcs (Yarakvaam and Zolotogorsk terranes), and accretionary wedges (Alyuchin, Adycha, Moma, and South Anyui terranes).

The central part of the Mesozoic orogenic belts of northeastern Asia is occupied by the large Kolyma-Omolon superterranes, which are made up of large angular terranes and composite terranes of continental affinity (Omolon and Omulevka), as well as island arcs (Alazeya-Khetachan and Oloi), accretionary wedge terranes (Moma), and smaller composite terranes. These were amalgamated into a single unit in late Middle Jurassic time, prior to their accretion to the North Asia craton in late Late Jurassic to Early Neocomian time. These terranes are overlain with angular unconformity by late Middle to Late Jurassic shallow-water-sedimentary and volcanogenic-sedimentary formations.

Cenozoic orogenic belts of the Koryak Highlands and Kamchatka contain terranes and composite terranes mainly of oceanic affinity (Parfenov et al., 1993a, 1993b): the Vetlovsky and West Kamchatka accretionary wedge terranes, Olyutorka-Kamchatka and East Kamchatka Peninsulas island arc terranes, and composite terranes. The South Kamchatka metamorphic composite terrane of unknown nature is located in southern Kamchatka Peninsula.

TIMING OF TERRANE ACCRETION

The collision of the Kolyma-Omolon superterrane with the North Asian craton produced two great longitudinal granite belts (main and northern) and a number of transverse ones (Parfenov, 1991) (Fig. 5). The granites cut many large thrusts along the periphery of the superterrane suturing it to the craton. $^{40}Ar/^{39}Ar$ dating of the main belt granites yield ages of 134-144 Ma (Hackett et al., 1992). The northern belt seems somewhat younger. One of the massifs of this belt is dated at 120 Ma by the $^{40}Ar/^{39}Ar$ method; K/Ar ages of the northern belt granites vary from 140 to 118 Ma (Bakharev et al., 1988).

Post-accretionary volcano-plutonic belts of different ages are a characteristic feature of northeast Asia. Some of them extend for 2000 km following the Pacific margin. These belts become younger in age closer to the Pacific Ocean. They consist of gently dipping continental calc-alkaline volcanics and associated granites of the magnetite

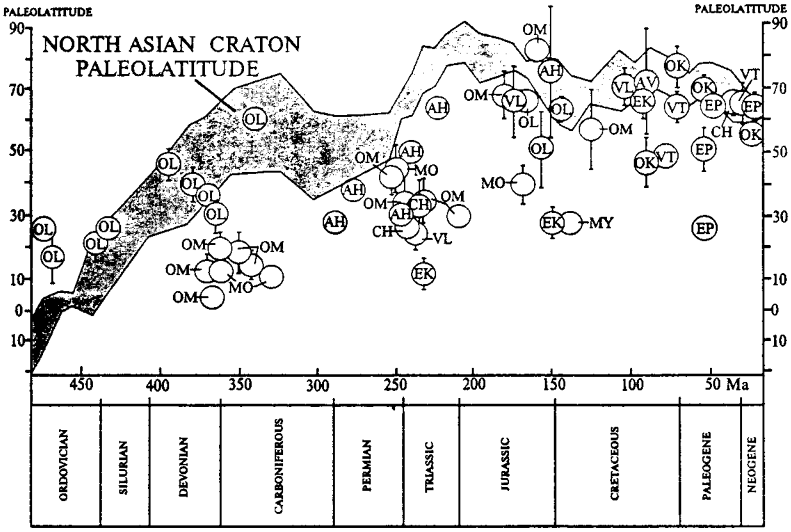


Fig.4. Available paleomagnetic data for northeast Asia plotted on a diagram of paleolatitude versus time (compiled by A.P. Neustroev). The centers of circles represent the paleomagnetic latitude for terranes of northeast Asia and vertical bars represent the 95-percent confidence limits. The paleolatitude curve of North Aisan craton is based on Khramov (1991) for the Siberian platform recalculated from a locality in its center (64° lat. and 115° long.). Paleomagnetic data for the terranes were recalculated for the same locality.

series, which unconformably overlie many of the terranes and, in some cases, a cratonic margin as well.

The volcano-plutonic belts define the positions of the earlier active continental margin of eastern Asia. Close to the Pacific Ocean margin, they are associated with forearcbasins and accretionary wedges. The oldest, the Late Jurassic to Neocomian Uda belt, occurs along the southeast margin of the craton and overlies the adjacent Okhotsk and Viliaga terranes. The Albian to Late Cretaceous Okhotsk-Chukotsk belt overlies the Uda belt and extends farther northeastward up to Chukotka. To the east of the Okhotsk-Chukotsk belt the Maastrichtian to Miocene Kamchatka-Koryak belt, the Late Eocene to Quaternary Central Kamchatka belt, and the Pliocene to Recent East Kamchatka belt are displaced sequentially toward the Pacific Ocean. This displacement of the volcano-plutonic belts and the corresponding active continental margins is due to sequential accretion to the continent of terranes brought by the Paleo-Pacific Ocean crust subducting beneath its margin. Timing of the accretionary events is defined by the age of the lower horizons of the volcano-plutonic belts. This enables the delineation of terranes that were accreted in the Late Neocomian (pre-Albian), Albian to Late Cretaceous, late Senonian to Paleocene, Early to Middle Eocene, and Oligocene to Miocene (Fig.5).

MAIN FEATURES OF THE TECTONIC EVOLUTION

According to plate tectonic reconstructions of the Arctic region between Asia and North American during the Paleozoic (Zonenshain et al., 1990), there was a relatively narrow oceanic basin located on the continuation of the Ural and West Siberian oceans and opening into the Paleo-Pacific. The Late Silurian to Early Devonian was marked by the widest opening of the Ural and West Siberian oceans according to the reconstructions of S. May (pers. comm., 1992). The collision of Europe and North America that took place at that time was followed by a short-term convergence of North America and Siberia. I am not aware of whether this event is supported by the available worldwide paleomagnetic data but one cannot dismiss the fact that the given interpretation well explains the Early Devonian orogenic events. These are expressed by angular unconformities at the base of the Devonian in a number of terranes in Northeast Asia, particularly exposures of the Chukotka composite terrane on Wrangel Island, in the Okhotsk terrane, in the Omolon composite terrane, and in the Prikolyma and Rassokha terranes of the Omulevka composite terrane. The same orogenic event might also be responsible for the erosion of Devonian deposits in the southeastern part of the North Asian craton, where Carboniferous rocks unconformably overlie Silurian, Ordovician, and Cambrian deposits. Westward, on the margin of the craton and over the greater part of the Omulevka composite terrane, no unconformities at the base of the Devonian are present.

Middle Devonian to Early Carboniferous calc-alkaline volcanites and granites are characteristic of the Omolon composite terrane and the Okhotsk and Oloi terranes. It is suggested these terranes are fragments of the Middle Paleozoic continental margin volcanic arc recently delineated in western North America (Plafker, 1990). The available paleomagnetic data on the Upper Devonian of the Omolon composite terrane (Khramov, 1984, 1986) agrees with this hypothesis.

Related to the closing of the West Siberian and Ural Oceans that continued up to the end of the Permian was the divergence of Asia and North America. The process was accompanied by rifting on the eastern margin of the North Asian craton and the detachment of a number of blocks that moved south toward the Paleo-Pacific Ocean. Rifting commenced in the Middle Devonian, while the break-up of the continental crust and the detachment of the largest blocks probably occurred in the Visean (Early-Carboniferous). This time was marked by an abrupt deepening of the Verkhoyansk passive margin and the formation of peculiar chaotic slump melanges and the accumulation of deep-water chert-clay deposits. The detached blocks were farthest from the craton in Late Permian to Early Triassic time, based on the available paleomagnetic data. Paleomagnetic data also indicate, as noted above, that the Omulevka composite terrane belonged to the North Asian craton in Riphean (Komissarova, 1991), Ordovician, Silurian, Devonian, and Early Carboniferous time, while in the Middle to Late Jurassic, it was 1500-2000 km to the south (Neustroev et al., 1993). Unfortunately, data on the late Paleozoic to Early Mesozoic are missing here. The Okhotsk terrane was a part of Siberia in the late Precambrian (Pavlov et al., 1991) while in the Middle to Late Triassic it was 30° to the south (Zonenshain et al., 1990). The Omolon terrane was 500 km away from Siberia in the Late Devonian and farthest away (4000 km) in the Late Triassic (Neustroev et al., 1993).

In Late Permian to Early Triassic time, Siberia collided with the North Taimyr - Severnaya Zemlya terrane, which brought about the formation of the Taimyr collisional granites that have been dated at 240-280 Ma (Bezzubtsev et al., 1986). This was followed by the formation of a 2000-2500-km-wide inlet between Eurasia

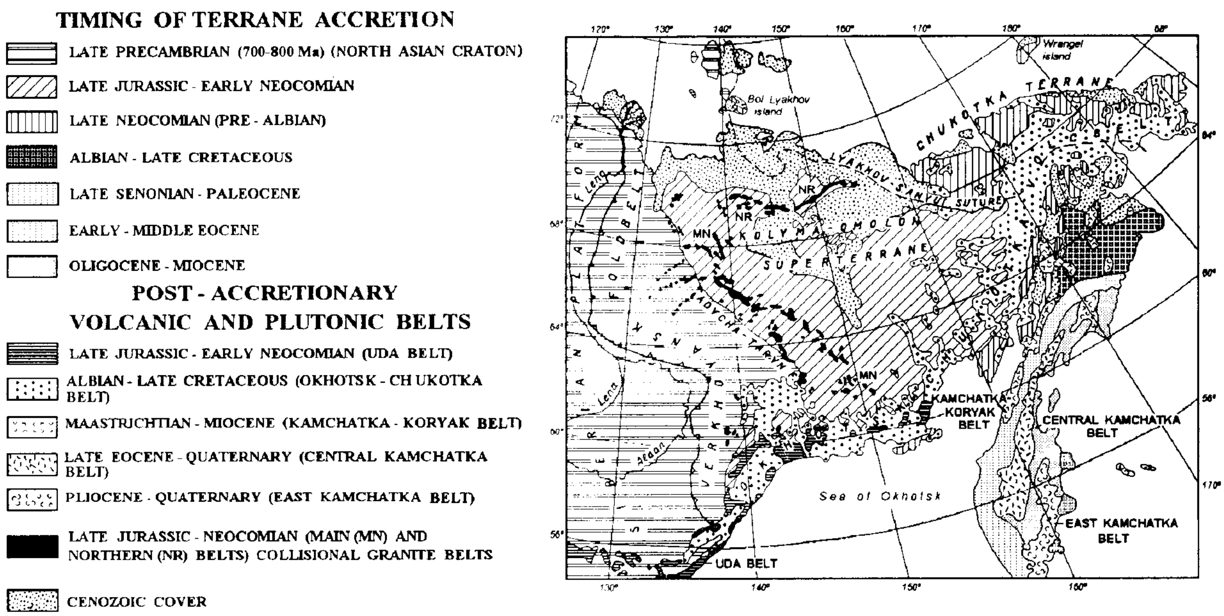


Fig.5. Timing of terrane accretion in northeast Asia.

and North America, which existed approximately up to the middle of the Cretaceous (Zonenshain et al., 1990; Coffin et al., 1992).

In Late Triassic time, the terranes that had moved south reversed their direction and moved toward the north. At that time, the Alazeya-Khetachan arc, or a chain of island arcs, formed. The Togiak island arc of Alaska was probably a part of this chain. The collision of the Omolon and Omulevka composite terrane with this chain in late Middle Jurassic time produced the Kolyma-Omolon superterrane, which then accreted to the North Asian craton in the late Late Jurassic to Early Neocomian.

Subsequent closing of the oceanic inlet between Eurasia and North America was related to the opening of the Canada Basin and the accretion of the Chukotka composite terrane to Asia. The timing of the accretion is pre-Albian. The Chukotka composite terrane and the eastern margin of the Kolyma-Omolon superterrane are overlain by Albian volcanics of the Okhotsk-Chukotsk belt. In pre-Albian time, the Koni-Murgal island arc and the Zolotogorsk continental margin arc terranes also accreted to the Asian continent. They, as well as the Chukotka composite terrane, are overlapped by the Okhotsk-Chukotsk volcanic belt.

The Albian to Late Cretaceous Okhotsk-Chukotsk belt defines the active margin of Asia at that time. In the north, it is bounded on the Pacific Ocean side by a fore-arc basin and its associated accretionary wedge (Parfenov and Natal'in, 1985). Found within the accretionary wedge are Jurassic to Early Cretaceous ophiolites, turbidites, and glaucophane schists, tectonic fragments of ophiolites and island arcs, glaucophane schists, biogenic limestones, and shallow-water arkosic sandstones with a Paleozoic and early Mesozoic boreal fauna. These tectonic fragments are delineated as a number of small terranes (Parfenov et al., 1993a, 1993b). To the east, there are larger terranes (Mainitsky, Alkatvaam, Ekonai) that have accreted to this active margin. These terranes contain late Paleozoic to early Mesozoic Tethian fauna (Bychkov and Dagis, 1984; Ustristkiy and Khramov, 1987; Sokolov, 1988). Paleomagnetic data suggest that they moved 4000-7000 km from the south during Late Jurassic to Cretaceous time and were in place by the Senonian (Didenko et al., 1990, 1992).

In late Late Cretaceous to Paleocene time, the active margin of Asia was displaced 300 km to the east toward the Pacific Ocean. Its position is defined by the Kamchatka-Koryak volcanic belt. The West Kamchatka terrane extends along the eastern margin of the belt from the south Koryak Highlands to western Kamchatka (Parfenov et al., 1993a, 1993b) and is composed of Senonian to Paleocene flysch deposits with olistostrome horizons. It seems to represent the accretionary wedge and trough of the Kamchatka-Koryak volcanic arc. In pre-Late Eocene time, the south Kamchatka metamorphic composite terrane accreted to the arc, together with the Olyutorka-Kamchatka island arc terrane and the Vetlovsky accretionary wedge terrane. According to paleomagnetic data, the Olyutorka-Kamchatka island arc was located several thousand kilometers to the south in Late Cretaceous time (Savostin and Kheifets, 1988; Gurevich and Surkis, 1991) and at about 600 km in Eocene time (Kovalenko, 1990).

In Late Eocene-Oligocene time, the active margin of Asia was again displaced to the east. At this time, the Central Kamchatka volcanic belt formed, which is a continuation of the Kuril island arc to the south, but is displaced westward along a transform fault. The East Kamchatka Peninsula's island arc composite terrane was the accreted to the Central Kamchatka arc. Paleomagnetic data show the position of the East Kamchatka composite terrane in Paleocene to Eocene time as about 2000 km to the south; and in post-Eocene time, some terranes of this composite terrane were rotated relative to each other at angles of about 70° (Bazhenov et al., 1991). Timing of the accretion is defined as Oligocene to Miocene because contemporaneous deposits of the Tyushevsky basin, located between the composite terrane and the volcanic belt, include detritus derived both from the west and east. The Pliocene witnessed the formation of the East Kamchatka volcanic belt, which is still active and continues to the south as the modern Kuril island arc. This belt overlies both the East Kamchatka Peninsula composite terrane and the pre-existing active margin of the continent.

It is noteworthy that uneven easterly displacements of the active continental margin of Asia during Late Cretaceous to Cenozoic time generally coincide with the accepted major changes of plate movement in the Pacific (Engebretson et al., 1985; Zonenshain et al., 1987).

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