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What Is Responsible for Development of the Asian–Pacific Transition Zone: The Geodynamics of Oceanic Plates or the Asian Continent?

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Abstract—The main unusual feature of tectogenesis of the Asian–Pacific transition zone in the Mesozoic–Cenozoic consists in the formation of left-lateral strike-slip faults, which form the East Asian global shear zone with paragenesis of its constituent variously oriented fault systems. Paragenetic analysis has revealed that continental blocks of the Asian–Pacific transition zone were displaced along systems of transit left-lateral strike-slip faults of the East Asian global shear zone by hundreds of kilometers in the southerly to southwesterly direction due to tectonic activity of the Asian continent, which drifted southwestward. This process was accompanied by the formation of compression and extension structures. Otherwise, it is difficult to explain the structuring of the overhanging margin of the continent by subduction of oceanic lithospheric plates in the northerly to northwesterly direction opposite relative to the displacement of the continental crust as is usually thought.

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According to the plate tectonics concept, the formation of the continental crust beneath the Asian–Pacific transition zone (APTZ), its structuring, and subsequent destruction with development of superposed belts (volcanic and marginal seas) resulted from normal and oblique subduction of oceanic plates under the Asian continent. The contribution of the latter to the APTZ development is practically excluded, which cannot be considered as being correct. This work is dedicated to study of the structure of the Asian–Pacific transition zone and its formation from the standpoint of tectonic activity of oceanic plates (regardless of available conceptual models of the outer geodynamic factors). The transition zone is relatively well investigated, which allows its dynamic–kinematic development with an important role belonging to the geodynamics of the Asian continent to be reconstructed.

The main peculiar feature of tectogenesis of the Asian–Pacific transition zone in the Mesozoic–Cenozoic consists in the formation of left-lateral NNE-oriented strike-slip faults, which form the East Asian global shear zone [1]. The established left-lateral displacement of continental blocks for tens to, occasionally (Tan Lu and Sikhote Alin strike-slip faults), hundreds of kilometers ([2–4] and others) could result only from the southwestward drift of the Asian continent and (or) the Pacific Plate in the northeasterly direction [5]. It appeared, however, that the “and (or)” problem remains unsolved, since the left-lateral strike-slip faults and observed present-day structural patterns of the Asian–Pacific transition zone could be formed in both situations. It is of importance to understand the kinematics of the abutting blocks of strike-slip faults: are left-lateral shifts of northwestern flanks a response to the northwestward drift of the Asian continent or, on the contrary, is such a kinematics of southeastern flanks indicative of the northeastward drift of the Pacific Plate? It is also important to establish the directions of motion of continental blocks during the formation of extension and compression structures. The paragenetic analysis of the structure of the East Asian global shear zone offers opportunities for solving these problems.

Three transit fault systems are dominant in the East Asian global shear zone (Fig. 1). One of them (longitudinal, main) is represented by left-lateral strike-slip faults extending parallel to the margin of the Asian continent (NNE 25°–30°), and two others are diagonal, arranged obliquely to the latter: marginal continental (left-lateral updip–strike-slip faults 50°–70°) and oceanic (mostly meridional left-lateral strike-slip faults) systems. The analysis included faults with proper geographic names, which implies the availability of relatively sufficient information on their morphological–kinematic features investigated by researchers from

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Russia, China, Japan, and Korea. The structure of the East Asian global shear zone is identical to that of world-known natural and experimentally modeled shear zones, which allows it to be considered as an integral structure with the paragenesis of its fault systems. For example, the paragenesis of the longitudinal (left-lateral Tan Lu and Sikhote Alin strike-slip faults) and diagonal (left-lateral updip–strike-slip faults of the Bohai–Amur zone) systems is relatively well known [7]. It is established that longitudinal left-lateral strike-slip faults were formed during the period lasting from the Jurassic (probably, Triassic) to the end of the Early Cretaceous synchronously with diagonal updip–strike-slip faults, which developed as compression duplexes of left-lateral strike-slip faults together with the Sikhote Alin imbricate–folded system (Fig. 2). By the Late Cretaceous, the Tan Lu strike-slip fault was transformed into an extension structure [8] with insignificant left- and right-lateral strike-slip faults [9 and others]. The Sikhote Alin left-lateral strike-slip faults remained active despite the replacement of dominant updip kinematics of faults belonging to the Bohai–Amur system by the mostly left-lateral shear one. This resulted in the left-lateral shift of the eastern boundary of the Archean–Proterozoic craton by sev-

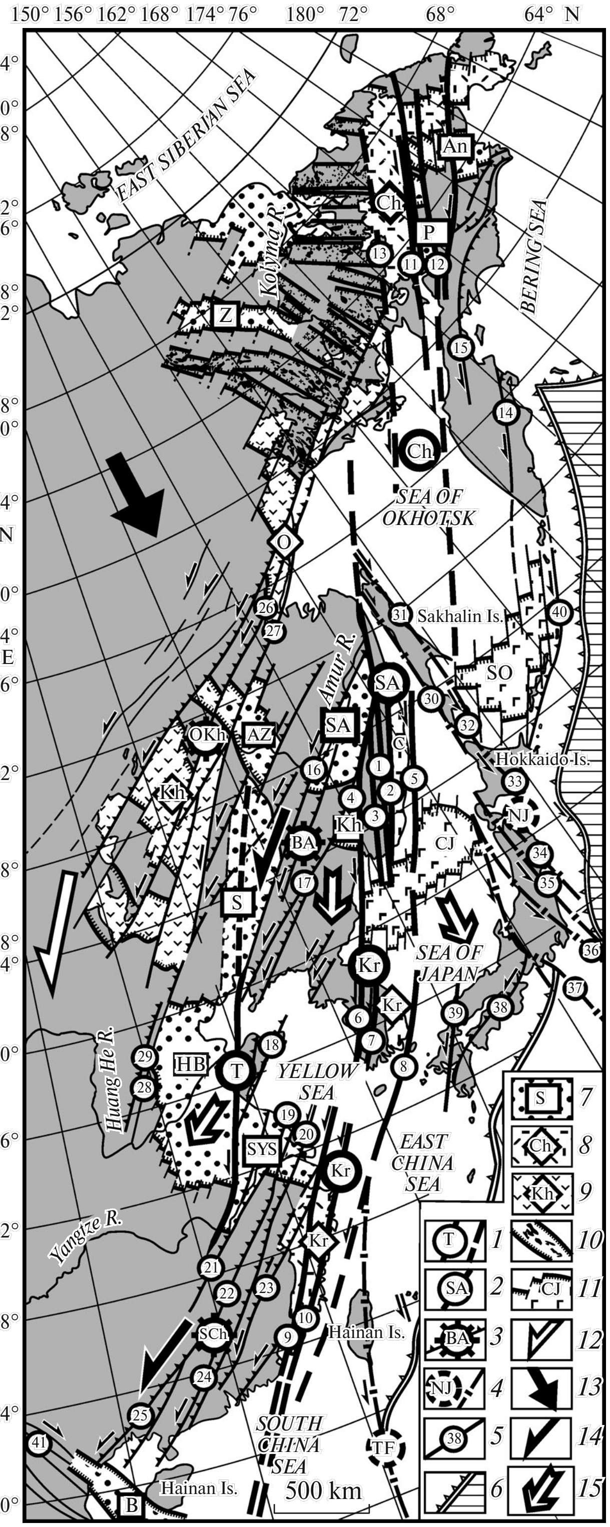

Fig. 1. The structure and schematic dynamic–kinematic development of the East Asian global shear zone (EAGSZ). Compiled using data from [1–8] and others. (*1*, *2*) Longitudinal system of left-lateral strike-slip faults (NE 25°–30°): (*1*) Tan Lu strike-slip fault (the dotted line shows its presumed continuation), (*2*) the main Chukotka–Vietnam zone of EAGSZ and its constituting segments (encircled numbers correspond to particular strike-slip faults of the zone): (SA) Sikhote Alin: (1) Central Sikhote Alin, (2) East Sikhote Alin, (3) Arsen'ev, (4) Ussuri, (5) Pribrezhnyi; (Kr) Korean: (6) Andong, (7) Gongju, (8) Tsushima; (Ch) China: (9) Lyushui–Haiphong, (10) Chang–Nanao; (Ch) Chukotka: (11) Anadyr, (12) Penzhina, (13) Even, (14) East Kamchatka, (15) Central Kamchatka; (*3*) diagonal continental marginal system of updip–strike-slip faults and its constituting zones: (BA) Bohai–Amur: (16) Ilan-Itun, (17) Dunhua–Mishan, (18) Yalu Jiang–Tsingtao; (SC) South China: (19) Suntao–Dushan, (20) Bailu–Khetsu, (21) Jiujiang, (22) Ganjiang, (23) Shaou–Xuan, (24) Syhuei–Uchuang, (25) Mishan–Dungsin; (OKh) Okhotsk–Khingan: (26) North Uda, (27) Uligdan, (28) Taidun, (29) Xiajianguang; (*4*) diagonal oceanic marginal system of strike-slip faults: (SJ) Sakhalin–Japan: (30) West Sakhalin, (31) Poronai, (32) Merei, (33) Idonnappu, (34) Hitokabe–Iriya, (35) Futaba, (36) Tanakura, (37) Itoigawa-Shizuoka; (TF) Taiwan–Philippine; (*5*) other faults beyond the defined zones: (38) Median Tectonic Line, (39) Nagato, (40) Median Kurile, (41) Red River; (*6*) Benioff (subduction) zones and oceanic crust (hatched); (*7*) sedimentary basins: (SA) Srednii Amur, (S) Sunlyao, (AZ) Amur–Zeya, (Kh) Khanka, (An) Anadyr, (P) Penzhina group, (HB) Huabei–Bohaiwan, (SYS) Subei–Yellow Sea; (Z) Zyryanka, (BB) Bak Bo; (*8*) East Asian volcanic belt and its segments: (CH) Chukotka, (S) Sikhote Alin, (Kr) Korean, (Ch) China; (*9*) Okhotsk–Khingan volcanic belt and its segments: (O) Okhotsk, (Kh) Khingan; (*10*) pull-apart structures controlling acid subintrusive volcanism; (*11*) riftogenic depressions with the oceanic crust: (CJ) Central Japan, (SO) South Okhotsk; (*12*) direction of the ocean drift; (*13*) direction of rotation (pole-fugal) forces; (*14*) direction of shifts of northwestern flanks of left-lateral strike-slip faults in the Bohai–Amur and South China shear zones with the Tan Lu rift opening; (*15*) direction of continental block displacements along strike-slip faults of the longitudinal and diagonal systems.

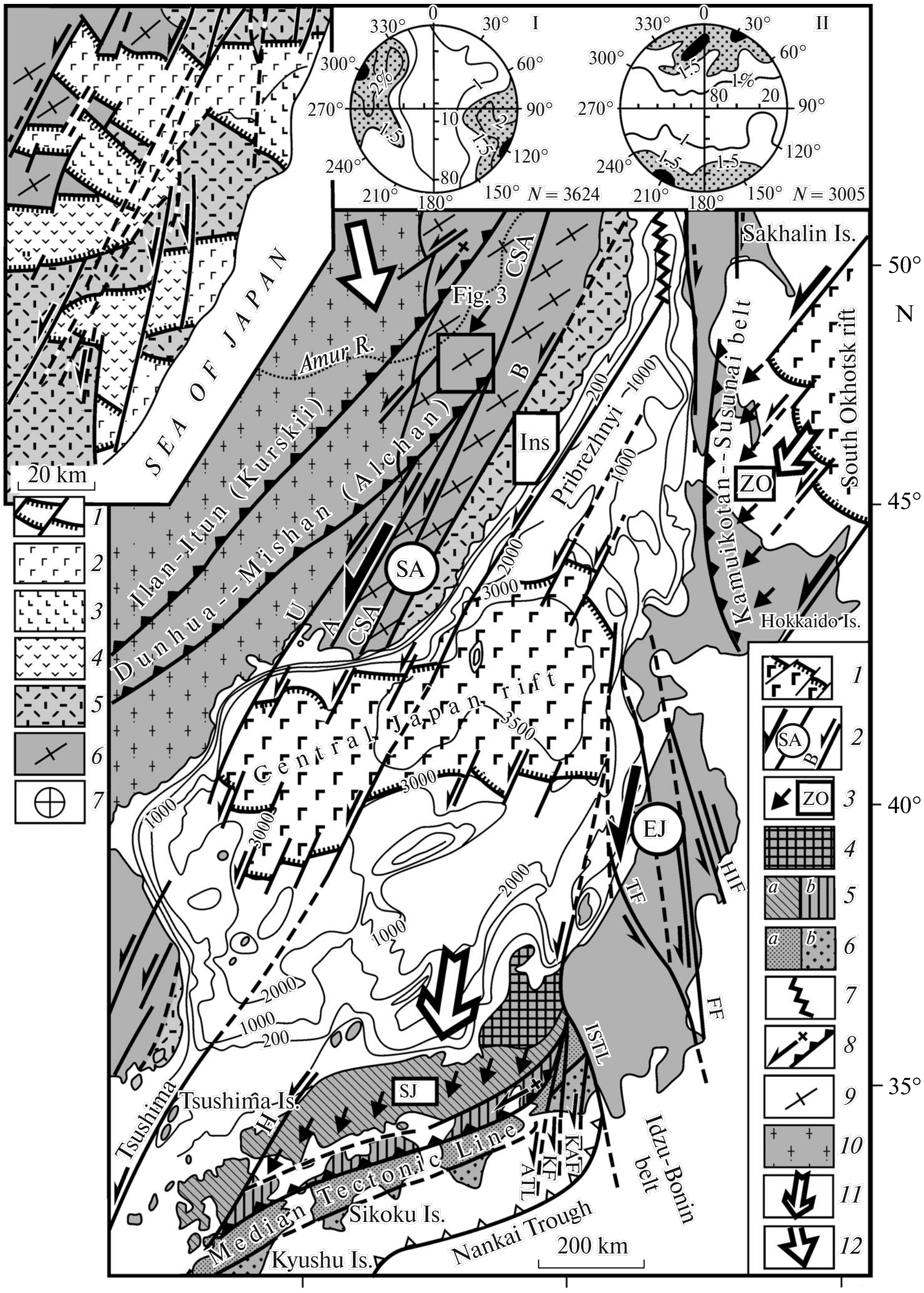

Fig. 2. Schematic dynamic–kinematic structure of the Sea of Japan region. Compiled using data from [2, 5–7, 10, 12] and others. (*1*) Rifts with the oceanic crust (extension duplexes of nonaligning left-lateral shear zones); (*2*) shear zones and their constituting left-lateral strike-slip faults: (SA) Sikhote Alin: (CSA) Central Sikhote Alin, (ESA) East Sikhote Alin, (A) Arsen'ev, (U) Ussuri, (EJ) East Japan: (TF) Tanakura, (FF) Futaba, (HIF) Hitokabe–Iriya, (ISTL) Itoigawa–Shizuoka, (ATL) Akaishi, (KKF) Kaf–Kasayama, (KF) Komtso, (STL) Sasayama; (*3*) frontal compression and accretion belts: (WO) West Okhotsk, (SJ) South Japan; (*4–6*) zoned structure of southwestern Japan: (*4*) Hida massif, (*5a*) mostly Carboniferous–Middle Triassic complexes, (*5b*) Jurassic accretionary complexes (Sambagawa, Chichibu, Kurasegawa), (*6*) Cretaceous–Cenozoic Shimanto accretionary belt: (*a*) northern Late Cretaceous segment, (*b*) southern Paleogene–early Miocene segment; (*7*) Tatar Strait rift; (*8, 9*) updip–strike-slip faults (*8*) formed in the Early Mesozoic as reversed faults consistently with the Sikhote Alin imbricate–thrust system (*9*); (*10*) Archean–Proterozoic craton including the Bureya, Jiamusi, and Khanka massifs and the Sino-Korean Platform; (*11*) directions of shift of continental blocks with the formation of back extension and frontal compression structures; (*12*) direction of rotation (pole-fugal) forces. Inset: (*1–4*) pull-apart structures (*1*) controlling late Miocene (*2*), early–middle Miocene (*3*), and Paleocene–Oligocene (*4*) basaltoid volcanism, (*5*) Late Cretaceous volcano-plutonic complexes of the first stage of crustal pull-apart processes with the formation of the East Sikhote Alin volcanic belt, (*6*) Early Cretaceous folded basement of the volcanic cover, (*7*) diagrams (upper hemisphere) demonstrating extensive measurements of tectonic fault planes (I) and dips of tectonic lines (II) reflecting the formation of extension structures in the shear field, (*N*) number of measurements; (Ins) inset.

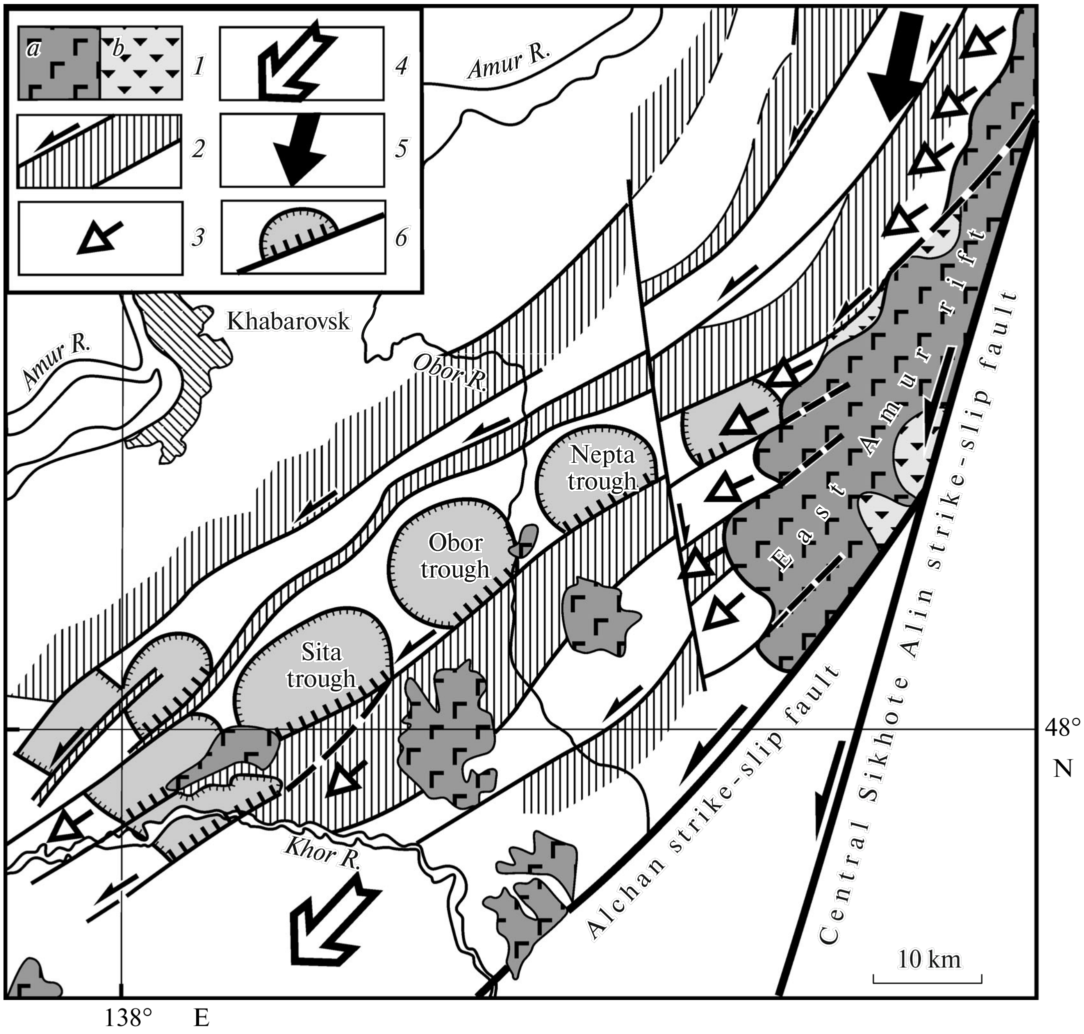

Fig. 3. A schematic dynamic–kinematic scenario of the East Amur rift opening. (*1*) Late Cenozoic basaltoids (*a*) and Upper Cretaceous volcano-sedimentary complexes (*b*) filling the rift; (*2*) blocks of the folded basement of the Srednii Amur sedimentary basin (according to geophysical data) bordered by strike-slip faults; (*3*) directions of extension in crustal blocks bordered by strike-slip faults; (*4*) direction of the shift of the northwestern flank of the Alchan left-lateral strike-slip fault with the formation of the back East Amur rift; (*5*) shear compression generated by motion of blocks along the Central Sikhote Alin left-lateral strike-slip fault in this direction; (*6*) Cenozoic depressions related to extension of blocks bordered by strike-slip faults synchronous with the parental Alchan strike-slip fault.

eral tens to a few hundreds of kilometers (Fig. 2) with development of Late Cretaceous–Cenozoic pull-apart sedimentary basins along these faults, where the left-lateral shear component played a decisive role [7]. The process was accompanied by synchronous opening of the Tan Lu fault with S-shaped patterns, which represented morphologically an extension duplex of nonaligning left-lateral strike-slip faults of the Bohai–Amur and South China zones of a diagonal system with development of a rift valley up to 80 km wide and the adjacent Huabei–Bohaiwan and Subei–Yellow Sea sedimentary basins bordered by stepwise normal faults oriented toward the Tan Lu fault as a parental extension structure. The formation of the Tan Lu rift resulted from southwestward left-lateral shifts of the northwestern flanks of the Bohai–Amur and South China nonaligning left-lateral shear zones, which is confirmed by the synchronous opening of the East Amur rift formed in the junction area of the left-lateral Dunhua–Mishan (Alchan in Russia) and Central Sikhote Alin strike-slip faults (Fig. 3). The East Amur rift was formed as a back extension structure of the SW-shifting northwestern flank of the Dunhua–Mishan fault due to SSW-oriented compression generated during the significant (60–200 km) shift of the northwestern flank of the Central Sikhote Alin strike-slip fault in this direction. The SW-directed shifts of northwestern flanks of strike-slip faults belonging to the diagonal and longitudinal systems represent a direct indication of the drift of the Asian continent in this direction, which was likely responsible for development of the left-lateral shear structure of the East Asian global shear zone.

The riftogenic sedimentary basins are relatively spacious, being comparable in size with deep basins of the marginal seas. Their features in common are the reduced thickness of the continental crust (by 10–15 km beneath sedimentary basins to minimum values under deep-sea basins) and almost synchronous development in a similar shear field, which implies also identity of their geodynamic development regimes. The Central Sea of Japan rift underlain by the oceanic crust is located between the nonaligning Sikhote Alin and East Japan left-lateral shear zones (Fig. 2). The Sikhote Alin zone, which is up to 300 km wide, is represented by left-lateral strike-slip faults with an integral displacement amplitude of at least 500 km [6]. The lateral shifts were accompanied by development of pull-apart extension structures (minor rifts), which controlled dominant basite volcanism (Fig. 2, inset). The ages of volcanics imply the following episodes of strike-slip fault activity: Late Cretaceous, Paleocene–Oligocene, early–middle Miocene, and late Miocene. The East Japan zone, which is approximately 300 km wide, consists of submeridional left-lateral strike-slip faults with displacement amplitudes amounting mostly to a few tens to a few hundreds of kilometers along some of them (Tanakura, 200–400 km; Futaba, 130 km; and others); the sum amplitude amounts to approximately 800 km [10]. The strike-slip faults were active in the Aptian–Campanian, Eocene–Oligocene, and Miocene ([10–12] and others). The Miocene movements along faults have been studied thoroughly in the Akaishi Mountains [12] (Fig. 2). In this region, the Shimanto accretionary belt, which formed in the Cretaceous–Miocene, is detached south of the Median Tectonic Line (MTL), and its fragments are displaced along the system of submeridional left-lateral strike-slip faults with a sum amplitude amounting to at least 150 km.

The Sikhote Alin and East Japan shear zones were formed in general synchronously and reflect episodes of the Central Japan rift opening, if the latter is considered as an extension duplex of nonaligning left-lateral shear zones (Fig. 2). This is confirmed by the fact that the East Japan left-lateral zone begins near the eastern wall of the Central Japan rift and extends southward to border (on the east) southwestern Japan, which is characterized by development of frontal compression structures (accretion of crustal blocks). It follows from such relations that the East Japan zone represents a flank left-lateral strike-slip fault formed due to the shift of southwestern Japan in the southerly direction in response to the durable pull-apart opening of the Central Japan rift during the Late Cretaceous–Cenozoic with its maximum intensity in the Miocene. If southwestern Japan is displaced in palinspastic reconstructions back northward, the latter occupies, joining the continent, a position close to the Central Japan rift, which likely changed its primary sublatitudinal orientation in the Late Cenozoic as an extension duplex of nonaligning strike-slip faults due to the significant left-lateral shift along the transit Tsushima–Pribrezhnyi left-lateral strike-slip fault (Fig. 2).

Unlike northeastern Japan with its intense left-lateral shear dislocations, southwestern Japan is characterized by a sublatitudinal zoned structure undisturbed by strike-slip faults with a distinct successive tectonostratigraphic advance toward the ocean (Fig. 2) ([13, 14] and others). The zoned structure of southwestern Japan is traditionally considered as resulting from subduction of oceanic plates under the Asian continent with successive accretion of their blocks to the ancient Hida massif ([10, 13, 14] and others), which joined the Sina–Korean craton prior to the opening of the Sea of Japan in the Miocene ([10] and others). At the same time, the above-mentioned evidence in favor of the southward displacement of southwestern Japan in response to the spreading pull-apart opening of the Central Japan rift (rollback) with the paragenesis of the South Japan frontal compression belt (accretion) allow another scenario to be proposed for explaining the nature of such zoned patterns.

It is believed to be proven that pre-Jurassic and Jurassic accretionary complexes located south of the Hida massif were formed as a part of the continent ([10] and others) and, consequently, as a constituent of the Sikhote Alin imbricate–folded structure. From such a scenario, it follows that the features reflecting development of the Sikhote Alin structures as a system of compression duplexes of left-lateral strike-slip faults at the early stage of their activity in the Jurassic–Early Cretaceous should be taken into consideration. These structures include horst-shaped antiforms, which increase laterally in size due to the built-up of their slopes by synsedimentary updip–thrust structures (tectonostratigraphic accretion) under shear compression. By their morphological–kinematic features, these structures are similar to accreted blocks of subduction nature [15]. Horst–accretionary shear systems were formed under the influence of subhorizontal synshear crustal and subcrustal detachments at different depths, which are reflected at the surface in listric imbricated complexes that stimulated development of a compositionally variable mélange with fragments of the suboceanic crust. Consequently, the belt of pre-Jurassic rocks and a narrow zone of serpentinite melange (Kurasegawa belt) with fragments of the continental crust (Chichibu belt) accreted in the Jurassic may be considered as an accretionary system that resulted from the uplift and accretionary growth of the Hida horst as a compression duplex of Sikhote Alin left-lateral strike-slip faults. Subsequently, in the Late Cretaceous–Cenozoic, tectonostratigraphic accretion of southwestern Japan continued synchronously with its separation from the continent in response to the shear opening of the Central Japan rift. The seaward displacement of southwestern Japan generated frontal compression, which was responsible for Cretaceous dynamometamorphism superposed on Jurassic accretion and formation of the frontal belt of accretionary imbricate–thrust structures. The successive growth of frontal compression structures accompanied by their uplifting determined the southward extension of the sedimentation area with the formation of the Shimanto belt, where zoned patterns are reflected in the replacement of dominant upper Cretaceous sediments in the north by lower Miocene sequences in the south (Fig. 2). The opening of the Central Japan rift (back extension structure) and formation of the Shimanto belt (frontal accretion structure) were synchronous with development of the East Japan left-lateral shear zone, which confirms their paragenesis.

The structure-forming flow of crustal masses with development of duplex extension and accretion structures is also reflected in the formation of the South Okhotsk rift (Fig. 2). Its opening during the Cenozoic in the southwest was accompanied by the formation of the West Okhotsk belt of imbricate–thrust accretion, which reflected the flow of crustal masses in this direction. In this area, the Kamuikotan–Susunai crust imbrication belt, characterized by the southwestern vergence and superposed dynamometamorphism, which is traceable through Hokkaido to southern Sakhalin, was formed. It is conceivable that tectonic imbrication in response to lateral compression generated thermal energy with temperatures sufficient for metamorphic transformation of rocks particularly in situations when the imbrication episode was brief (pulse mode).

Thus, due to tectonic activity of the Asian continent, which drifted southwestward, continental blocks of the Asian–Pacific transition zone were displaced by hundreds of kilometers in the SSW direction along systems of transit left-lateral strike-slip faults. Otherwise, it is difficult to explain the structuring of the overhanging margin of the continent by NNW-directed subduction of oceanic plates opposite to continental crust displacements, as is usually thought.

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