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Subduction Erosion at Pacific-Type Convergent Margins

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Abstract—The paper presents a review of processes of subduction or tectonic erosion at Pacific-type convergent margins (PTCM) including definition of "tectonic erosion", its triggers, driving forces and consequences. We review examples of tectonic erosion at the Circum-Pacific PTCMs and at the fossil PTCMs of the Paleo-Asian Ocean (PAO) currently hosted by the Central-Asian Orogenic Belt (CAOB). Recent geological and stratigraphic studies have shown two types of PTCMs: accreting and eroding. Accreting PTCMs consist of older deposits of accretionary and frontal prisms and grow oceanward, i.e. the trench retreats. Eroding PTCMs are characterized by the destruction of the prism, approaching arc and trench and typically form during shallow-angle and fast subduction of an oceanic slab with oceanic floor relief highs. The mechanism of tectonic erosion includes destruction of oceanic slab, island arcs, accretionary prism, fore-arc and related prism. Tectonic erosion is a common phenomenon at many Circum-Pacific PTCMs, e.g., in South America, Tonga and Nankai troughs, Alaska. Accretion and subduction of oceanic rises contributes greatly to the processes of formation, transformation and destruction of continental crust at PTCM. The episodes of tectonic erosion can be also reconstructed for an ancient ocean, for example, for the PAO, which evolution and suturing formed the CAOB. Many CAOB foldbelts (Altai, Tienshan, eastern Kazakhstan, Transbaikalia, Mongolia) carry signs of disappearance of big volumes of continental crust (arcs). Studying processes responsible not only for the formation of continental crust, but also for the disappearance of big volumes of crustal material is important for correct evaluation of the nature of intra-continental orogenic belts, e.g., CAOB, and development of reliable tectonic models.

Keywords: Pacific-type convergent margin, tectonic erosion, Circum-Pacific, Paleo-Asian Ocean, slab relief
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1. INTRODUCTION

Pacific-type convergent margin (PTCM) is a tectonically active zone of interaction between two lithospheric plates (island-arc type, typical of the western Pacific) or a zone of interaction between an oceanic plate and an active continental margin (Andean type, typical of the eastern Pacific). PTCM, which develops over the subduction zone, is the main site of formation of new (juvenile) crust mainly due to accretion and supra-subduction magmatism of intra-oceanic arcs (Fig. 1). PTCMs are very important geological entities because on one hand they are major sites of juvenile crust formation on the Earth, but on the other hand they are places of strong crust destruction [7, 32, 49, 61, 69, etc.].

The processes of generation and destruction of the crust have been studied by many researchers, wherein about 90% of the research works were devoted to the formation of the crust: hundreds, if not thousands, research papers have been focused on supra-subduction magmatism and accretionary complexes, with only a small number of works devoted to tectonic or subduction erosion [18, 66, 69, 72, etc.]. The processes of tectonic erosion of magmatic arcs and adjacent accretion complexes are very common at convergent margins of the Circum-Pacific, for example, over the subduction zones of South America (Guatemala-Costa Rica), southwestern (Tonga), and western (Japanese Trench) Pacific. As a result, a large amount of crustal material, including juvenile, is destructed and completely disappears from the Earth's surface by subducting into the mantle. Consequently, the original ratio of juvenile and recycled continental crust, formed during the past epochs of the Pacific-type orogeny, is disrupted.

Traditionally the proportions of juvenile and recycled crust have been determined based on geochemical and isotope data obtained from granitoid igneous rocks. Those traditional approaches ignore or underestimate geological data suggesting that a part of supra-subduction igneous rocks could have been lost

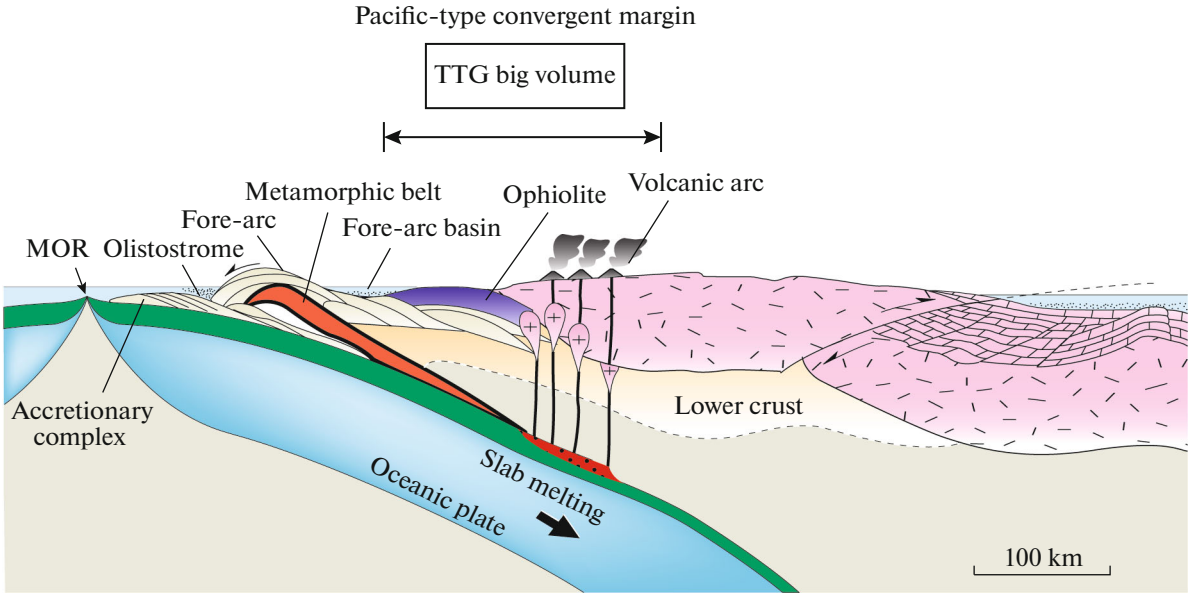


Fig. 1. A general scheme of a Pacific-type convergent margin (PTCM) and its main elements: subducting oceanic plate, accretionary complex, fore-arc prism, volcanic arc, back-arc basin [53].

during tectonic erosion. In addition, the role of mafic magmatism in crustal growth is often underestimated and the sedimentary rocks formed due to the erosion of intra-oceanic arcs are not taken into account. Therefore, the nature of a Pacific-type inland foldbelt can be reconstructed with bias. Recently the zones of subduction have received another focus as pathways to deliver surface materials of both oceanic and continental crust to the deep mantle and their accumulation in the mantle transition zone [15, 39, 50, 53, 61, 79, 80].

This paper overviews processes of tectonic erosion with foci to the concept of "tectonic erosion", its causes, factors and consequences, examples of modern tectonic erosion at Circum-Pacific PTCMs and fossil PTCMs of the Central Asian Orogenic Belt (CAOB), the world largest Pacific-type foldbelt formed during the evolution of the PTCM of the Paleo-Asian Ocean and its subsequent suturing [23, 78, 83].

2. THE CONCEPT OF SUBDUCTION OR TECTONIC EROSION

Recent studies of geology and stratigraphy of PCM have shown the presence of two types of PCM: accreting and eroding (Fig. 2) [66]. The accreting or growing margins are characterized by rocks deeply buried under thick older accreted units and frontal prism of actively deforming sediment scraped off the subducting plate. With time, accreting margins widen, i.e., the trench retreats seaward (Fig. 2a). Eroding or non-accreting margins are characterized by the close approach of the margin's rock framework to the trench and small or lacking older prisms of accreted lower plate sediment. With time, eroding margins narrow with respect to a reference point on the margin, i.e., the trench approaches the arc (Fig. 2b) [19, 61, 63, 66, 70, 79].

According to the available estimates the modern Pacific Ocean is surrounded by 65% eroding PCM and 20% accreting PCM (Fig. 3) [19, 66]. The remaining 15% are transform plate boundaries [27]. Accreting margins are traced by large belts of ocean-floor sediments, which are almost continuously detached from the surface of the subducting slab and mechanically (tectonically) merged with the previously accreted (older) sediments of the hanging wall of a subduction zone (Fig. 2a). The accretionary prism, which grows towards the ocean for at least 10–20 million years, consists of three main elements: 1) a frontal prism, where sediments are actively deformed and accreted oceanward; 2) a middle prism, where sediments accrete landward and merge with the previously accreted units of the prism; 3) an inner prism. The largest accretionary (growing) prisms (>40 km wide) typically form at convergent margins with parallel trenches filled by thick (more than 1.5–2 km) sediments and if the rate of orthogonal subduction of the downgoing slab is less than 40–50 km/Ma, e.g., near the islands of the northern Cascadia, Makran, the Lesser Antilles arc and Sumatra (Fig. 3) [66].

However, the majority of the modern PTCMs are of eroding type (Figs. 2b, 3). The concept of subduction or tectonic erosion implies the separation and transportation of sediments and consolidated/solid rocks of the upper plate (hanging wall of the subduction zone) into the subduction channel, along which

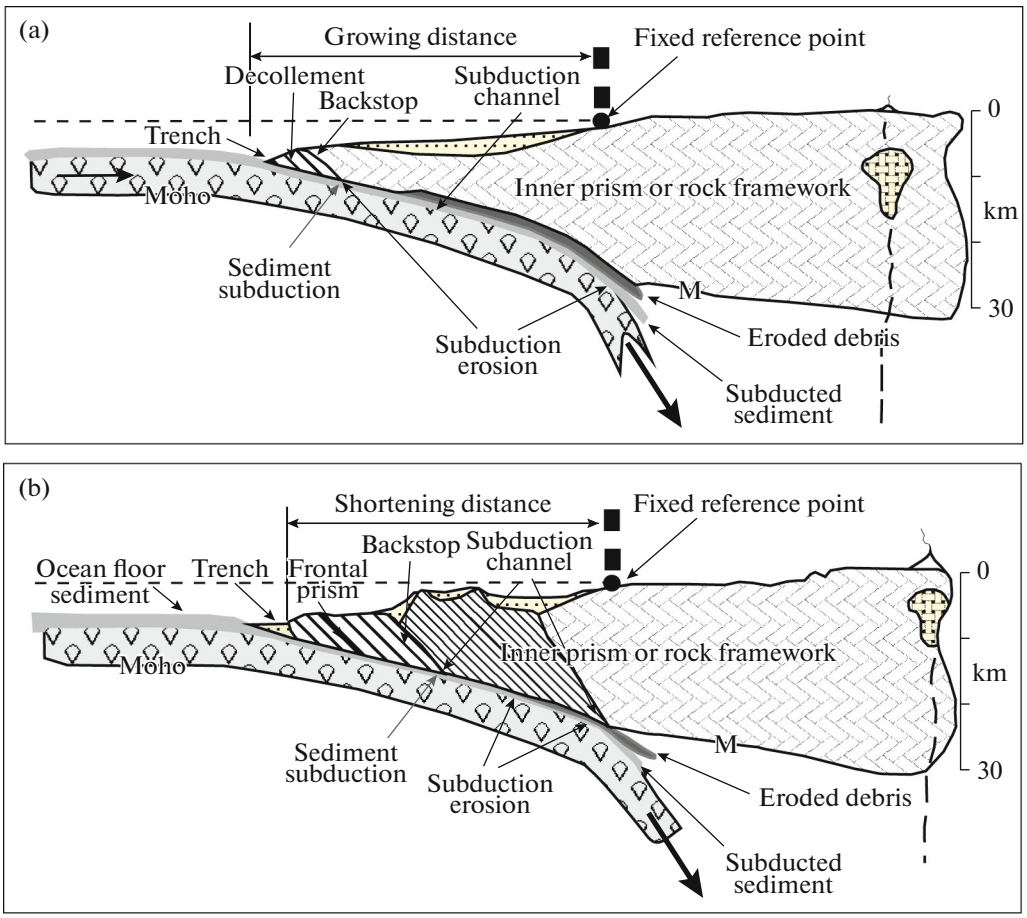


Fig. 2. Pacific-type convergent margins [65]: (a) accreting margins grow oceanward, i.e., trench retreats; (b) eroding margins shorten, i.e. trench approaches arc.

material then moves to the deep mantle together with the subducting plate. Tectonic erosion destroys all three elements of accretionary prism: frontal and middle prisms (the upper part of the hanging wall), inner prism, and the basement of magmatic arc, i.e. the bottom of the hanging wall [18, 29, 74].

3. MODERN CONCEPTS OF SUBDUCTION EROSION: CAUSES AND CONSEQUENCES

The first evidence for subduction erosion at P-type active margins was obtained from seismic reflection profiles across the Tonga [30] and Nankai (Japan) trenches [31, 73]. The seismic profiles clearly show that weakly consolidated clastic material is trapped by the grabens formed by faults and fractures over the surface of subducting oceanic plate. Later the processes of subduction erosion were described at other modern and young PTCMs of the Pacific Ocean, first of all, in Japan [35, 55, 61] and South America [72].

The mechanism of subduction erosion includes destruction of oceanic slab, island arcs, accretionary prism and fore-arc (Fig. 4) by thrusting, oceanic floor relief (horst/graben), and (hydro)fracturing (Fig. 4b) [69, 76, 79]. In some cases, ocean-floor relief features, e.g., seamounts, ridges, horst and grabens, can enhance tectonic erosion at PTCM. The most important elements of PTCM are magmatic arcs, in particular, intra-oceanic arcs, the site of formation of new juvenile crust.

Modern magmatic arcs are characterized by crust thicknesses of 20–30 km and are typically several hundred kilometres long [64, 69]. Frontal subduction erosion results from a combination of erosion and structural collapse of the forearc wedge into the trench (Fig. 4a), and basal subduction erosion by abrasion and hydro-fracturing of rocks above the subduction channel [20, 21, 76]. Basal subduction erosion of the middle and lower parts of the fore-arc is caused by abrasion and hydraulic fracturing of rocks (Fig. 4b) resulting in the destruction and transportation of the base of PTCM hanging wall to the subduction channel [68]. Thus, frontal and basal tectonic erosions destroy and transports down fore-arc consolidated and non-consolidated rocks thus narrowing the entire active margin. As a result, the thickness of subarc crust, arc



Fig. 3. Proportions of growing or accreting margins and narrowing or non-accreting margins in the Circum-Pacific and adjacent regions [modified from 19, 27].

size and the distance between trench and arc reduce and the arc hypsometrically subsides [66, 68]. The degree/scale of basal tectonic erosion can increase during strong earthquakes associated with subduction zones [78].

The most important factor in subduction erosion is ocean-floor relief. What happens to an ocean-floor landform (island, seamount, plateau, ridge) when it approaches subduction zone? Subduction erosion and accretion are two major tectonic processes/scenarios active at modern PTCMs. Positive relief features of the oceanic floor may enhance both accretion and tectonic erosion. The tectonic erosion is provided by thee flattening of subducting plate [68] and dissecting of the active margin resulting in the formation a slab window. During subduction, seafloor landforms can be accreted to the active margin and/or fully or partially subducted into the deep mantle. Some researchers believe that topographically high oceanic islands/seamounts can enhance accretion [25, 32, 34]. The mechanical attachment of oceanic islands to the active margin can enhance accretion of sediments detached from the surface of the subducting plate and therefore increase accumulation of both accretionary prism and fore-arc deposits as oceanic islands/seamoutns can create a barrier and even temporarily block the subduction zone [1]. All this contributes to more intensive "scraping off" of sedimentary and even igneous rocks from the surface of the subducting slab and their attachment to the hanging wall of the active margin. The blockage of the subduction zone by oceanic rises can also lead to obduction of ophiolites and/or an exhumation of previously subducted rocks.

The degree of accretion of seafloor landforms depends on several factors, of which the height of the landform and the dip angle of the subducting slab are of crucial importance. In case of relatively high oceanic rises, only their upper parts are typically accreted, whereas in case of accretion of large oceanic plateaus, the thickness of accretionary prism greatly increases [13, 14]. The angle of subduction of oceanic plate depends on its age and/or thickness, i.e., the older is the plate and, therefore, the greater is its thickness, the steeper is the angle of subduction. For example, the angle of subduction of the relatively young oceanic crust of the Philippine Plate into the Nankai trough at

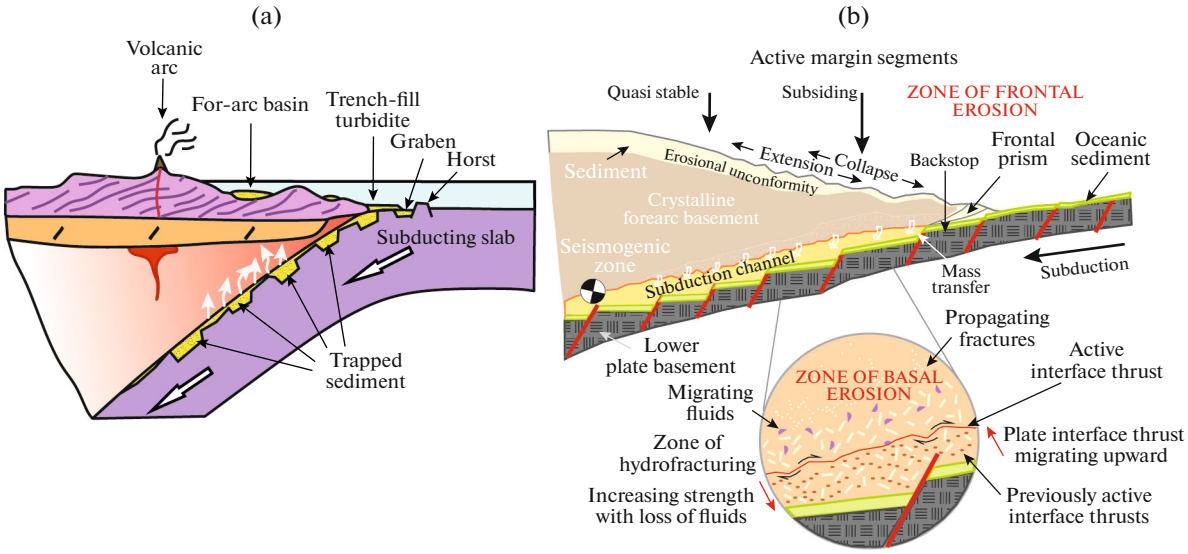


Fig. 4. Tectonci erosion as a process of destruction of oceanic slab, island arcs, accrdetionary prism and frontal arc at PTCM as a result of subducting oceanic plate relief and faults (a) or hydro-fracturing (b) [76, 79].

the southern part of the Japanese Islands [61], is shallow. This results in the "scraping off" of the deeper levels of the subducitng slab and accretion of all seamounts and even MORB basalts (Fig. 5a). The mature crust is thicker and heavier, e.g., the Pacific Plate in the Mariana Arc region. Consequently, it subducts at a steeper angle resulting in MORB subduction, but seamount OIBs accretion only (Fig. 5b). Flat-subduction (flat-slab-subduction) is also possible in case of increased plate buoyancy due to aseismic ridge subduction, e.g., those at the eastern shoreline of South America [10, 28]. If oceanic rises get partially accreted, their remained parts also subduct into the deep mantle. In general, subduction of elements of oceanic floor relief enhances tectonic erosion of PTCM hanging wall including accretionary prism and adjacent volcanic arc (Fig. 5b) [11, 58, 66, 68, 74]. So, eroding PTCMs typically exist at oblique, shallow (flat) and rapid subduction, in particular, in case of subducting ocean-floor ridges and aseismic chains of small oceanic rises (seamount, island). Accreting PTCMs are associated with orthogonal, steep and slow subduction involving oceanic plateau and high/large oceanic islands. Interaction of subduction zone with ocean-floor relief enhances tectonic erosion causing destruction of accretionary prism. This contributes to magmatic lull, arc subsidence and transportation of big masses of eroded material from both arc basement and accretionary prism to the deep mantle.

Subduction of mid-ocean ridges (MOR) is another important factor of subduction erosion related to ocean-floor relief. The relief of MOR and the relief formed by a system of horsts and grabens (Fig. 4) associated with transform faults and faults formed by the bending of the subducting slab destroy the hanging wall of subduction zone, i.e., the basement of accretionary prism and magmatic arc. This leads to the detachment of oceanic plate stratigraphy igneous and sedimentary rocks off the basement of accretionary prism and detachment of plutonic or subvolcanic intermediate to felsic igneous rocks (diorite, tonalite, plagiogranite and other granitoids) off the basement of arc [54, 62]. The fragments of those rocks can be fur-

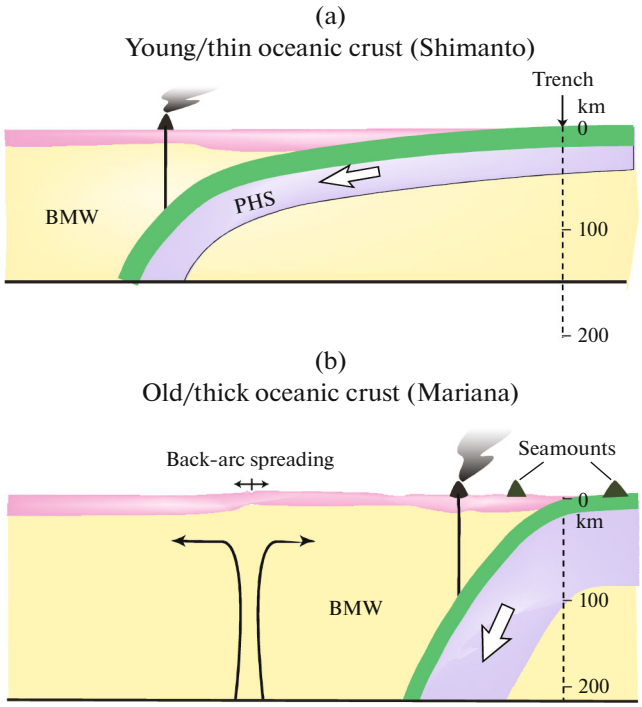


Fig. 5. Subduction of young (a) and mature (b) oceanic crust [modified from 51]. BMW—big mantle wedge [83].

ther destroyed to even a greater extent and subducted to the deep mantle [39, 61], or can be incorporated into serpentinite melange and then, together with high-pressure metamorphic rocks, exhumed to the surface [1, 2, 6, 22, 56, 65]. During the destruction of the hanging wall of the subduction zone, the distance between the arc and the trench decreases, and the axis of the volcanic arc shifts landward (Fig. 2). Consequently, the surface tip of the arc can hypsometrically subside to appear under water [36].

4. EXAMPLES OF TECTONIC EROSION IN THE CIRCUM-PACIFIC

The processes of subduction erosion of magmatic arcs and accretionary complexes are widely manifested at convergent margins of the Pacific Ocean and adjacent regions, e.g., over the subduction zones of South America (Guatemala-Vosta-Rica), SW Pacific (Tonga, Philippine), Alaska and Japanese Islands (Nankai Trough) (Fig. 3). In the Circum Pacific, the strong destructions of crust along the Central Chile shoreline [16] and Tonga Trough [11] have been well studied and appeared linked with the subduction of mid-ocean ridge and Louisville seamount chain, respectively. No notable accretionary prisms form by the subduction of the Philippine Plate indicating direct orthogonal subduction of intra-oceanic arcs into the Nankai trough [80]. Large lens-shaped rock packages are detached along the Costa-Rica segment of the Middle America fore-arc [57].

Recent geological, geophysical and U-Pb zircon age data from the Japanese Islands [35, 36, 55, 61] suggest that the processes of tectonic erosion were active at older PTCMs of the Circum Pacific. For example, the tectonic erosion of the hanging wall basement of an accretionary complex in the eastern Hokkaido resulted in the cessation of magmatism, i.e., the magmatic arc turned into an amagmatic arc, reduction of crust thickness and topographic subsidence of the shoreline [36]. Evidence for the tectonic erosion in the Shimanto accretionary complex comes from the absence of older accreted units between the coeval Shimanto prism and Ryoke granitoid batholith in Honshu Island, but their presence in the Kyusyu and Shikoku islands (Fig. 6) [55, 61]. The U-Pb ages of detrital zircons from turbiditic sandstones of different ages sampled in the Honshu Island indicate that in early Carboniferous time an Ordovician intra-oceanic arc disappeared from the geological record of the Japanese Islands [26, 35]. An event of tectonic erosion can be reconstructed in the middle-late Jurassic accretionary prism and continental margin of the Sikhote-Alin orogenic belt [42] (Fig. 7). This accretionary prism is adjacent to an active continental margin volcano-plutonic belt. There is no Permian accretionary complex present in other regions of the Sikhote-Alin [82]. The Jurassic accretionary prism hosts only fragments of Triassic-early Jurassic passive margin and transform continental margin deposits (Sergeev terrain) [4], which survived during subduction erosion. At present, no pieces of a middle-late Jurassic volcanic arc have been identified in the Sikhote-Alin continental margin. Such evidence and other data suggest a scenario of shallow subduction [5] possibly responsible for the strong subduction erosion [68].

In the convergent margins of the western and eastern Pacific regions, there have been studied several typical localities of subducting ridges and seamount/island chains (Fig. 8). The subduction of the Kodiak-Bowie Seamount chain into the Aleutian Trench possibly contributed to the related accreting margin (Fig. 3), as the NE Alaska accretionary complex hosts the 24 Ma Kodiak Seamount. Note that the convergent margin at the SW segment of the Aleutian Trench along the Alaska shoreline is eroding and shows no accreted or approaching seamounts.

Bathymetric and seismic survey results indicate that the shoreline of central Costa-Rica is a zone of active interaction of subducting seamounts and convergent margin (Fig. 8b) [75]. The Cocos Plate subducting into the trench is covered by numerous seamounts (Fig. 8c). Multi-ray bathymetry survey imagery exposes gaps in the accretionary prism formed as seamounts transit through it (Fig. 8d) [12, 75, 77]. During a relatively short period, those gaps appear to heal by local sediment flows, but multi-ray bathymetry record their traces remained on the surface [75]. The Costa-Rica shoreline is seismically active region with both the seamounts and Cocos Ridge approaching the trench (Fig. 8b). The seismic profiles made across the shoreline shows that this segment of the subduction zone is an area of strong tectonic overpressure caused by the subducting plate. The available estimations of degree of brittle deformation show that the rock fracturing increase from the leading flank of the subducting seamounts to their tops, which are also responsible for the seismicity in the region [48].

A seismic reflection profile made across an accretionary prism near the Osa Peninsula of Costa-Rica shows subducted seamounts and their related nucleation of deformations (Fig. 9). The data on seismicity of that region indicate that the 2002 famous Osa earthquake and its after-shocks nucleated at the leading flank of two subducting seamounts. The results of a 3D numerical experiment suggest that the zones of highest tectonic overpressure served epicenters of earthquakes. Moreover, the maximal values of brittle deformation increase from the apex of the seamounts trenchward. In total, the data on seismicity and brittle deformation/fracturing along the base of the overriding plate indicate their relation to the seafloor roughness off the subducting Cocos plate (Fig. 8b-d) [48]. We conclude that the interaction of accreting and subducting oc eanic rises with PTCM contribute to the formation, transformation and destruction of continental crust at lithospheric plate convergent margins.

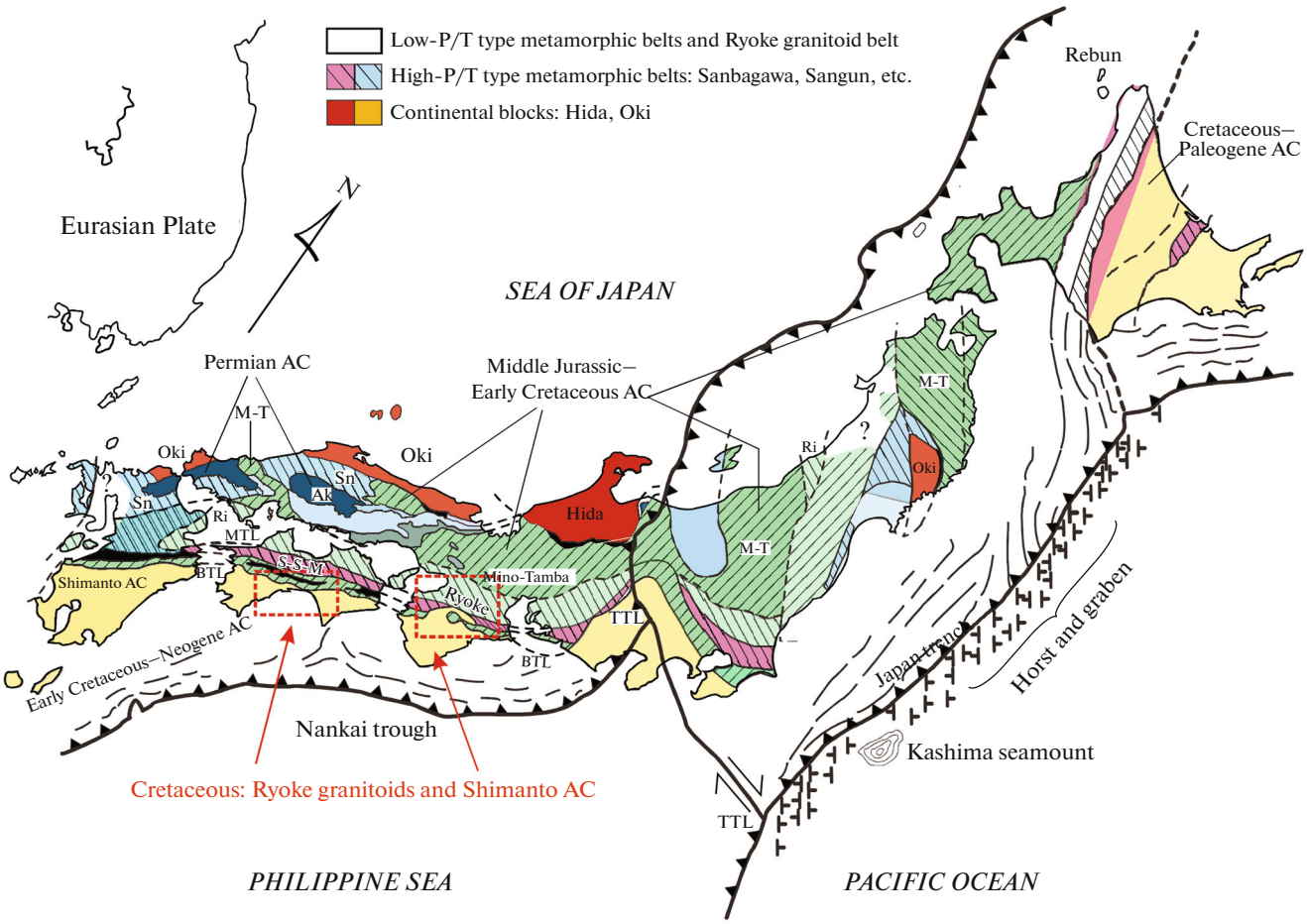


Fig. 6. The tectonic scheme of central and SW Japan after [33, 35, 62]. Ak—Akiyoshi AC; BTL—Buzugo tectonic line; M-T—Mino-Tamba AC; MTL—medium tectonic line; C-C-M—Sanbozan-Sanbagawa-Mikabu belt, Sn—Sangun belt, TTL—Tanakura tectonic line. The dashed rectangles outline the segments of preserved and disappeared pre-Cretaceous accretionary complexes (out of scale).

A good example of subducting ridge erosion is the Chile shoreline, in particular, its southern segment, the location of the subduction of the mid-oceanic ridge separating the Nasca and Antarctic plates. Until recent time, the convergent margin between the South-American and Antarctic plates had been transform, but now eroding (Fig. 2) [27]. Evidence for this comes from the unconformity present over older formations of the accretionary prism indicating its subsidence below water level, as well as from the small volume of sediments forming the accretionary prism compared to an expected volume calculated by the thickness of sediments entering the subduction zone and average subduction rate [66]. In general, continental or shallow-water deposits resting unconformably on deep-marine oceanic deposits document the shift of trench axis landward. Such a setting has been fixed at the Chile shoreline, where the arc migration matches the landward trench advance in response to the truncation and thinning of the fore-arc as a result of tectonic erosion [40].

Tectonic Erosion and Crust Formation

Tectonic erosion plays an important role in crust formation for estimating proportions of juvenile or recycled crust in the structure of this or that orogenic belt, continent, or craton. Figure 10 shows that active continental margins overgrow through accretion of intra-oceanic arcs plus a certain volume of the upper layers of the oceanic crust minus subducting oceanic lithosphere (dominated by basalts and underlying gabbro and peridotite) and tectonically eroded material of arcs and accretionary complexes [66, 68]. The growth of continents through accretion and the loss of crust through tectonic erosion are two opposite scenarios of plate interactions at PTCM. Accretion increases the volume of continental crust by 0.3 km^3 per year, while tectonic erosion reduces that to 1.3 km^3 per year. The estimations made by Clift and co-authors [19] show that the continental crust gains 4.2 km^3 per year and loses 6.2 km^3 per year and therefore may fully disappear in time (Fig. 10). Note that the full disappearance of continents is unlikely as the smaller is the number of

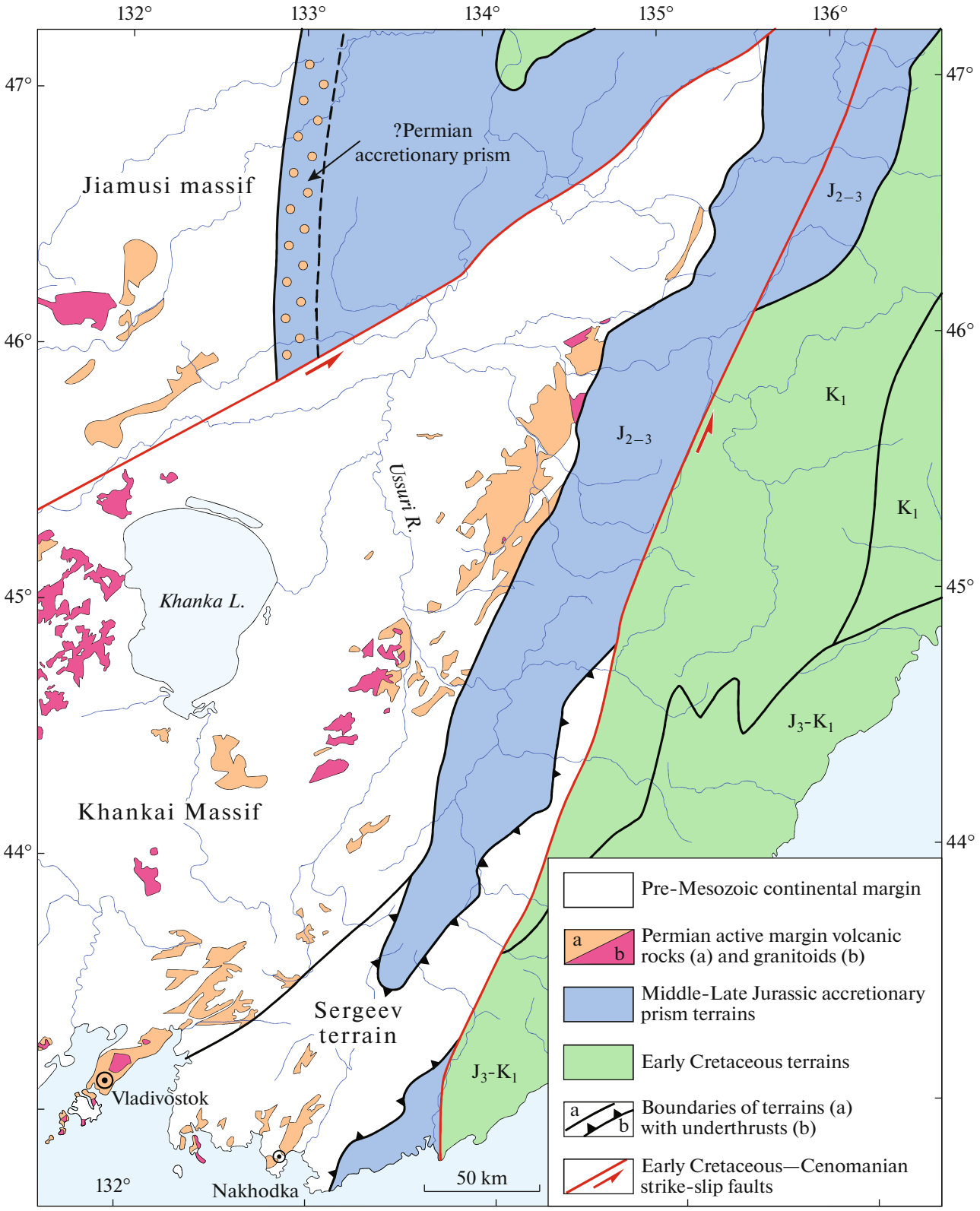


Fig. 7. A tectonic scheme of southern Russian Far East and adjacent regions in NE China suggesting Jurassic tectonic (subduction) erosion.

continents, the lower is the probability of their destruction and erosion. An important conclusion made by the authors [19] is the higher rate of subduction and its related recycling of continental crust material back to the upper mantle and, possibly, deeper, compared to the delamination of lower crust material. The subduction of crust deep to the mantle fits the global geophysical model of whole-mantle convection [41, 71] and the geochemical data indicating that the material of subducted crust triggers mantle plumes and their related mantle sources.

Given that the global long-term rate of subduction erosion is much greater than that of crustal additions (Fig. 9) [19, 67, 69], it was suggested that the processes of subduction erosion operated back to the Paleozoic and Mesozoic paleo-oceans, for example the Paleo-Asian Ocean, which closure later formed the CAOB (see Introduction) [17, 23, 24, 59, 63, 84]. A key aspect of the study of fossil Pacific-type orogenic belts is geological data, such as the presence of accretionary complexes, intra-oceanic (island) arcs, elements of Ocean Plate Stratigraphy (OPS) and blueschist belts formed after MORB and OIB [2, 3, 52, 63, 64]. The geological data from the CAOB, i.e. the presence of intra-oceanic arcs, accreted OPS and blueschists, and the numerous whole rock Nd isotope data [37] confidently prove that the CAOB is the world largest Pacific-type fossil orogenic belt and the main loci of the formation of Phanerozoic juvenile continental crust [63]. However, recent Hf-in-zircon isotope data from the CAOB showed that the CAOB continental crust includes at least 40% of recycled or re-worked crust [46, 47]. The reason of such a discrepancy could be the processes of subduction erosion of a part of juvenile crust (Fig. 10).

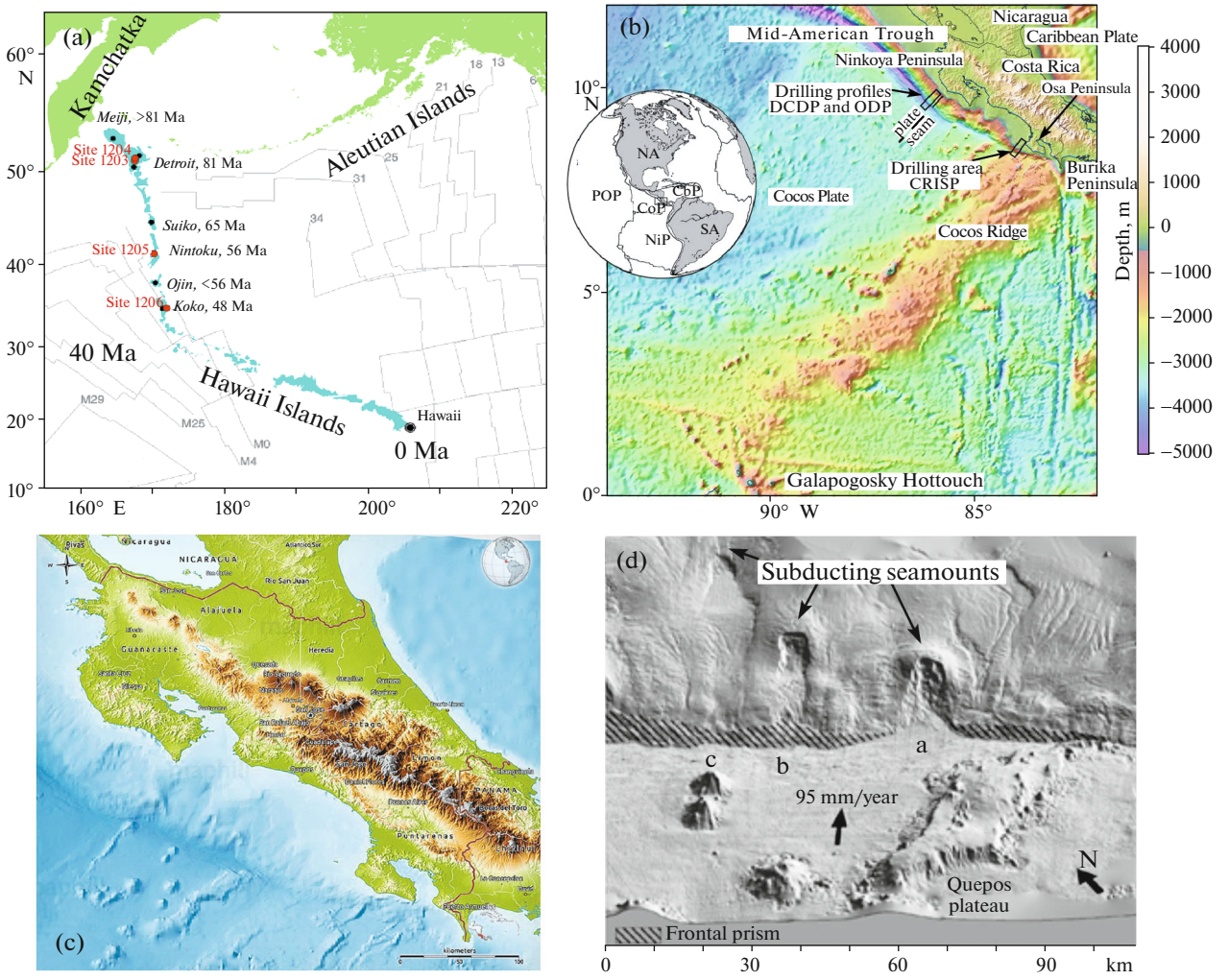


Fig. 8. (a) Emperor-Hawaii Chain of seamounts and oceanic islands. (b) Costa-Rica shore as a zone of active subduction and tectonic erosion. (c) 3D imagery of the Cocos subducting plate. (d) multi-ray bathymetric survey imagery of central Costa-Rica illustrating the effect of subducting seamounts: (a) destruction of accretionary prism by subduction seamount; (b) previously destroyed but healed segment; (c) healed prism affected by secondary oceanic floor elements [75].

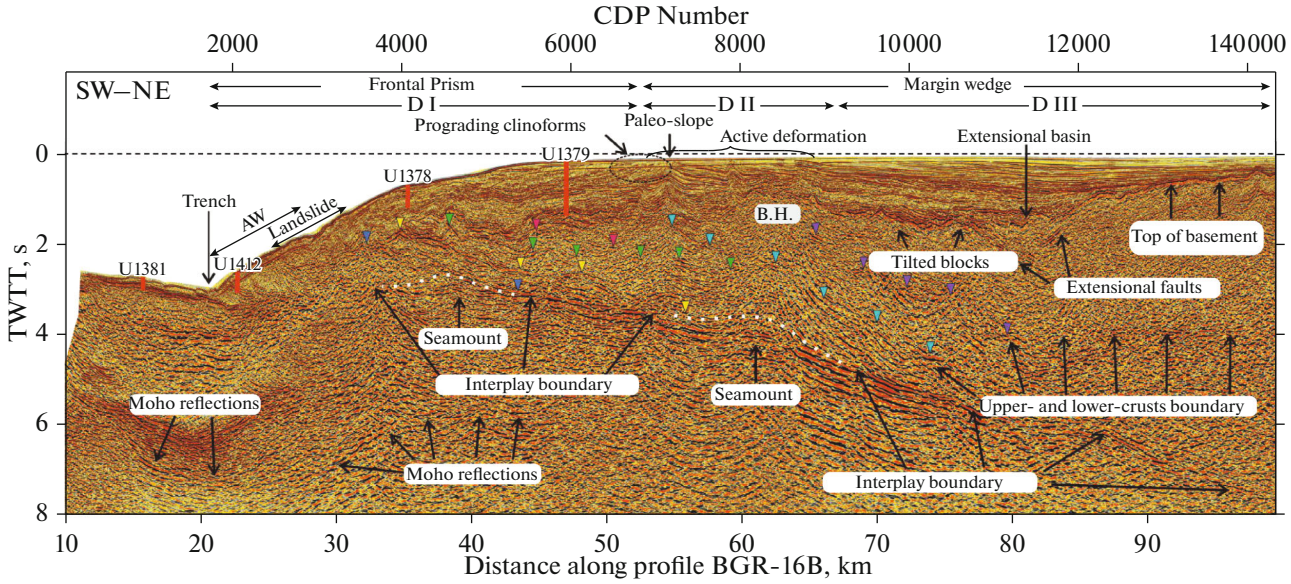


Fig. 9. A wide-angle multi-channel seismic reflection profile across the Osa

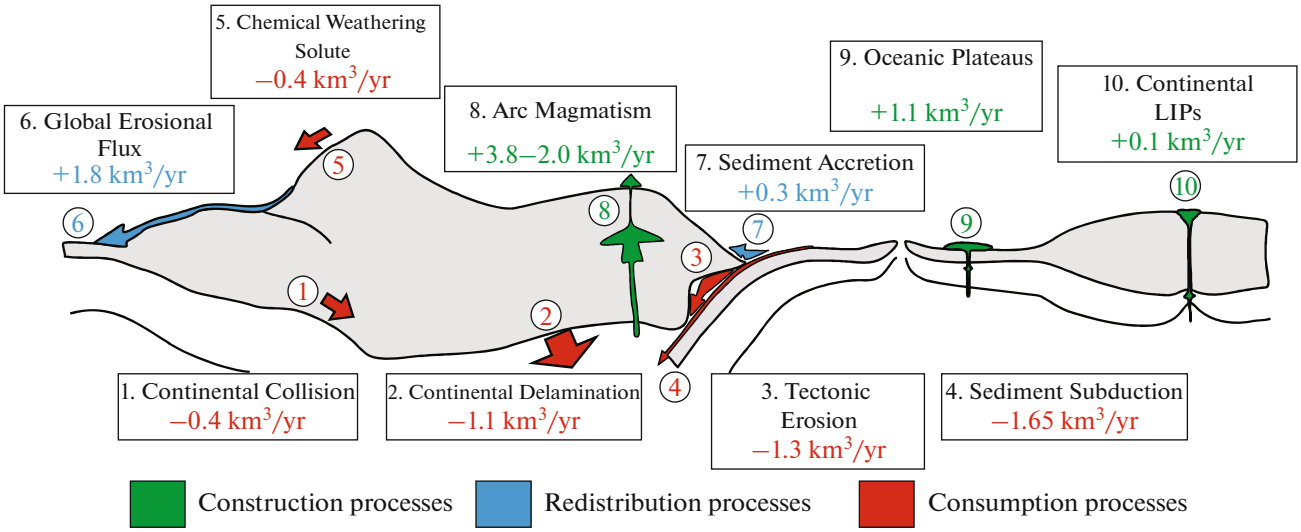


Fig. 10. Global long-term evaluations of rates of crust formation and destruction [19] showing that the former are notably higher than the latter.

Periods of Tectonic Erosion at Convergent Margins of the Paleo-Asian Ocean

In Earth's history in general and in the Phanerozoic history of Asia in particular, PTCMs were dominated either by processes of accretion or by processes of destruction of a major part of juvenile continental crust formed at island arcs and accreted oceanic rocks. During the formation of the Asian continent, in particular, its nuclei, i.e. the CAOB [60] formed by the suturing of the Paleo-Asian Ocean, the processes of accretion dominated at PAO PTCMs in late Neoproterozoic to early Paleozoic time and in late Paleozoic to early Mesozoic time, while the processes of tectonic erosion were very active during the middle Paleozoic [63]. The most probable regions of the CAOB in term of subduction erosion are Paleozoic supra-subduction complexes of NW Altai, central and eastern Kazakhstan, southern Transbaikalia-northern Mongolia, southern (Kyrgyzstan, Uzbekistan) and northern (Kyrgyzstan) Tienshan (Fig. 11). The Pacific-type orogenic belts of these regions carry evidence for the disappearance of big volumes of continental crust, e.g., show a reduced distance between coeval supra-subduction and accretionary units. In addition, those regions host abundant turbidite and greywacke sand-

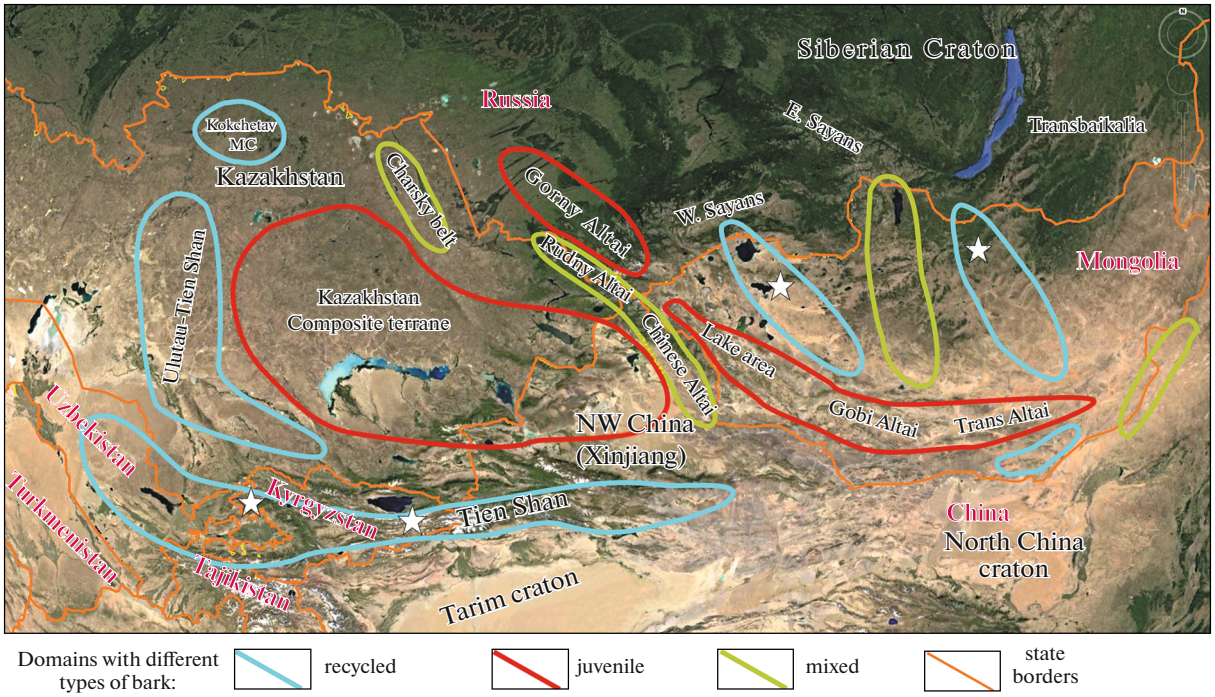


Fig. 11. A scheme of the Central Asian Orogenic Belt showing crustal segments of different origins [63]. White starts show locations most promising for studying tectonic erosion at the PTCMs of the Paleo-Asian Ocean.

stones while their coeval and geochemically similar igneous formations are present in notably subordinate amounts.

Geological criteria of subduction erosion are (1) small sizes of outcrops of igneous rocks possessing supra-subduction geochemical affinities; (2) reduced (compared to actualistic analogues) distance between trench and arc, if preserved; (3) presence of blocks of mafic to felsic arc-related igneous rocks in serpentinite melanges typical of Pacific-type orogenic belts. The destruction of intra-oceanic arcs and the transportation of the eroded material down to the trench results in the formation of characteristic sedimentary clastic rocks: turbidite and greywacke sandstones. Those turbidites and greywackes formed at intra-oceanic subduction zones (arcs) are compositionally (bulk) similar to their parental igneous rocks; greywackes and turbiditic sandstones contain detrital zircons, which age refers to the time of supra-subduction magmatism. On the contrary, sandstones formed at continental arcs are compositionally more felsic and may contain detrital zircons older than the associated supra-subduction igneous rocks.

While an ocean is subducting and closing/suturing, magmatic arcs can partly or completely disappear from geological record because of subduction erosion. Unlike arcs, a major portion of greywacke turbidites amd sandstones remains on the surface and allow us to determine a nature of a former magmatic arc – intra-oceanic or continental. If the geochemical features of sandstones match an average composition of mafic and andesitic island-arc igneous series, e.g., tholeiitic and calc-alkaline basalts and andesites, if their isotope composition indicates juvenile sources (positive epsilon Nd in whole rock and Hf-in-zircon) and if the distribution of U-Pb ages of their derived detrital zircons is unimodal, the parental magmatic arc was intra-oceanic. If the composition of sandstones suggests mainly sub-alkaline andesitic and felsic rocks in the provenance, e.g. dacite-granodiorite, rhyolite-granite, if the epsilon Nd in whole rock and Hf-in-zircon are negative and if the distribution of U-Pb ages of their derived detrital zircons is polymodal, we can suggest that the parental arc likely formed on a continental margin (or active continental margin).

Accordingly, identification of episodes of tectonic erosion in fossil folded belts formed by the suturing of paleo-oceans requires multidisciplinary research. Main approaches are (1) detailed field works to evaluate the parameters of island-arc magmatic units, such as length, width and thickness, and the distance between arcs and trenches; to make representative collections of samples of igneous and sedimentary rocks; (2) U-Pb dating of zircons from igneous rocks (andesitic and felsic varieties) and detrital zircons from sandstones to know their ages and the character of age spectra (unimodal vs polymodal); (3) geochemical analysis to determine the concentrations of major and trace elements of igneous and sedimentary rocks; (4) Nd whole rock and Hf-in-zircon isotope studies to

define a character of their source rocks, juvenile or recycled; (5) summarization of obtained data, highlighting main periods and rates of subduction erosion for each selected region of the CAOB and all together. In terms of practical application, a promising issue could be finding out if there are links between subduction erosion and formation of copper-porphyry deposits by analogy with those tracing the subduction zone along the western coast of South America.

CONCLUSION

Subduction or tectonic erosion results in destruction of a big amount of crustal material, including juvenile, and its disappearance from Earth's surface. This shifts initial proportions between juvenile and recycled crust, as established during previous epochs of Pacific-type orogeny, towards the latter. The proportions of juvenile and recycled crust in fossil intracontinental orogens formed in places of suturing of paleo-oceans have been a subject of hot discussions among geoscientists during the last 20 years [8, 9, 37, 38, 43, 44, 46, 47, 63], as they are of special importance, both in theory for evaluating crustal growth rate and in practices for determining a nature of orogeny, Pacific-type (subduction-accretion) or Himalayan-type (collisional) for further prospecting for this or that type of mineral resources, respectively. Traditionally, the proportions between juvenile and recycled crust have been estimated by geochemical and isotope data from granitoids or felsic volcanic rocks. However, those traditional approaches ignore or underestimate geological data suggesting that a part of island-arc igneous formation could have been "lost" during subduction erosion. As a result the nature of this or that intra-continental orogenic belt may remain disputable as happened with the Central Asian orogenic Belt formed by the suturing and closure of the Paleo-Asian Ocean [17, 23, 37, 46, 47, 59, 63, 79, 84]. Therefore, highlighting the periods of subduction erosion at convergent margins of the Paleo-Asian Ocean and reconstructing probably eroded Paleozoic intra-oceanic arcs should be performed using the criteria developed at the convergent margins of the Pacific Ocean. The most probable regions of the CAOB in term of subduction erosion are Paleozoic supra-subduction complexes of NW Altai, central and eastern Kazakhstan, southern TransBaikalia-northern Mongolia, southern (Kyrgyzstan, Uzbekistan) and northern (Kyrgyzstan) Tienshan. Studying the processes resulting not in the formation of new crust in a traditional way, but also resulting in the disappearance of big volumes of crustal materials is necessary to provide realistic evaluation of the nature and growth rate of CAOB continental crust, to develop correct tectonic models of CAOB evolution and to improve the quality of research and exploration of mineral deposits.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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