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Marginal Seas—Terminological Crisis

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Abstract—The terms *marginal sea, peripheral sea*, and *backarc sea* are widely used in the contemporary Russian geological literature as synonyms but do not have, in my opinion, unequivocal treatment. The application of the term *marginal sea* is briefly discussed. The seas of the Pacific transitional zone are reviewed. It is proposed to define a marginal sea as a marine basin a few thousand kilometers in extent and connected with the open ocean. Domains underlain by crust of the continental and oceanic types must coexist therein. The domains with oceanic crust are expressed in the topography as deepwater basins (one or several), where fragments of continental crust may also occur. A marginal sea must be bounded by at least one island arc.

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INTRODUCTION

Terms *marginal sea, peripheral sea*, and *backarc sea* are widely used in the contemporary Russian geological literature but do not have, in my opinion, unequivocal treatment.

In the geological glossary published in 1973 in the former USSR, a marginal sea (with "peripheral sea" as a synonym) was defined as a sea "localized between continents and oceans (at the margins of continents) and commonly separated from the oceans only by islands, peninsulas, or seamounts, which ensure free water exchange with the oceans..." [8, p. 482]. Marginal seas "cover shelf (North, Barents, Kara seas) or fill separate basins (Sea of Okhotsk, Bering, Andaman seas)" [ibid].

In the fourth edition of the Glossary of Geology published by the American Geological Institute in 1997, a marginal sea is defined as a "semienclosed sea adjacent to a continent, floored by submerged continental mass" [37, p. 390]. In the Russian translation of this glossary, this definition is accompanied by an editor's comment: "The floor of many marginal seas is underlain by oceanic-type crust, and the formation of such seas is related to stretching of the continental crust rather than to its submergence" [37, p. 390; Russian translation, vol. 2, p. 12]. A shallow marginal sea situated on the continental shelf, rarely exceeding 150 fathoms (up to 300 m), for example the North Sea, is defined as a *shelf sea* [37, p. 587].

In the glossary of geographic notations and terms, a marginal (semienclosed) sea is defined as "a part of the ocean adjoining a continent and partly separated from the open ocean by peninsulas, islands, or bottom thresholds, e.g., the Sea of Japan" [16, p. 361].

In a paper published by V.E. Khain in the Soros Educational Journal [http://journal.issep.rssi.ru/], it is said that deep marginal seas open in the far back of a subduction zone. In the character of the crust and the origin they are similar to minioceans.

"Spreading in backarc basins develops on a separate fragment of an oceanic or continental microplate. The processes inherent to the axial zones of oceans occur within marginal seas on a minor scale. They differ from the former not only in dimensions but also in degree of depletion of the oceanic crust and upper mantle. The oceanic lithosphere in marginal seas is depleted to the greatest extent" [4, p. 233]. An overview of the character of the tectonic evolution and structure of marginal seas at active convergent margins confirms the wide diversity of their morphology and origin, except for one common feature—they are formed behind a subduction zone and volcanic island arc..." [ibid, p. 236].

The term *marginal sea* was introduced by Dutch geologist Ph.H. Kuenen in 1950 [14]. He, in turn, was guided by term *adjacent sea* defined by Sverdrup et al. [88] as "semienclosed seas adjacent to and connected with the oceans" (cited after [66, p. 4]). The North (North Polar?—A.M.), Mediterranean, and Caribbean seas were given as examples.

The present-day concept of marginal seas is based on a publication by D. Karig in 1971 [14], where he writes that "the semi-isolated basins and series of basins of intermediate to normal oceanic depths that lie behind island arc systems are termed marginal basins" [14, p. 2542]. In general, this term corresponds to the definition of marginal sea given by Kuenen.

Thus, the ambiguity of the term *marginal sea*, which is evident even for contemporary objects, leads to its broad treatment in paleogeodymanic reconstructions. This question should be specially discussed at geological conferences in order to elaborate the criteria for identification of ancient marginal basins.

Otherwise, it would be impossible to develop more or less common approaches to terrane analysis, geological cartography of large regions, metallogenic research, and prospecting of petroleum fields.

Let us give an example of the geodynamic reconstruction of the Urals for the Late Devonian. "On the basis of the composition of rocks and localization of facies, it has been established that the clastic sedimentary rocks of the Zilair Group were formed in two separate basins divided by a cordillera existing on the place of the present-day Uraltau Massif. The models of these basins are comparable in their characteristics with a marginal sea (territory of the Zilair Synform and Ufa Amphitheater) and a backarc basin (Magnitogorsk Zone)" [http://www.igg.uran/Lab_Lithology/]. Thus, the region underlain by the ancient continental crust is referred to as a marginal sea, whereas the district area close in geodynamic setting to the contemporary active transitional zones is regarded as a backarc basin.

Comprehensive reviews on the structure of particular marginal seas and their groups situated in various regions and in different tectonic settings have been published in Russia [5, 7, 9, 23, 25, 29, 31, 39, 42 among others].

The objective of the current review is a classification of marine basins localized in the West of the Pacific Ocean and commonly regarded as marginal.

OVERVIEW OF THE GEOLOGY OF THE SEAS IN THE NORTHEAST, EAST, AND SOUTHEAST OF ASIA

The active margins of East Eurasia are distinguished by intense magmatic and metamorphic processes and high seismicity, including recent volcanic activity. In topography, these are a complex combination of island arcs, mountain ranges, and shallow- and deepwater basins varying in age, structure, and development.

Seas of Northeastern and Eastern Asia

The Bering Sea, Sea of Okhotsk, and Sea of Japan are situated in the northern and northwestern Pacific Ocean, being separated from it by island arcs and deepwater trenches.

The Bering Sea is separated from the Pacific Ocean by the Aleutian Islands and the Komandorsky Islands as their western continuation (Fig. 1). The total extent of the island system as a whole is about 2500 km. Active and Holocene volcanoes are localized along the Aleutian island arc, including the Alaska Peninsula (NOAA/NESDIS/National Geophysical Data Center). The Komandorsky Islands [41, 43] are composed of Paleogene–Neogene volcanic and volcanosedimentary complexes.

The outer slope of the Aleutian island arc [48, 55] is complicated by numerous scarps and terraces. The plate convergence in the eastern segment of the Aleutian arc develops at a rate of 6–7 cm/yr at an angle relative to its front. As a result, compressive structural elements and strike-slip faults appear at the island-arc slope.

The Bering Sea is separated into two domains differing in geological and geophysical features and bottom topography. The shelf with the Pribilof, St. Lawrence, Nunivak, and St. Matthew islands occupies its northern and northeastern parts [3, 47, 81]. The Holocene volcanic edifices are located on some of these islands. The shelf attains 600 km in width and 200 m in depth. Its basement consists of fold–nappe structural elements exposed at the surface in the Koryak Highland and in southwestern Alaska [2, 13, 74], as well as in the Okhotsk–Chukotka volcanic–plutonic belt. The shelf is separated from the deepwater part of the sea by a steep slope 30–300 km wide complicated by numerous scarps, slumps, and canyons (Navarin, Zhemchug, etc.) [3].

The deepwater part of the Bering Sea comprises the Komandorsky and Aleutian basins divided by the near-meridional Shirshov Ridge. A small deepwater basin is situated between the Bowers Ridge and the Aleutian Islands.

The Shirshov Ridge extends for 670 km between 170 and 171° E having a width of 100 km in the north and the south and widening to 250 km in the central segment [3, 28]. The depth of its crest varies from 200 to 1000 m. The crust thickness is estimated at 20 km. The Shirshov Ridge is composed of the Triassic and Upper Cretaceous–Paleocene cherts, tectonized metabasic rocks, amphibolites after gabbroic rocks, and tuffaceous sedimentary rocks. The Bowers Ridge extends for 770 km and its maximum width is about 200 km. The depth of its crest varies from 200 to 700 m.

The thickness of the oceanic-type crust in the Aleutian Basin is 15–16 km. Its floor is a nearly horizontal plain 3800–3900 m deep. The Komandorsky Basin has oceanic-type crust 12–14 km thick [3, 34, 49]. Its floor is also a nearly horizontal plain 3800–3900 m deep. The sedimentary cover is 2000–6000 m thick.

The thickness of the sedimentary cover in the Bering Sea ranges from 1000 to 10000 km [3, 49, 74] and is 500–1000 m in the inner shelf. A system of isolated troughs extends along the shelf slope. In some of them, the thickness of the sedimentary cover attains 8000–10000 m (Fig. 1).

The Sea of Okhotsk is separated from the Pacific Ocean by the Greater and Lesser Kurile Islands and the Kamchatka Peninsula [18, 19, 21, 29, 30, 59, 65] (Fig. 2). Their middle Pliocene, Holocene, and active volcanoes are combined into the Kurile–Kamchatka island arc, more than 1400 km in total extent [http://www.kscnet.ru/ivs/grant/grant_05/kurily/]. The arc consists of an inner (volcanic) and outer (amagmatic) part separated by a trough. In the southeast, the arc is

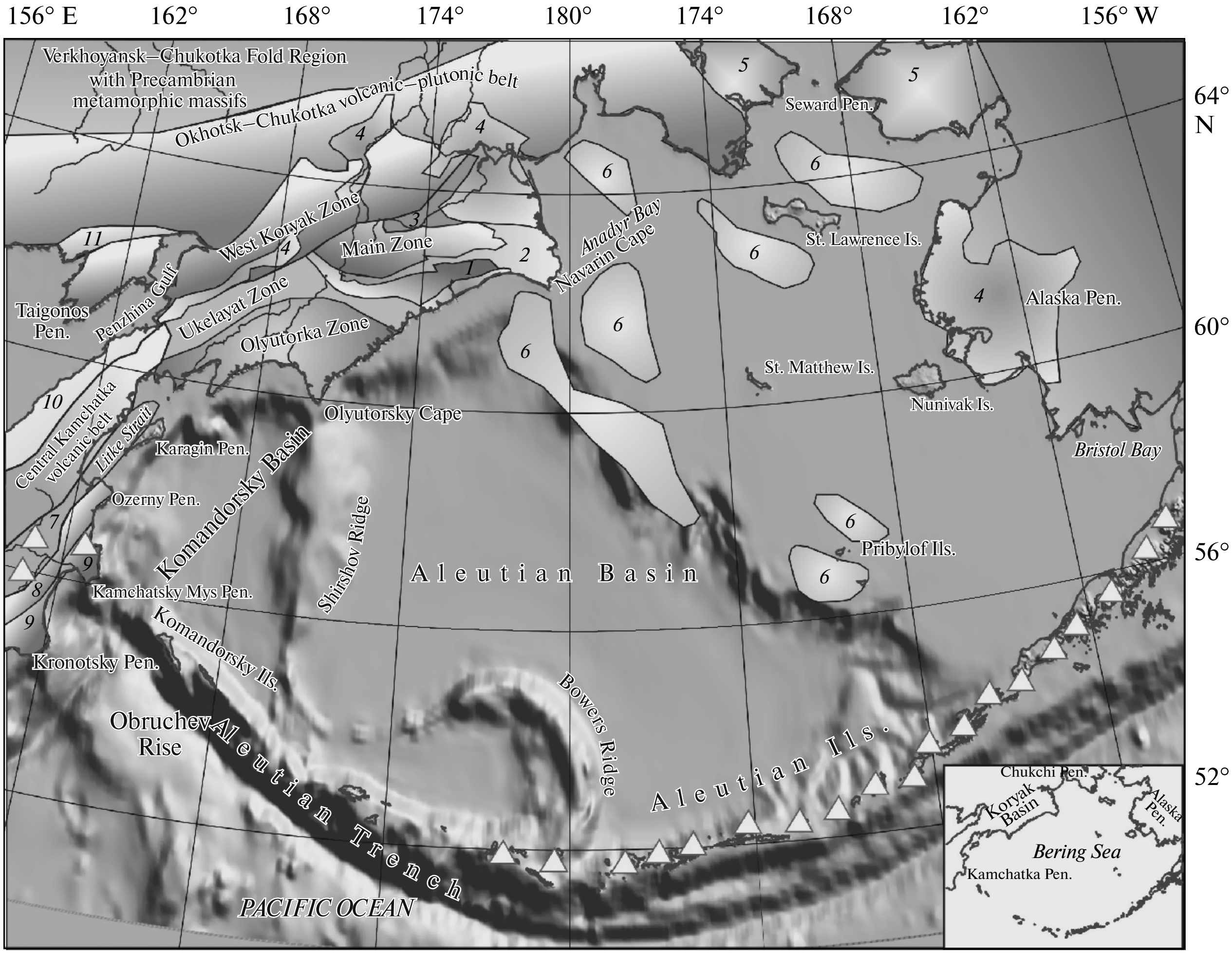


Fig. 1. The main geographic objects and structural elements of the Bering Sea and its framework: a conceptual scheme, after [9; http://north-east.ginras.ru/result/]; the topographic base: offshore [ETOPO5 Set. Global Relief DATA CD. NOAA Product #G01093-CDR-A0001]; land [GTOPO30 Global Digital Elevation Model. EROS Data Center, 1996; http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html]. Numerals in figure: (1–3) zones of the Koryak Highland: *1*, Ekonai; *2*, Al'katvaam; *3*, Onemen; *4*, superimposed Cenozoic basins; *5*, Chukchi Massif and its counterparts in Alaska; *6*, main depocenters of sedimentation; *7*, Central Kamchatka Depression and Litke Trough; (*8–10*) zones in Kamchatka: *8*, Eastern Ridges (Kumroch, Tumrok, and Valagin); *9*, Eastern Peninsulas (Ozerny, Kamchatsky Mys, Kronotsky); *10*, West Kamchatka Trough. Triangles, active volcanoes.

conjugated along its entire strike with the deepwater Kurile–Kamchatka Trench.

The Lesser Kurile islands are composed of largely Upper Cretaceous rocks. The submarine Vityaz Ridge occurs at its extension [20]. The trough between the Greater and Lesser Kurile island arcs is filled with Neogene and Quaternary tuffaceous sedimentary rocks.

The shelf of the Sea of Okhotsk, 180–250 km wide and no greater than 200 m deep [27, 40], comprises the submerged areas and the Oceanology Institute and Academy of Sciences rises with maximum depths of 940 and 894 m, respectively. These rises are separated by the Makarov Trench. The Sea of Okhotsk has continental crust 10–40 km thick, except for the Kurile (South Kurile) Basin. The basement of the Sea of Okhotsk is heterogeneous. The M discontinuity is characterized by complex topography; the seismic wave velocity along this surface varies from 7.8 to 8.1 km/s.

The NW-trending Deryugin Trough is situated to the east of Sakhalin Island [27, www.copernicus.org/EGS/egsga/nice01/], separated from the northern part of this island by the submarine Schmidt Rise apparently composed of Cretaceous ophiolitic association [32, 33]. The Deryugin Trough is filled

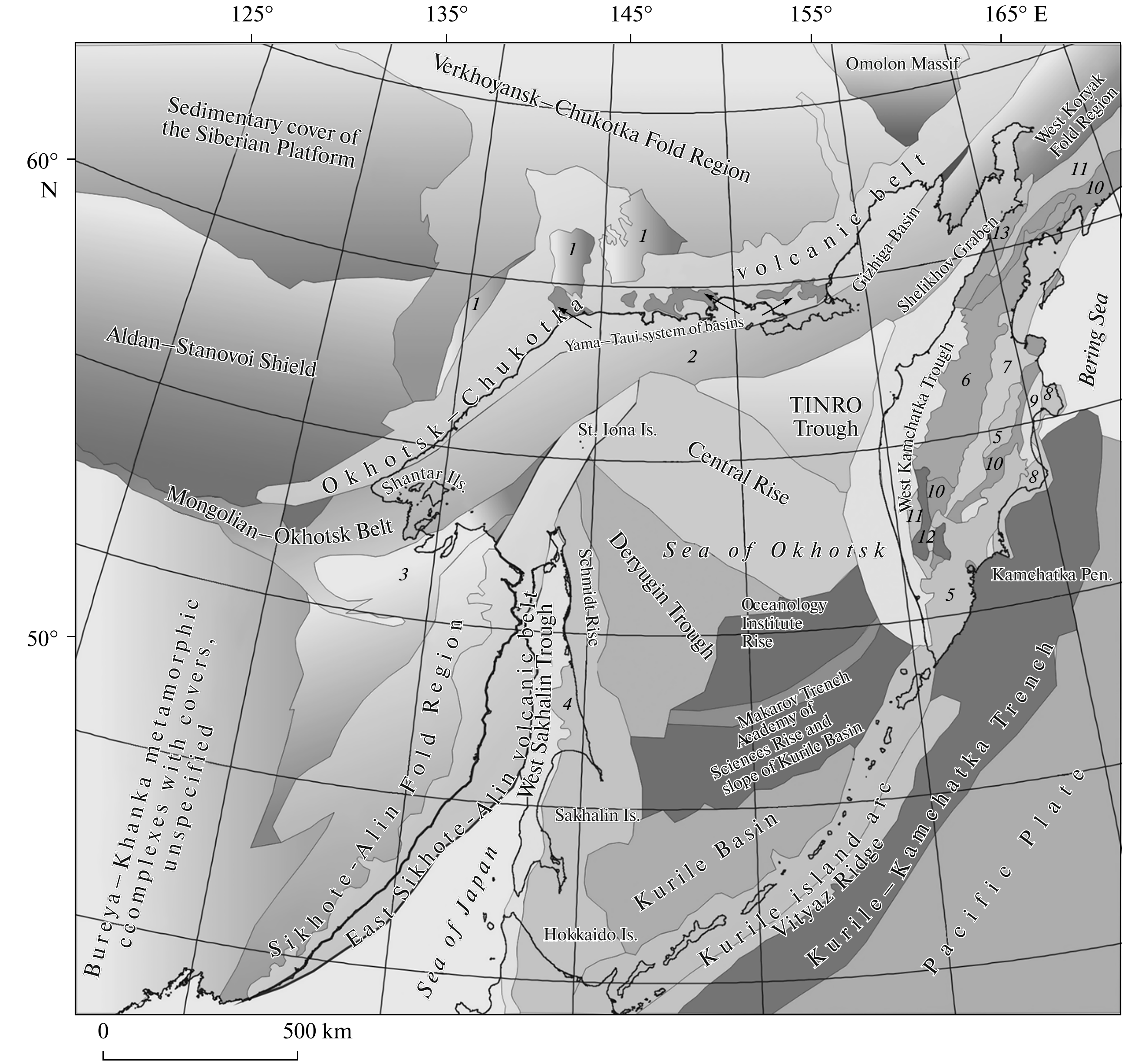


Fig. 2. The main geographic objects and structural elements of the Sea of Okhotsk and its framework: a conceptual scheme, after [9, 11, 12, 36, 40]; the topographic base: offshore [http://topex.ucsd.edu/marine_grav/mar_grav.html]; land [GTOPO30 Global Digital Elevation Model. EROS Data Center, 1996; http://edcwww,cr.usgs.gov/landdaac/gtopo30/gtopo30.html]. Numerals in figure: *1*, Okhotsk Massif; *2*, extension of the West Korayak fold–nappe region beneath the Magadan Shelf; *3*, Badzhal–Ul'ba region of fragments of the Lower Mesozoic accretionary prism; *4*, fragments of the Mid- and Late Cretaceous accretionary prism of East Sakhalin; *5*, East Kamchatka and Kurile volcanic belts (Pleistocene–Holocene); *6*, Central Kamchatka volcanic belt (Neogene–Quaternary); *7*, Central Kamchatka Depression and Litke Trough; 8, Kronotsky–Komandorsky island paleoarc (Late Cretaceous–Oligocene); *9*, Vetlovo–Goven accretionary prism (Eocene–Miocene); *10*, Achaivayam–Valagin island paleoarc (Late Cretaceous–Oligocene); *11*, Omgon–Ukelayat terrigenois rocks of continental rise (Upper Cretaceous–Eocene); *12*, metamorphic rocks of the Omgon–Ukelayat and Achaivayam–Valagin terranes; *13*, West Kamchatka volcanic belt (Eocene–Oligocene).

with Oligocene–Quaternary sedimentary complex up to 12 km thick.

The South Kurile Basin has a maximum depth of 3521 m [15, 27, 46]. This is an abyssal plain, the southwestern part of which is overlain by sedimentary cover 4000–7000 m thick. The M discontinuity occurs at a depth of 11–13 km. The basin was formed from the early Oligocene to the late Miocene under extension conditions. Its active submergence began in the early Pliocene.

The so-called Magadan shelf is situated in the north of the Sea of Okhotsk. Its basement is composed of Permian–Triassic and Jurassic–Lower Cretaceous island-arc complexes, Paleozoic and Mesozoic paleooceanic and island-arc rock associations of ancient accretionary complexes [35]. In the Early Paleogene, a system of N–S- and NE-trending half-grabens and horsts was developed parallel to the present-day coast of the Sea of Okhotsk [6, 17]. The sedimentary cover beneath the water column is 3000–5000 m thick, reaching 8000–9000 km in isolated depocenters.

The enormous West Kamchatka–East Okhotsk Trough extends along the western coast of the Kamchatka Peninsula; its main part is flooded by the Sea of Okhotsk. In the north, near the TINRO Basin (where the maximum depth is 993 m), this trough is connected with the sedimentary basin of the Magadan shelf and continues to the Shelikhov Bay and the Gulf of Penzhina.

The basement of the trough is composed of Jurassic–Cretaceous rocks, which have a fold–nappe structure formed in the Maastrichtian–Danian and are unconformably overlapped by Cenozoic tuffaceous and terrigenous rocks, which are locally deformed into recumbent folds and complicated by thrust faults [10, 36].

In the west, the Sea of Okhotsk is framed by the fold–nappe structure of the Hokkaido–Sakhalin region [12]. The tectonic zones of Central Hokkaido extend to South Sakhalin, whereas the eastern zones are regarded as unique or correlated with the eastern part of Central Sakhalin. In the present-day structure of the margins, these complexes are disturbed by Late Mesozoic near-meridional strike-slip faults and Cenozoic movements associated with the opening of marginal seas.

The Sea of Japan is separated from the Pacific Ocean by the Japan Islands (Fig. 3). The average depth is 1350 m; the maximum depth is 3742 m. The topography of the Sea of Japan is characterized by a few large basins and rises, separate seamounts and banks. The Central and Honshu deepwater basins are underlain by the oceanic crust, while the thinned continental crust is typical of rises [26].

The Sea of Japan is surrounded by the Sikhote-Alin, Sakhalin, and Japan fold–nappe regions and the Korean Shield [11, 22].

The thickness of the sedimentary cover in the Sea of Japan reaches a maximum at its margins (up to 2000–3000 m) and decreases inward, where it is no greater than 1500 m. The crust thickness at the southeastern margin of the Asian continent is 35–40 km; 12–15 km in deepwater basins of the Sea of Japan; about 35 km beneath Honshu Island; and no greater than 8 km in the adjacent Pacific Ocean.

The present-day Sea of Japan was formed as a result of the separation of the Japan Islands from the mainland 25–15 Ma ago; an important contribution was thereby made by strike-slip faults, especially in the Cretaceous [11].

The Yellow Sea and the northern part of the East China Sea cover the shelf, the depth of which near the coast of China is not greater than 10 m [39, 69, 70, 72, 80, 87] (Fig. 4). The depth gradually increases east- and southward up to 80 and 130–150 m, respectively. The shelf is underlain by structural elements of the Chinese Platform and the Korean Shield. A vast sedimentary basin was formed here in the Mesozoic and Cenozoic. Its present-day structural appearance was determined, to a great extent, by Late Cretaceous and early Oligocene rifting. The late Miocene compressive phase gave rise to folding and thrusting in the eastern part of the region followed by quiet subsidence and deposition of thick terrigenous sequences. The Okinawa Trough is situated in the southern part of the East China Sea north of the Ryukyu island arc.

The basement of the Ryukyu island arc, approximately 1200 km in extent, is composed of Upper Paleozoic–Lower Cenozoic metamorphic rocks. The forearc ridge extending along the entire outer zone of the Ryukyu island arc consists of rocks belonging to the accretionary wedge formed by subduction of the Philippine Plate at a rate of 5 cm/yr. The Ryukyu island arc is separated from the Philippine Plate by a deepwater trench exceeding 6000 m in depth (the maximum depth is 7881 m).

Seas of Southeastern Asia

The seas of Southeastern Asia and their framework are distinguished by complex geology (Fig. 4) due to their localization in the deformation zone at the junction of the Pacific, Indo-Australian, and Eurasian lithospheric plates.

The shallow-water submarine plains adjoining the Malacca Peninsula, Indochina, and Kalimantan Island and situated in the west of Indonesia are combined under the collective name of the Sunda shelf [64], where the sea depth varies from a few meters to 100 m. The uniqueness of this region is determined by the collision sutures which frame it on all sides. A number of basins with oceanic crust newly formed in the Cenozoic (South China, Sulu, Sulawesi, etc.) are situated in the east. Large strike-slip displacements are related to the collision Himalayan Orogen that extends in the west and northwest.

The tectonic framework (continental core) of the Sunda shelf (Malay Peninsula, Indochina, Sumatra, Java, and Kalimantan islands) comprises Mesozoic ophiolites and island-arc complexes with fragments of Proterozoic continental crust accreted in the Indosinian time. Intense granitoid magmatism took place in the Permian and Triassic.

Numerous sedimentary basins diverse in origin and in some places extremely complex in structure were formed on the Sunda shelf in the Paleogene–middle Miocene. The thickness of the Cenozoic sedimentary cover in some of these basins attains 14000 m. The present-day appearance of Southeast Asia was created in the Pleistocene.

The South China Sea extends from Taiwan to the Singapore straits for almost 2900 km [38, 39, 51, 68, 92; http://www-odp.tamu.edu/publications/184_IR/; http://www.coi.gov.cn/scs/introduction/; http://www.kscnet.ru/].

The main part of the sea is occupied by a deepwater basin (3700–4400 m) with oceanic-type crust formed from the early Oligocene to the middle Miocene. Its thickness varies from 4.5 to 8.5 km. The basin is separated from the Asian continent by a shelf 220–330 km wide. A chain of submarine rises extends in central part of the sea. Their strike changes from WNW to NE. About 30 seamounts more than 1000 m in height and about 20 hills 400–1000 m high are known therein.

The Manilla and Palawan deepwater trenches extend along Philippine Islands and Palawan Island in the eastern and southern parts of the South China Sea.

The sedimentary, basins varying in structure, thickness of sedimentary cover (3000–17000 m), and outlines in plan view, were formed in the Paleocene–Oligocene along the northern margin of the South China Sea as a result of extension and subsequent subsidence of the lithosphere. Areas of late Miocene–Recent submarine volcanism occur in the northwestern part of the shelf in the South China Sea, its islands, and on land in Vietnam.

The Sulu Sea washes the islands of the Philippine Archipelago (Mindoro, Panay, Negros, and Mindanao) in the northeast and east; the Sulu Archipelago in the southeast; Kalimantan Island in the southwest; and Palawan Island and the smaller islands that crown the NE-trending submarine ridge in the northwest [http://www.doe.gov.ph/PECR2005/; http://kalibo.tukcedo.nl/]. In plan view, the sea is close to rectangular (500 × 600 km) and elongated in the northeastern direction. The submarine Kagayan Ridge, composed of Neogene island-arc associations, divides the Sulu Sea into two basins: the East Palawan basin and the basin of the Sulu Sea. The greatest depths (up to 5000 m; 5576 m maximum) are confined to the southeastern part. The depth gradually decreases to 100 m or lower toward Palawan Island.

The basement of the Sulu Sea consists of deformed pre-Cenozoic ophiolites and Cretaceous–lower Eocene cherty and volcanic complexes as thick as 9000 m. The section is built up by Miocene–Pleistocene marine terrigenous sediments (deltaic complexes) with numerous interbeds of volcanic material. The structure of the East Palawan Basin is controlled by the thrust front striking in the northeastern direction; the thrust faults dip to the northwest and are displaced by nearly vertical faults extending in the meridional direction. The basin is filled with Upper Mesozoic–Quaternary marine terrigenous–carbonate sequences reaching 7000 m in thickness. The Paleogene grabens and horsts are established at the base of the basin. The thickness of the synrift sedimentary complexes reaches 3000 m.

The Sulawesi Sea is located between Kalimantan Island and the Philippine Archipelago. Its length is 850 km and its width is about 570 m. A chain of active volcanoes extends along the northern part of Sulawesi Island (the eastern part of the Minahasa Peninsula) and continues in the Sangihe Archipelago.

The Sulawesi Sea is a deepwater (up to 5500 m) basin bounded by steep slopes and very narrow shelves [71; http://en.wikibooks.org/wiki/The_Geology_of_Indonesia/Sulawesi_Sea]. The maximum depths are confined to the northeast near Mindanao Island, where they attain 5700 m (Cotaboto Trench). A depth reaching 5500 m is established in the trench of North Sulawesi, which extends along the southern part of the sea. The maximum depth of the Sulawesi Sea is 6220 m.

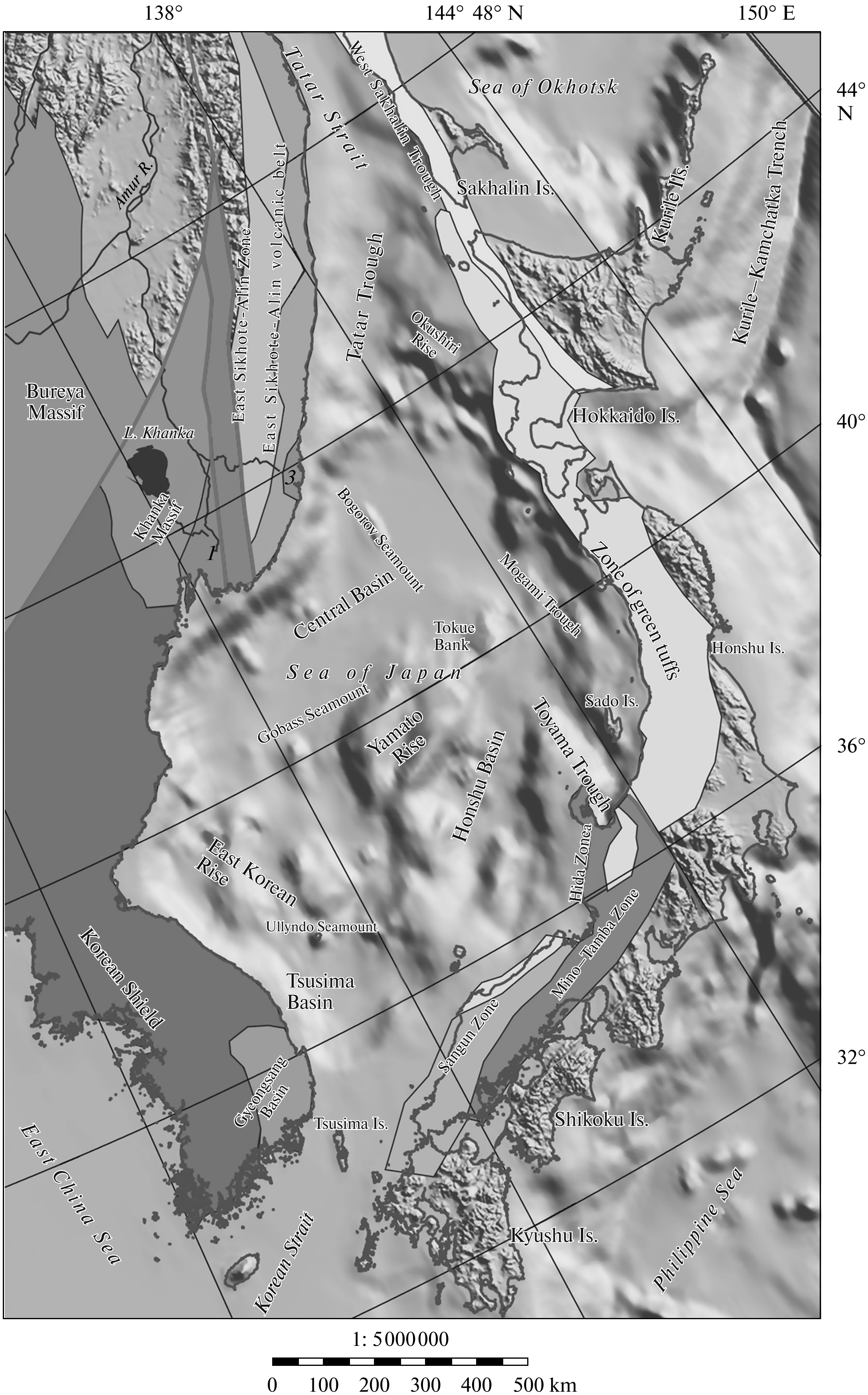
The basin is underlain by Maastrichtian or Paleogene oceanic crust. The maximum thickness of the sedimentary cover (4500 m) is confined to the southeastern part of the sea.

The Banda Sea extends for more than 1000 km from Sulawesi Island to Selatan–Timor Island [44, 45, 60; http://dic.academic.ru/dic.nsf/ruwiki/189773; http://smileplanet.ru/index/0-1023]. The sea consists of six basins more than 4000 m deep separated by submarine rises and ridges. The maximum depth (7440 m) is noted in the Weber Basin.

The Banda arc consists of the outer part (Timor, Tanimbar, and Seram islands), the inner part, and the Weber Basin. The outer part is characterized by widespread rock complexes formed at the passive margin of Australia. At present, they make up thrust sheets and nappes localized largely to the north of the Timor Trough, and Timor, Wetar, Flores, and Tanimbar islands.

The aforementioned territory is located in a zone of elevated seismicity. About 400 volcanic edifices, including 100 active volcanoes, are situated in the southeastern part of the sea (Weber Basin) and on the submarine ridge of the inner Banda volcanic arc. This volcanic chain extends westward up to the Andaman Sea. The deepwater Sunda–Java Trench is localized to the south. In the east, the chain of volcanoes gradually deviates to the north, forming an arc in the eastern part

Fig. 3. The main geographic objects and structural elements of the Sea of Japan and its framework: a conceptual scheme, simplified and modified after [8; http://north-east.ginras.ru/result/]; the topographic base: offshore [ETOPO5 Set. Global Relief DATA CD. NOAA Product # G01093-CDR-A0001]; land [GTOPO30 Global Digital Elevation Model. EROS Data Center, 1996; http://edcwww,cr.usgs.gov/landdaac/gtopo30/gtopo30. html]. Numerals in figure: (*1–3*) zones: *1*, Arsen'ev; *2*, West Sikhote-Alin; *3*, Maritime. Heavy lines, master faults; isobaths are shown in meters.


138°
144° 48° N
150° E
44° N
40°
36°
32°
Sea of Okhotsk
Tatar Strait
West Sakhalin Trough
Sakhalin Is.
Kurile Is.
Kurile–Kamchatka Trench
Amur R.
East Sikhote-Alin Zone
East Sikhote-Alin volcanic belt
Tatar Trough
Okushiri Rise
Bureya Massif
L. Khanka
Khanka Massif
Hokkaido Is.
3
1
Bogorov Seamount
Central Basin
Mogami Trough
Zone of green tuffs
Tokue Bank
Honshu Is.
Sea of Japan
Gobass Seamount
Sado Is.
Yamato Rise
Toyama Trough
Honshu Basin
East Korean Rise
Hida Zonea
Ullyndo Seamount
Mino–Tamba Zone
Korean Shield
Tsusima Basin
Sangun Zone
Gyeongsang Basin
Tsusima Is.
Shikoku Is.
East China Sea
Korean Strait
Kyushu Is.
Philippine Sea
1: 5000000
0 100 200 300 400 500 km

of the Banda Sea, which bends to the east and reaches the southern group of the Molucca Islands.

The current investigations suggest that the Banda Sea began to form in the Late Triassic or Jurassic with separation of the West Burma Block from Australia. The present-day appearance was created as a result of the formation of young oceanic crust in the Neogene.

The Molucca Sea is situated between the Sulawesi Sea, the Sangihe Archipelago in the west, and Halmahera Island in the east [62, 63, 75, 90]. The sea extends for 950 km from south to north; its width is about 250 km in the northern and central parts and more than 800 km in the south. The submarine rise extends along its axis at a depth of 1500–1600 m. The depth increases to 2500–3000 m to the east and to the west, reaching a maximum (>4500 m) in the southeastern part of the sea. A number of islands crown the rise; the Talaud Island in the northern part is the largest.

The Molucca Sea, with oceanic crust of unknown age is bounded by two subduction zones inclined to meet each other. These are the Philippine zone in the east and the Cotaboto zone in the west. At the same time, the area of the Molucca Sea itself is subducted beneath the arcs of Sangihe Island, northeastern Sulawesi, and Halmahera Island. Active volcanoes are situated on the latter island. Convergence of the above arcs controls the structure of the inner parts of the sea, where deformed ophiolites and volcanic rock associations overlap deepwater trenches along thrust faults. These rocks are exposed on Talaud and Mayu islands and on the islands in the southern part of the Molucca Sea.

The structure of the Molucca Sea is limited in the south by the left-lateral Sorong strike-slip fault system, which extends from the northwest of New Guinea to Sulawesi and separates island-arc associations from the continental crust of the Australian passive margin.

Seas of Eastern Australia

Two thirds of the Australian continents are occupied by complexes of the ancient platform occurring in its western and central parts [39]. These complexes extend to the shelf of the Arafura Sea and further to southern New Guinea. The S–N-trending Paleozoic Tasman Fold–Thrust Belt is situated in the east of Australia. Its northern extension is established in central New Guinea; the southern extension, in Antarctica; and its eastern continuation, in the west of New Zealand.

The region to the east of Australia (Fig. 5) is considered [67, 84, 85] to be a system of marginal seas and residual arcs formed from the Cretaceous to Quaternary as a result of the breakdown of Gondwana and convergence of the Pacific and Indo-Australian plates. In my opinion, the Coral, Fiji, and Tasman seas make up a single basin with very complex structure, which will be called below the East Australian basin. Its width from the Australian coast to the Kermadec–Tonga Trench is about 2000 km and its extent from the Solomon Islands to the south of Australia is ~2500 km.

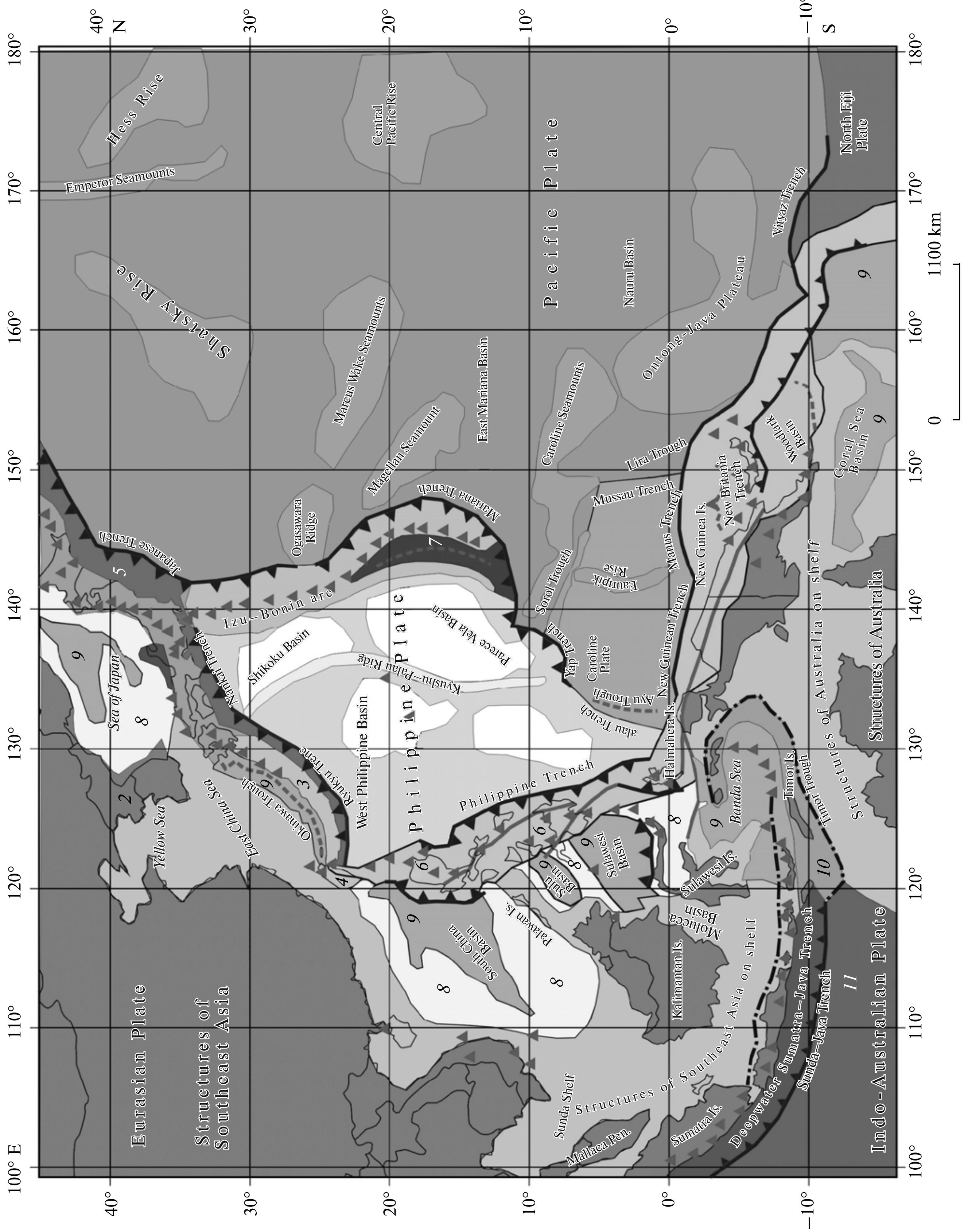
Seismic focal zones dip to the northeast in the northeastern part of the East Australian Basin and to the northwest in the Tonga–New Zealand sector. This indicates that the Indo-Australian Plate plunges to the northeast and the Pacific Plate plunges to the northwest.

Active and historical subaerial volcanoes occur on New Britain, the Solomon Islands, Tonga, and New Zealand.

A system of bottom depressions and rises striking in the near-meridional direction is recognized in the East Australian Basin from west to east: the basin of the Tasman Sea, the Dampier Ridge, the Middleton Basin, the Lord Howe Rise, the Fairway Basin and ridge of the same name, the New Caledonia Basin, the Norfolk Ridge and basins, and the southern Loyalty Basin and ridge of the same name. Beginning from the Miocene, the entire region was a foreland of the Vanuatu subduction zone, where the Indo-Australian and Pacific plates converge [50, 52, 54, 55, 76–78, 85, 86, 89].

In the southern part of the Tasman Sea (maximum depth of 5943 m), rifting started in the Maastrichtian and then propagated to the north [http://stommel.tamu.edu/~baum/]. As a result, the Lord Howe Rise with thinned continental crust moved off the Australian continent, leaving a basin with oceanic crust behind. It is inferred that its basement is composed of Paleozoic rocks overlain by Cenozoic sequences a few hundred meters in thickness. In the basin of the Coral Sea, spreading began in the Paleocene. In general, extension was completed in the middle Eocene, when the nappe structure was formed on New Caledonia Island. Further, the ridge plunged gradually and reached its present-day attitude at a depth of 1000–3000 m.

Fig. 4. The main geographic objects and structural elements of the transition zones between Southeast Asia and North Australia, on the one hand, and the Pacific and Indian oceans, on the other: a conceptual scheme, after [60, 70, 90; http://north-east.ginras.ru/result/]; the topographic base: offshore [GEBCO, 2009]; land [GTOPO30 Global Digital Elevation Model. EROS Data Center, 1996; http://edcwww,cr.usgs.gov/landdaac/gtopo30/gtopo30.html]. Numerals in figure: *1*, archipelago of Japan; *2*, Korean Peninsula; *3*, Ryukyu island arc; *4*, Taiwan; *5*, slopes of the Ryukyu, Japanese, and Kurile island arcs; *6*, Philippine Archipelago; *7*, Mariana Trough; *8*, thinned continental crust; *9*, newly formed oceanic crust; *10*, subducted continental crust of Australia; *11*, oceanic crust of the Indian Ocean; heavy lines, master faults; chain lines, contemporary spreading zones; zones with triangular ticks, axes of deepwater trenches; lines without triangular ticks, axes of deepwater paleotrenches; dashed lines, major thrust systems. Triangles, active volcanoes.


Eurasian Plate
Structures of Southeast Asia
Pacific Plate
Philippine Plate
Indo-Australian Plate
Structures of Australia
Structures of Australia on shelf
Structures of Southeast Asia on shelf
North Fiji Plate
Caroline Plate
Hess Rise
Emperor Seamounts
Shatsky Rise
Central Pacific Rise
Marcus Wake Seamounts
Magellan Seamount
East Mariana Basin
Nauru Basin
Ontong-Java Plateau
Caroline Seamounts
Vityaz Trench
Lira Trough
Mussau Trench
Manus Trench
New Guinea Is.
New Britania Trench
Woodlark Basin
Coral Sea Basin
Ogasawara Ridge
Mariana Trench
Japanese Trench
Izu–Bonin arc
Nankai Trench
Shikoku Basin
Parece Vela Basin
Kyushu–Palau Ridge
Sorol Trough
Eauripik Rise
Yap Trench
Ayu Trough
New Guinean Trench
Palau Trench
Halmahera Is.
Sea of Japan
Yellow Sea
East China Sea
Okinawa Trough
Ryukyu Trench
West Philippine Basin
Philippine Trench
Banda Sea
Timor Is.
Timor Trough
Sulawesi Basin
Sulu Basin
Sulawesi Is.
Molucca Basin
Palawan Is.
South China Basin
Kalimantan Is.
Sunda Shelf
Mallaca Pen.
Sumatra Is.
Deepwater Sumatra–Java Trench
Sunda–Java Trench
1100 km
0
100° E
110°
120°
130°
140°
150°
160°
170°
180°
40° N
30°
20°
10°
0°
–10° S

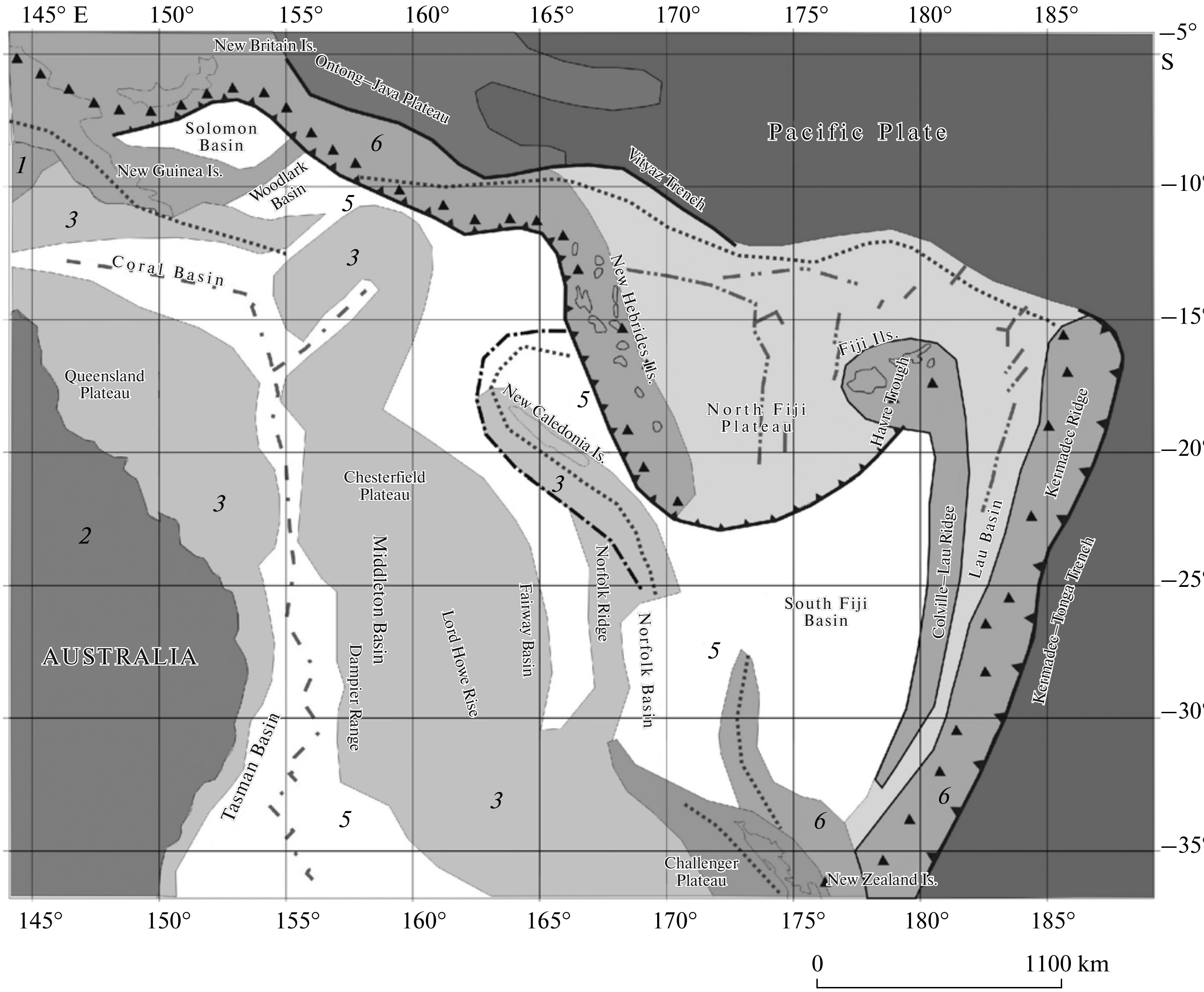


Fig. 5. The main geographic objects and structural elements of the transition zones from East Australia to the Pacific Ocean: a conceptual scheme, after [56, 78, 85, 89]; the topographic base: offshore [GEBCO, 2009]; land [GTOPO30 Global Digital Elevation Model. EROS Data Center, 1996; http://edcwww,cr.usgs.gov/landdaac/gtopo30/gtopo30.html]. Numerals in figure: (*1*, *2*) structures of: *1*, Australian Craton on shelf; *2*, Paleozoic–Early Mesozoic Tasman Fold–Nappe Belt; *3*, normal and thinned continental crust in offshore areas; *4*, Taranaki Trough; *5*, deepwater basins with oceanic crust; *6*, Cenozoic accretionary belts with superimposed younger zones of subduction, spreading, and island arcs; two dots–dash lines, contemporary spreading zones; solid line with triangular ticks, axes of deepwater trenches; solid lines without triangular ticks, axes of deepwater paleotrenches; chain lines, the major thrust systems; dotted lines, Eocene–Pliocene island arcs; two dots–dash lines, paleospreading system of the Tasman Sea. Triangles, active volcanoes.

The Fairway Basin extends along the eastern part of the Lord Howe Rise, being separated from the New Caledonia Basin by a narrow uplift of the basement. The bottom depth varies from 1500 to 3000 m. The thickness of the continental crust reaches 15 km. The total thickness of the lower Paleocene–Holocene sedimentary rocks exceeds 4000 m.

The New Caledonia Basin with the oceanic-type crust was formed as a result of rifting in the Cretaceous or Late Cretaceous–Paleocene. In the north of this basin, the thickness of the sedimentary cover attains 9000 m (?) and only a few hundreds of meters in the south.

New Caledonia Island is located in the north of the Norfolk Ridge. Its continental crust is composed of autochthonous Lower Paleozoic and Mesozoic volcanic and sedimentary rocks and allochthonous Upper Cretaceous–Upper Paleocene basalts and deepwater sediments overlapped by harzburgite–dunite allochthon up to 3500 m thick. In the southeast of the Norfolk Ridge, the basin of the same name has the continental crust; its deepwater part was formed in the Miocene as a result of backarc spreading. The Loyalty

Ridge, situated to the northeast of New Caledonia Island, is interpreted as an Eocene volcanic arc formed by subduction of the Cretaceous–Paleogene Pacific crust.

The South Fiji Basin, about 1000 km in extent, is localized between the Norfolk Ridge and the basin bearing the same name in the west and the Lau–Colville Ridge in the east. The basin opened 23–18 Ma ago with the formation of a new oceanic crust. The North Loyalty Basin is characterized by NE-trending magnetic anomalies corresponding to the crust dated at 43.8–35.3 Ma. The basement is overlain by middle Eocene and younger cover.

Seas of the Western Periphery of the Pacific Ocean

The Philippine, Caroline, and the northern part of the Fiji Sea sharply differ from the seas described above (Fig. 4).

The Philippine Sea is limited by the archipelago of Japan and the Ryukyu islands and Taiwan in the northwest and by the Philippines, more than 7000 km long, in the west. In the south and east, the sea boundary extends through the Caroline Islands, Guam, and the archipelagos of Mariana, Kanazawa, Ogasawara, and Nampo Islands. Abeam the southern Kyushu Island, the width of this sea is about 600 km; in the middle part it is 2000 km in width; and in the south about 500 km. Between the Japanese and Molucca islands, the sea reaches almost 3800 km in extent. The average depth is 4108 m [http://igras.ru/].

The Philippine Sea, with the oceanic-type crust 7–10 km thick, is divided into two deepwater basins by the N–S-trending submarine Kyushu Ridge composed of island-arc calc-alkaline volcanic rocks (33–32 Ma) overlain by upper Oligocene–lower Miocene sedimentary rocks.

The West Philippine Basin is divided by a ridge (its southern end is situated at ~15° N) into two deeps 6000 m and greater in depth. The ridge extends for almost 1000 km, has an axial trough similar to the rifts of slow-spreading ridges in morphostructure, and is regarded as an axis of paleospreading. According to the magnetic anomalies, the basin is Paleocene–Eocene (60–37 Ma) in age. Megamullion structures established in the basin serve as evidence for extension of the oceanic basement with exhumation of mantle rocks at the surface.

The East Philippine Basin is situated to the east of the Kyushu–Palau Ridge and is divided by a NE-trending rise into the Shikoku (northern) and Parece Vela (southern) deeps reaching 5800 km in depth. From linear magnetic anomalies, the crust in these deeps is dated as Miocene and middle Oligocene–early Miocene (30–18 Ma), respectively.

The East Philippine Basin is limited in the east by the Izu–Bonin volcanic arc [83], which is divided in the north of the Parece Vela Deep into the residual West Mariana Ridge, abandoned in the late Miocene, and the active Mariana arc. The Mariana Trough, with depth up to 4000 m, started to form between them approximately 10 Ma ago as a result of rifting, which gave way to local spreading 4–3 Ma ago. The thickness of the oceanic crust in the East Philippine Basin varies from 6–9 km in the south to 15 km in the north.

The Mariana arc originated in the Eocene and underwent recurrent volcanic pulses in the Pliocene and Quaternary. In the east, the arc borders on the Mariana Trench, where the deepest point in the World Ocean (10920 ± 10 m) was established in the Challenger Basin by Japanese R/V *Tokyo* in 1984. The related seismic focal zone, traced down to 660 km, is also the deepest.

No accretionary wedge has been revealed in the trench. Dredging and DSDP and ODP drilling showed that the eastern slope of the Izu–Bonin arc is composed of igneous rocks, including peridotites, boninites, and tholeiites.

The Philippine Sea is bound by the Ryukyu (Nansei) and Nankai deepwater trenches in the northwest; by the Philippine Trench, with a maximum depth of 10540 m [http://encyclopedia.thefreedictionary.com], and its northern extinct continuation (the Quezon Trench) in the southwest; by the Izu–Bonin and Mariana trenches, accompanied by island arcs of the same names, in the northeast; and by the Yap and Palau trenches in the south.

The thickness of the sedimentary cover in the Philippine Sea reaches 500 m, on average, and increases to 1400 m in the area located to the south of Japan.

The main part of the Philippine Archipelago is composed of complexly built rock complexes pertaining to Cretaceous and younger ophiolites (paleooceanic basins), island arcs, fore- and backarc basins, as well as metamorphic rocks [www.mgb.gov.ph/miningportal/geology/; http://www.doe.gov.ph/PECR2005/petroleum/pdf/]. In the southwest of the archipelago (northern Palawan Island, the Buruanga Peninsula on Panay Island, the Romblon islands, and southern Mindoro Island), gneisses, mica schists, and marbles with Late Paleozoic fauna are cut through by granitoid intrusions. All these rocks are overlapped by Upper Permian–Jurassic terrigenous, cherty, and carbonate rocks.

The Caroline Sea is situated to the north of New Guinea [45, 57] and separated by the Caroline Islands from the Philippine Sea and the Pacific Ocean. The Yap, Palau, New Guinean, and Mussau deepwater trenches and the Sorol Trough in the north surround the sea. The East and West Caroline deepwater basins, separated by the near-meridional Eauripik Rise, are localized in the central part of the sea.

The Caroline Sea is localized between the Pacific, Philippine, and Indo-Australian plates and underlain by oceanic crust formed in the East Caroline Basin as a result of Cenozoic symmetric spreading in the east-northeastern direction. A number of jumps of extension axes—chrons 12 (33.1 Ma), 10 (28.7 Ma), and 8 (26.6 Ma)—nearly parallel to the volcanic Eauripik Rise are noted in the West Caroline Basin. The active spreading center occurs in the Ayu Trough.

The North Fiji Basin (Plateau) is situated between the New Hebrides Archipelago in the west and Fiji in the east [58, 84]. In the north, it is bounded by the Vityaz Trench, and in the south, by an arcuate uplift that joins the southern part of the Vanuatu and Fiji islands. The basin extends 1200 km from north to south and 700 km from west to east. Several spreading centers are known within the basin; the Central and South Pandora centers are the best studied. In morphology, they have much in common with the rift zones of the Mid-Atlantic Ridge. Spreading began 3.5 Ma ago. Its rate decreases northward (20°30′ to 17° S) from 83 to 50 mm/yr.

The Fiji Archipelago [39] is composed of andesites cut through by intensely deformed and metamorphosed Eocene gabbro (50–43 Ma). These rocks are unconformably overlapped by Upper Miocene volcaniclastic island-arc rocks metamorphosed under conditions of zeolite facies. The Pliocene basalts, including alkaline varieties, and clastic sediments lie almost horizontal but are uplifted to a height of 1000 m [39]. The thickness of the crust beneath this archipelago reaches 23–32 km.

The New Hebrides Archipelago consists of three chains of volcanoes [73]. The western chain is late Oligocene–middle Miocene in age; the eastern chain is Miocene–Pliocene; and the central chain, 1500 km in extent, combines recent and active volcanoes erupting basalts and basaltic andesites.

In the southeast, the archipelago is bounded by a deepwater trench of the same name, which is traced along its slope [24]. The extent of the trench at isobath of 5500 m is 1600 km; the width is 40 km, on average. The maximum measured depth is 9174 m.

The Lau Basin has a well-expressed spreading system striking ~700 km in the near-meridional direction [53, http://www.ridge2000.org/science/info/science_plan.html]. The basin comprises a chain of large volcanic ridges, which often propagate to meet one another with overlapping for tens of kilometers. The rate of extension reaches 3 cm/yr in the south and 10 cm/yr in the north. The recent phase of extension started to develop 6–4 Ma ago in the northern part of the basin and gradually encompassed the southern area. In general, it is commonly deemed that the Lau Basin originated 10 Ma ago.

To the east of the Lau Basin, the Kermadec–Tonga volcanic arc extends, along with the related deepwater trench of the same name. The ophiolites at the base of the arc are overlain by island-arc associations, which began to form in the Eocene.

CONCLUSIONS

The above review shows that the term *marginal sea* designates fragments of the lithosphere differing in structure and geological history. Its unambiguous application is difficult because geographers and geologists using the same words in studies having different objectives. Thus, the term *marginal sea* does not correspond to a particular tectonotype, and in this regard, should be perceived as a term of free use. This implies that the application of this term to reconstruction of past geological settings should be accompanied by comments specifying what the author considers to be the distinguishing features of the given setting.

It is evident that, broadly speaking, the marginal seas are situated at the active and passive margins. The former are characterized by contrasting topography with depths reaching many thousands of kilometers. They are localized in regions with manifestations of island-arc magmatism and are underlain by oceanic or continental crust and by their combinations, whereas the latter overlie only continental crust, and their depth is, as a rule, 100–300 m. The magmatic occurrences in these seas are substantially distinct from the island-arc type, e.g., some areas in the Barents Sea. We feel that another term should be used for such seas, unambiguously placing them into a special category. In my opinion, the term *shelf sea* is the most appropriate in this respect. At the same time, in the literature, and particularly on the Internet, this term is applied even to such objects as the Baltic and White seas (see, for example, http://www.geonaft.ru/glossary). This is an obvious mistake, which should be not be continued. The aforementioned seas, having a number of distinct features, are almost completely situated on the East European Platform and thus are tectonotypes of epiplatform seas.

Active continental margins are traditionally subdivided into the Andean and West Pacific types. According to the universally adopted models, the former margins are characterized by ocean-to-continent transition corresponding to a lateral series of deepwater trenches and a volcanic–plutonic belt, whereas the latter margins fit the deepwater trench–island arc–marginal sea series.

The above discussion shows that the universal conceptual scheme does not reflect the complexity of the natural geological settings. Two types of marginal seas do exist in the transition zone from the East and Southeast Asia to the Pacific Ocean. The seas of the first (pericontinental) type are directly related to the continental crust or incorporate fragments of continental crust differing in dimensions. The seas of the second (perioceanic) type are unrelated to the continental crust.

The seas on the oceanic crust (ensimatic or epioceanic) often correspond to microplates, e.g., Philippine, Caroline, North Fiji. On the one hand, they are unrelated to the structure of the continents, and on the other hand, their own structure is discordant to the morphostructures of the Pacific Ocean, as is, for example, evident from the discordant strikes of the Magellan, Caroline, and other seamount chains. At present, these seas are situated at the western margin of the Pacific Plate and separated from it by either active (Mariana, Izu–Bonin) or almost abandoned (Vityaz) trenches and deepwater troughs. The former are combined with active arcs and the latter with submarine rises (paleoarcs). They are characterized by a general extensional regime, which is emphasized by active rifting and even spreading zones. The epioceanic seas either contact with one another along deepwater trenches (Palau–Yap) or are separated by large rises with oceanic crust of elevated thickness (Ontong–Java Plateau) [31].

The pericontinental seas, being constituents of active transitional zones, do not have, like these zones themselves, a single reference structure which could be applied to all objects.

The most complex variant of the ocean-to-continent transition is exemplified in the segment of Southeast Asia (Fig. 4). The transition from the Pacific Ocean to the continent (from west to east) is described here by the following lateral series: the Mariana and Izu–Bonin deepwater trenches—active Izu–Bonin island arc complicated by the Mariana spreading zone—the complexly built Philippine Sea with oceanic crust—zone (belt) of Cenozoic accretion with superimposed younger zones of subduction, spreading, and island arcs (archipelago of the Philippine Islands)—zones of deepwater basins with oceanic crust superimposed on the structure of Southeast Asia.

It should be elucidated that the zone of Cenozoic accretion extending from Taiwan to the Solomon Islands [82] is composed of folds and nappes, which were formed in the Cenozoic as a result of collision of the Pacific, Indo-Australian, and Eurasian plates, including the complexes of the abandoned island arcs and ophiolites. The absence of fragments of the continental crust is characteristic. At present, the belt is limited by either subduction zones dipping to meet each other (eastern part of the South China Sea) or zones of active and preceding subduction. The evolution of this belt is not complete, so that active volcanic zones, large fault zones varying in kinematics, or spreading centers are formed on the Cenozoic basement.

A series of deepwater basins with newly formed Cenozoic oceanic crust (South China, Sulu, Sulawesi, Banda) framed by the thinned continental crust of Southeast Asia is situated to the west. They strike in the east-northeastern direction and apparently inherit the orientation of the structural elements of the Alpine–Himalayan Belt, being sharply discordant to the structures of the Philippine Archipelago. The current compressive regime of the entire region is expressed in active zones of thrusting and significant vertical displacements. In the west, the basins with oceanic crust are framed by extensive shallow-water shelves, which rest on continuation of the structures of Southeast Asia devoid of fragments of ancient platforms [61].

The transition from the Pacific Ocean to the continent off East Australia substantially differs from the situation described above. As has been shown before, the East Australian Basin (Fig. 5) comprises not only fragments of the Paleozoic and Mesozoic Tasman Complex, but also the newly formed basins with oceanic-type structure. The structural units of East Australia generally strike in the near-meridional direction, determining the orientation of the submarine structural elements. Their separation as a result of rifting started off Australia as early as the Maastrichtian [78]. Later, in the late Paleocene, this process propagated northward, reaching the present-day Coral Sea. At the same time, rifting passed into the phase of spreading in the south. In the course of further Cenozoic evolution, the dismembering of the eastern margin of Australia resulted in the appearance of newly formed basins with oceanic crust. Their formation was combined with the development of Eocene–Pliocene island arcs (Fig. 5).

It cannot be ruled out that the Laptev Sea, located at the extension of the ultraslow-spreading Gakkel Ridge, as well as the Red and Labrador seas, serve as a model of the formation of the basins described above from the embryonal phase of penetration of the front of the mid-ocean ridge into a dismembered framework to the subsequent extinction of the whole system. Such seas can apparently be called riftogenic (synrift).

The third variant of the active ocean–continent transition zone is displayed in the eastern and northeastern segments of Asia as a lateral series: oceanic plate—deepwater trench (Japan or Kurile–Kamchatka)—island arc (Japan or Kurile)—marine basin (seas of Japan or Okhotsk). A rift at the stage of transition to spreading (Okinawa Trough), rather than a sea, can occur on the continental side of the island arc. In such a zone of transition from ocean to continent, the continental crust occurs either beneath extensive shelves, e.g., in the Bering, Yellow, and East China seas, or as fragments in the newly formed oceanic crust; the Yamato Rise in the Sea of Japan is an example.

Thus, it is proposed to define a marginal sea only as a marine basin, which extends for a few thousands of kilometers without losing connection with an open ocean. It must contain both domains with continental and oceanic crust. The latter domains are expressed in the topography as one or several deepwater basins, where fragments of the continental crust may occur. The marginal see should be bound by at least one island arc.

In conclusion, following Karig [14], I propose to use the weak but popular term *backarc basin* only for basins that split island arcs and have an active spreading system (the Mariana Trough, Lau Basin) without applying it to larger basins. I believe that the term *peripheral sea* should be removed from Russian tectonic vocabulary as unnecessary.

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