ISSN 1019-3316, Herald of the Russian Academy of Sciences, 2015, Vol. 85, No. 4, pp. 331–341. © Pleiades Publishing, Ltd., 2015.
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From the Researcher's Notebook

Half a century ago, principles of the theory of lithosphere plate tectonics, or plate tectonics, were first formulated. Since then, the theory has become substantially more complicated and tectonic processes and phenomena have been identified that are not described by the theory. This relates to certain types of vertical movements, primarily to the newest uplifts that led to the formation of modern mountain systems. Comparison of geological processes (both those described by the theory of plate tectonics and those unexplained thus far) with data of the seismic tomography of the mantle has made it possible to outline a new tectonic model, according to which the source of observable tectonic manifestations is lateral flows of upper mantle matter, propagating from superplumes—flows of matter and energy rising from the mantle's bottom. These lateral flows not only move lithospheric plates but also determine structural–substantial transformations of the lithosphere and the upper underlithospheric mantle, which lead to vertical movements and mounting building.

DOI: 10.1134/S1019331615040048

Toward Postplate Tectonics

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The main theses of plate tectonics as a kinematic model were formulated in the works of J. Wilson, F. Vine, D. Mathews, B. Isacks, J. Oliver, L. Sykes, and other scientists. According to this model, lithospheric plates, which comprise the earth's crust and the uppermost part of the mantle, with a total thickness of up to 50 km under the oceans and ~100 km under the continents, move from spreading zones along transform faults to subduction and collision zones, gaining thickness using deep magmatic material in the spreading zones and compensating lithospheric growth by dipping into the underlying mantle in the subduction and collision zones; the plate flow is described by their rotation in relation to the Euler poles.

Attempts were made to find the sources of plate flow in the plate-tectonic mechanism itself; the extending effect of the buildup of magmatic material in spreading zones and the strapping effect of subducted parts of plates were discussed. However, O.G. Sorokhtin [1] showed that they are only of local significance and cannot ensure plate flow in general. D. Forsyth and S. Ueda proposed a mechanism of global mantle heat convection as a general source of motion, and E.V. Artyushkov and Sorokhtin spoke in favor of more efficient chemical–density convection related to mantle differentiation and the replenishing of its outer core with ferrous components.

Perhaps the most important achievement of plate tectonics was the unification of efforts of geologists, geophysicists, and geochemists to solve common problems, which substantially advanced their mutual understanding, as well as understanding of tectonic processes. At the same time, knowledge buildup required complication of the initial plate-tectonics model. A subject of discussion was and still is the parameters of mantle convection as a source of plate flow. According to seismological data, a transition layer between the upper and lower mantle was distinguished. Velocity jumps of seismic waves at its upper (~410 km) and lower (~670–680 km) boundaries are so great that they can occur only during phase mineral transformations of mantle matter. These are exo- and endothermic onsets that under certain preset system parameters make general mantle heat convection impossible, which suits the concept about the absence of significant matter exchange between the lower and upper mantle [2, 3]. However, Sorokhtin [1] gave convincing considerations in favor of general mantle chemical–thermal density convection. Proceeding from the assumption of complete circulation of mantle matter during a tectonic cycle, he concluded on sufficiently high velocities of convective flows, during which mineral transformations do not interrupt them and manifest themselves only in the uplifting or dipping of the transition layer's boundaries by a value of about 20 km. At present, arguments in favor of the combination and combined effect of general-mantle and upper-mantle convection on the lithosphere appear the most substantial [4].

The initial variants of the theory of plate tectonics assumed that spreading zones were ascending branches of mantle convection and subduction zones were its descending branches, expressed by mantle seismofocal zones to depths of ~650 km. This concept gained a footing when K. Krieger and T. Jordan traced geophysical anomalies associated with subducted slabs below the transition layer down to depths of ~900 km.

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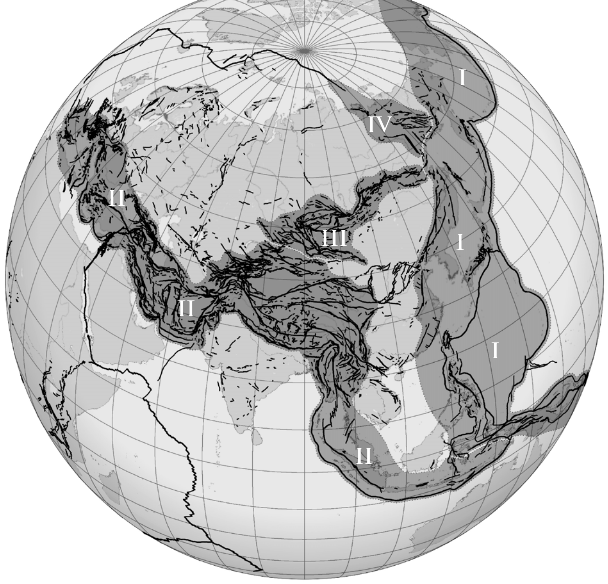

Fig. 1. Diffuse plate boundaries (mobile belts) of Eurasia. Belts (gray color): (I) Prepacific, (II) Alpine–Himalayan, (III) Altai–Stanovoi, and (IV) Momsky–Chersky. The largest active faults are shown.

Seismic tomographic studies confirmed that some slabs penetrate into the lower mantle but this does not happen everywhere [5, 6]. It became obvious that spreading zones cannot be direct reflections of ascending convection branches. The example of the African plate demonstrates this vividly. The spreading zones that frame it in the west and east are occasionally parallel. Since the African plate builds up during their development and the compensating regions that absorb lithospheric matter inside the plate are absent, the distance between the spreading zones increases; i.e., either one of them or both change their position on the sphere and, consequently, relative to the ascending convection branches. Eventually, it was admitted that it is possible to speak only in the most general sense about the motion of lithospheric plates and the position of spreading and subduction zones being coherent to mantle convection branches; there is no confluence between them.

Two other inconsistencies with the initial variant of the theory of plate tectonics were revealed as geological data were accumulated. They are the lithosphere's tectonic layering and the uncertainty of plate boundaries.

The term *tectonic layering of the lithosphere* roughly corresponds to the concept "detachment tectonics." These are differences in the strain–stress condition and structures simultaneously developing in various layers of the lithosphere, leading to their breakdown and lateral displacement against one another. The idea of tectonic layering was first proposed by A.V. Peive in 1967. Developing this idea, he wrote [7, p. 7]:

> The material of individual parts of the tectonosphere moves in the lateral direction discriminatingly, i.e., with different velocities. If we assume that the main zone of tectonic flow and material motion is the asthenospheric layer of the upper mantle, there are also enough grounds to admit the great role of differentiated lateral mass motions along the crust's foundation, as well as inside the crust.

Further development of the concept of the lithosphere's tectonic layering was prioritized by Russian scientists for both ancient and modern tectonics and was most fully reflected in works of the RAS Geological Institute [8]. It was shown that, in relation to the upper crustal layer, the underlying crustal part plays the same role of a mobile and relatively plastic substrate as the asthenosphere in relation to the lithosphere in general [9]. L.I. Lobkovskii [10] proposed a model of two-layer plate tectonics, according to which it is realized in mobile belts more or less independently at the crustal and mantle levels. For such belts, two-layer tectonics is the best approximation of reality, compared to the postulate of plate integrity, but even this concept does not explain the entire complexity of tectonic layering near plate boundaries.

Diffusivity became apparent, i.e., the dispersion of contemporary boundaries of certain plates within wider belts [11]. Figure 1 shows a mobile belt (I) of the western margins of the Pacific Ocean that continues as active structures in the west of the North American continent. This is the region of interaction between the Pacific, Eurasian, and North American plates. The northern part of the belt is heterogeneous; its Californian segment, which coincides with the San Andreas Fault zone, is a transform fault, and the northern and northwestern segments, formed by the Aleutian, Kuril–Kamchatka, and Japanese island arc systems, were formed in the conditions of subduction. In its transform part, the San Andreas Fault zone is the upper crustal plate boundary and is traced down only to a depth of ~20 km. The breakdown surface, beneath which the Pacific Plate continues eastward for 200–300 km, lies deeper. There, the deep-seated plate boundary may be a buried system of rift and transform zones, similar to the structure of the Gulf of California and expressed by geophysical anomalies, volcanic manifestations, and secondary disruptions of the upper crustal layer [8].

The subduction boundaries of the Pacific Plate are drawn by convention along forearc troughs. However, difficulties arise in drawing the boundary between the North American and Eurasian plates, which is interrupted within the Prepacific mobile belt. Two explanations of this problem were proposed: the Okhotsk Minor Plate is located between the main plates; the

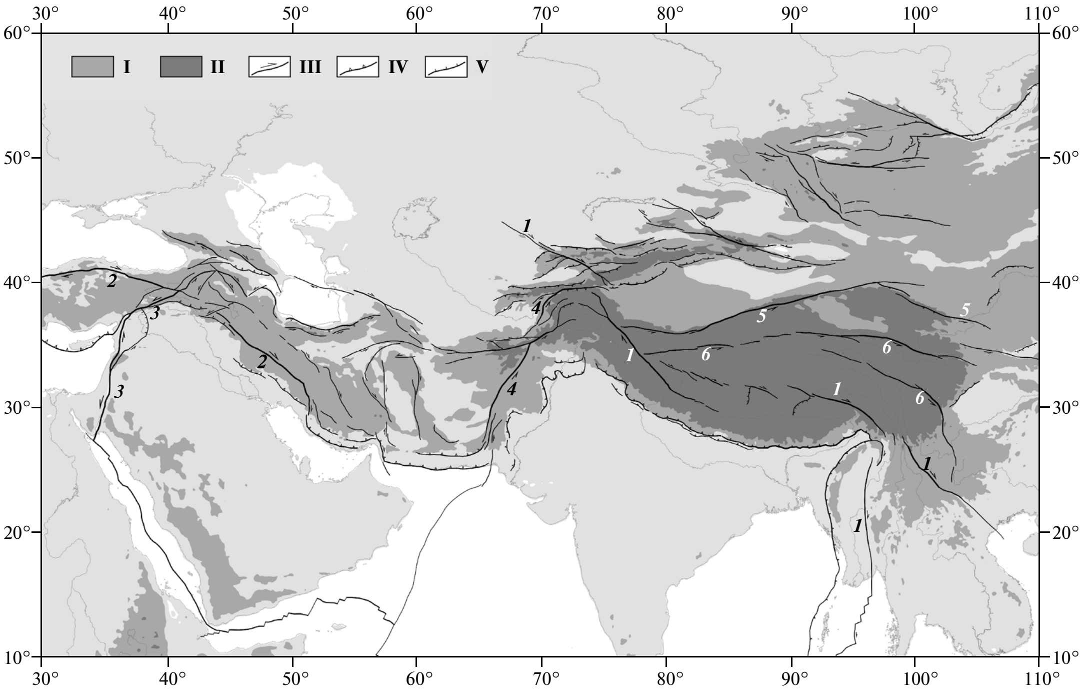

Fig. 2. Alpine–Himalayan Orogenic Belt. (I) Uplands of 1000–3000 m; (II) mountains and highlands higher than 3000 m; (III–V) large active faults: (III) displacements, (IV) overthrusts and upthrusts, and (V) faults. The largest right-lateral displacement systems: (*1*) from the Talas–Fergana Fault to the Sagaing and Red River faults and (*2*) the North Anatolian and the Zagros Main Recent Fault. The largest left-lateral displacement systems: (*3*) the Levantine–East Anatolian, (*4*) the Chaman–Darvaz, (*5*) the Altyn Tag, and (*6*) the Kunlun–Yunnan.

region singled out as the Okhotsk Minor Plate is part of the North American Plate. A.I. Kozhurin [12] proved that both explanations contradict the existing geological data and that the plate boundary here is the entire deformation zone.

The diffusivity of boundaries is even more obvious in the regions of recent collision plate interaction, where its structural manifestations are dispersed in belts of hundreds of kilometers wide (see Fig. 1). Inside the belt are relatively weakly deformed elongated blocks, or microplates, divided by zones of deformation concentrations. At the current stage of development of the Himalayan–Tibet segment of the Alpine–Himalayan collision belt, such zones are identified on the southern flank of the Himalayas, the boundary of Southern and Central Tibet, the northern flank of Tibet and Qaidam (Altyn Tagh Fault), and the southern flank of Tian Shan (Fig. 2). The velocity of Late Quaternary displacements in each of the zones reaches ~1–1.5 cm/yr [13], and it is impossible to prefer any of them as the boundary between the Indian and Eurasian plates. In fact, the marginal parts of interacting large plates undergo general, although unevenly distributed, deformation.

The above geological phenomena complicate plate tectonics and make us abandon certain postulates of its initial version, but do not change the essence of the theory. The main principle that structural manifestations of the tectonic process are the result of plate interaction remains unshakable.

TECTONIC UPLIFTS THAT LED TO RECENT MOUNTAIN FORMATION

Study of recent tectonic movements, expressed in the formation of the contemporary mountain systems in the central part of the Alpine–Himalayan collision belt (see Fig. 2), has led us to the conclusion that the sources of these movements are not limited to the framework of the theory of plate tectonics [14–17].

Mountain systems of the Alpine–Himalayan Belt, marked by the highest summits, mainly inherit the northern margin of the Neotethys Ocean, while its southern margin formed few mountain systems, the largest of which are the Himalayas and Zagros. The belt's lateral zonality with rejuvenation of the continental crust toward the south depends on the geodynamics of the Tethys development. Its southwestern margin was passive, while the northeastern margin was active. On the passive margin, rifting, as it developed into spreading, partitioned Gondwana, and its fragments moved northeastward, where the Tethys oceanic lithosphere subducted under the margins of northern plates. The sequential formation of the Paleo-, Meso, and Neotethys led to the accretion to the northern margins of ever-new Gondwana fragments, divided by sutures (seams where crustal relics of the closed parts of the ocean are present), accretionary wedges, and magmatism manifestations of the corresponding stages of the Tethys. This process, which started with the disintegration of Pangea in the Late Paleozoic, is clearly traced in the Meso-Cenozoic, when northern plates merged into the Eurasian Plate. The active margin was complicated by back-arc troughs with thinned (suboceanic) crust, which often inherited relics of earlier Tethyan basins and those closed in parallel with the Tethys or later. During the repeated closure of basins with oceanic and suboceanic crust, the belt's lithosphere preserved relics of oceanic crust fixed as high-velocity volumes at various lithospheric levels and was manifested in xenoliths of erupted rocks. The Tethys represented a northwestward-narrowing bay of the Pacific, and horizontal dislocations at different stages of its development and closure generally increased eastward. This trend also manifested itself in the Late Cenozoic as increased amplitudes of lateral displacements from west to east in particular structures (for example, in larger displacement amplitudes on the western flank of the Indian Plate, compared to the Arabian Plate), as well as on the scale of belt segments, shortened by different values [16, 18].

In the Eocene, collision covered vast areas of the belt. Its eastern part became more or less hilly dry land, while in the west, dry land sections alternated with epicontinental marine basins. Relics of the Neotethys and back-arc basins with thinned crust showed up against this background. Later, during the first stage of recent mountain formation, which embraced ~30 Ma from the Oligocene to the end of the Miocene and partially the Pliocene, the direction of collisional shortening changed from stage to stage owing to changes in the direction of the movement of the Gondwana slabs [16]. During the first stage (Oligocene–Early Miocene), they moved to the north-northwest; during the second stage (end of Early Miocene and Middle Miocene), to the northeast; and during the third stage, to the north or north-northwest. Various Neotethys relics and the majority of back-arc basins closed accordingly; the intensity and nature of movements changed; and various tectonic zones experienced compression and lateral shortening, which led to local thickening of the crust of such zones and the formation of uplifts expressed in the relief, whose area increased with time. In Central Asia, the growth of uplifts was occasionally accompanied by intensive granite formation. Judging by the thin clastic rocks carried away from material uplifts and the size of cut-ins into surfaces and relief steps, these uplifts, with few exceptions, were as high as medium-altitude mountains (up to 1500–2000 m). The calculations of the isostatic uplift, owing to crust thickening during compression, made by Artyushkov for the Central Tian Shan [15], and similar calculations made for the Greater Caucasus [17] coincide with geological and geomorphological assessments. In other words, uplifts that appeared at the first stage were an isostatic reaction to crustal thickening during compression, i.e., a regular result of the collisional interaction of plates. In cases when calculations indicated the possibility of a larger uplift, the effect of crustal thickening was compensated by compacting its lower part [19].

Large-scale deformations of crustal masses during the first-stage uplifts, accompanied by metamorphism and crustal magmatism, led to homogenization and consolidation of the upper part of the earth's crust in those regions of the belt where this had occurred earlier, preparing the second stage of mountain building, embracing the Pliocene–Quaternary and occasionally only the Quaternary. The signs of crustal consolidation were the absence of large Pliocene-Quaternary granite massifs, the increasing role of block movements to the detriment of folded deformations and the fact that the continuing compression of the belt started to be implemented mainly by strike slips along faults, and localization of volcanism in restricted zones that are often related to slips. Strike-slip systems were formed of several thousand kilometers in length [16, 18] (see Fig. 2).

Over the past 5–2 Ma, the velocities of vertical tectonic movements increased sharply, and the height of the uplifts that existed by that time at least doubled and even tripled in some cases [16, 20]. The current mountain systems and high plateaus were formed; coarse molasse (a complex of primarily coarsely fragmented rocks) began to accumulate in piedmont and intermountain troughs. Uplifts were most significant in Central Asia, but they also appeared in other parts of the belt. In addition, the general rise of mountain systems independently of the antecedent structural differentiation occurred in regions such as Pamir, Hindu Kush, Karakorum, and High Zagros. The increased ascending movements were not due to accelerated plate movement and increased collisional shortening; occasionally shortening intensity decreased. For example, in the Alps and Western Carpathians, collision ended back in the Middle Miocene, and mountains started to grow in the Pliocene. In the Greater Caucasus, the growth of uplifts accelerated in the Pliocene–Quaternary against the backdrop of decreasing velocity of compression, recorded both by GPS data and by the summation of displacements of active faults. Even where compression strengthened (the Himalayas, Pamir, Central Tian Shan), only 20–50% of the total surface uplift falls on uplifts associated with crustal thickening during collisional shortening. The majority of intermountain faults also rose, although more weakly than ridges, which cannot be considered as manifestations of compression.

According to seismological and gravimetric data, deconsolidation of upper parts of the mantle was

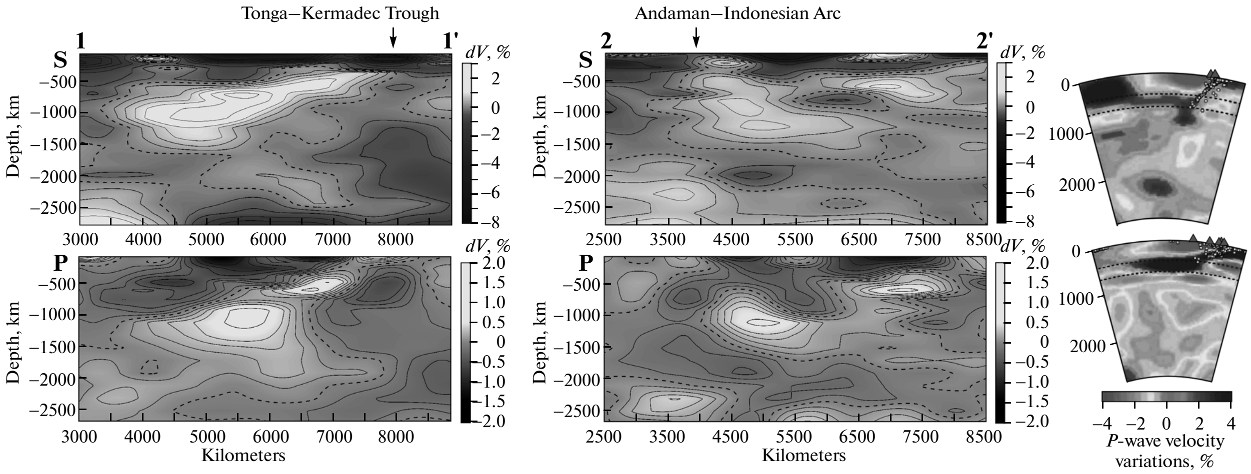

Fig. 3. Seismic tomographic profiles of the mantle by *S* and *P* waves through the Tonga–Kermadec and Indonesia–Philippines regions at the junction of island arc systems of the Indonesian segment of the Alpine–Himalayan Belt and the western Pacific. Compiled by S.Yu. Sokolov by cross-sectioning global 3-D models NGRAND and HWE97P [5, 6, 22]. The contours are drawn through 0.5% for *S* waves and 0.25% for *P* waves; the dashed line shows zero values. Profiles 20 and 24 are given for comparison through island arc systems of northeastern Asia, having been drawn using more accurate data of local seismic networks by *P* waves [23]. The flattening of subducted slabs is seen at the level of the mantle's transition layer.

detected under the highest mountain systems of Central Asia (the Himalayas, Tibet, Kunlun, Pamir–Hindu Kush–Karakorum region, Central and Eastern Tian Shan); the same signs were detected in the gravitational field of the Lesser Caucasus (an overview of the above data is given in [16]). A decrease in the velocities of seismic waves, associated with the rise of the asthenosphere, was identified under the Eastern Carpathians [19]. According to Artyushkov's calculations, based on the detection of isostatic anomalies below –150 mGal under Tian Shan, such a deconsolidation ensures surface rise by ≥1.1 km, probably by ≥1.5 km [15]. Another source of deconsolidation was the retrograde metamorphism of mantle and mantle-density-similar highly metamorphosed protocrustal rocks, caused by the effect of cooled fluids [15, 16, 21]. The deconsolidation of the upper parts of the mantle and the lower parts of the crust led to an additional rise of the surface and the formation of the current mountain relief. On the northern edge of the belt (Greater Caucasus, Western Tian Shan), where the deconsolidation of the upper parts of the mantle was revealed only locally, the deconsolidation of highly metamorphosed protocrustal rocks was the main factor of increased mountain building [17].

In order to explain these lithospheric transformations, not envisaged by the theory of plate tectonics, we have analyzed the data of the seismic tomography of the mantle obtained using the global seismological network [5, 6, 22]. The Indonesian segment of the Alpine–Himalayan Belt has no manifestations of the second stage of mountain building; subduction structures are developed there; and, at depths of 700–800 km, they transfer into subhorizontal high-velocity zones, which continue under the southeast of the Asian continent (Fig. 3). Such flattening-out subduction zones were revealed earlier along the periphery of the Pacific Ocean at depths of 400–700 km (according to more accurate data of local seismic networks). Y. Fukao et al. called them stagnating slabs, and D. Zhao termed them big mantle wedges (BMWs) [23].

Probably, such BMWs existed in the subduction epoch and under more western mountainous segments of the Alpine–Himalayan Belt (Arabian–Caucasian and Himalayan–Tibetan), but now the mantle structure is different there. A vast region of reduced *dVs* and *dVp* values (the values that characterize deviations from statistical averages of velocities of P and S seismic waves, respectively), covering the entire mantle (Fig. 4), is seen on the submeridional seismic tomographic profile through Africa and the Arabian–Caucasian region. In its upper part, it covers the territory from the edge of Africa south of Madagascar to the Red Sea, and, being pitched southward, it has its southern edge under South Africa at the lower-mantle level. This structure was called the Ethiopian–Afar superplume. To the north of it stretches the upper-mantle layer with reduced velocities of seismic waves, which reaches the Greater Caucasus, under which it is thinner than under the Lesser Caucasus; the lowest *dVs* values were recorded directly under the lithosphere.

Such an upper-mantle layer with reduced seismic-wave velocities is also traced in the profile from the Ethiopian–Afar superplume through the Indian Ocean, the Indian Platform, and High Asia (from Tibet to Tian Shan) to the Kazakhstan Paleozoids

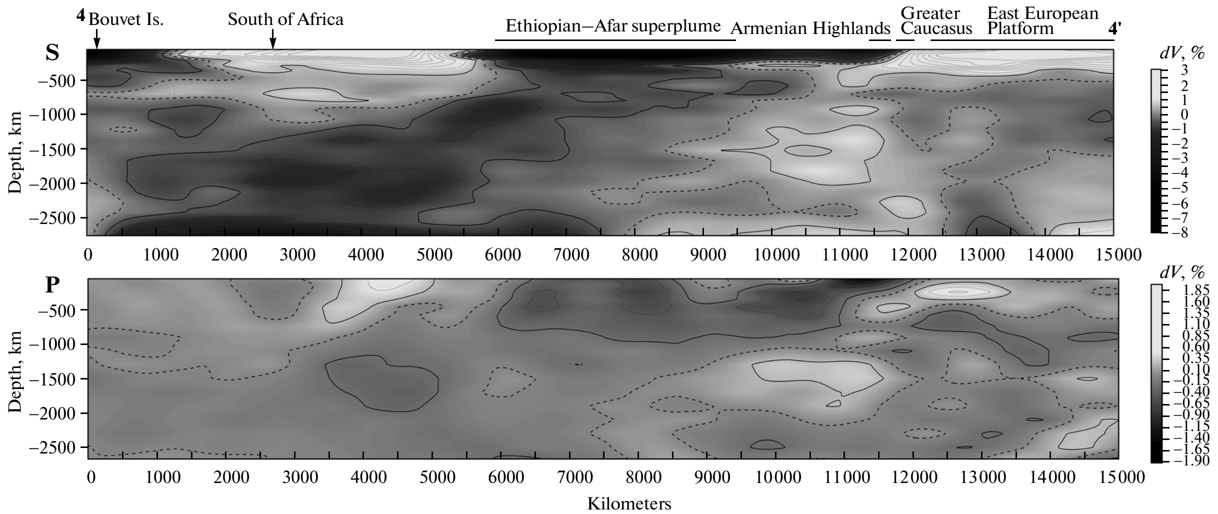

Fig. 4. Seismic tomographic profiles of the mantle by *S* and *P* waves through the African Platform, the Ethiopian–Afar superplume, the Arabian Plate, and the Caucasus to the East European Platform. Compiled by S.Yu. Sokolov by cross-sectioning the data of global 3-D models NGRAND and HWE97P [5, 6, 22]. The contours are drawn through 0.5% for *S* waves and 0.25% for *P* waves; the dashed line shows zero values.

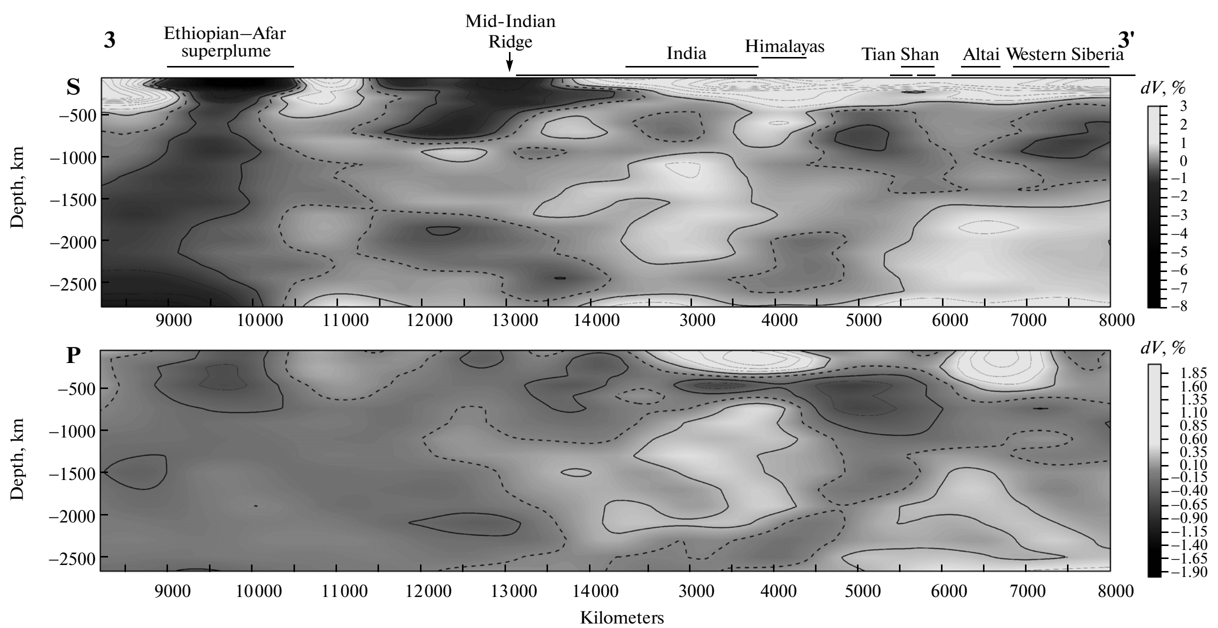

Fig. 5. Seismic tomographic profiles of the mantle by *S* and *P* waves from Kenya through the Mid-Indian Ridge, the Indian Platform, and High Asia to the Western Siberian epi-Paleozoic Platform. Compiled by S.Yu. Sokolov by cross-sectioning the data of global 3-D models NGRAND and HWE97P [5, 6, 22]; the contours are drawn through 0.5% for *S* waves and 0.25% for *P* waves; and the dashed line shows zero values.

(Fig. 5). In the *dVp* profile, this layer underlies directly the thin lithosphere of the Indian Ocean and, further north, thins and dips to depths of 400–500 km under the Indian Platform; it is almost reduced under the south of Tibet; and it grows thicker to depths of 300–800 km under High Asia. A region with increased velocities of seismic waves shows up above the layer. In the *dVp* profile, the high-velocity layer is traced from the southern edge of the Indian Platform to the northern edge of Tibet at depths of 100–300 km, the layer's maximum thickness and the highest *dVp* values being recorded under the south of Tibet. In the *dVs* profile, the high-velocity layer stretches from the Indian Platform to the Kazakhstani–West Siberian part of the Eurasian Plate; in addition, inside the layer, a lens of very high *dVs* values from the Himalayas to the northern edge of Tian Shan is distinguished. Under the south of Tibet (the region of the Neotethys suture–

Indus–Tsangpo zone), the layer grows thicker to 400 km, and, under it, another subhorizontal high-velocity lens differentiates at depths of 600–700 km. Probably, part of the thickened upper layer and this lens are relics of a Neotethyan flattened slab.

Two aspects appear to be essential in the seismic tomographic pattern described above. First, in the mantle structure of the Indonesian segment of the Alpine–Himalayan Belt, where subduction zones still function, they continue approximately at the level of the transition layer as structures similar to BMWs. Second, in the belt segments further to the west—the Himalayan–Tibetan and Arabian–Caucasian—where subduction ended in the interval from the end of the Eocene to the Middle Miocene with the closure of the last Neotethyan relics, the general element of the structure of the sublithospheric upper mantle is powerful layers with reduced velocities of seismic waves, continuously traced from the Ethiopian–Afar superplume. Although the superplume is traditionally viewed as a region of the rise of deep-seated heated mantle matter, we interpret these layers as hot fluids that propagate from the superplume [14]. Now it forms a lengthy submeridional zone that covers the entire belt of volcanic rifts of East Africa and continues to the south of Madagascar. If we assume that the superplume has been located close to its current position from the end of the Paleozoic, then the parts of disintegrated Gondwana that occurred above it at different times experienced rifting developing into spreading, which led to the formation and development of the Tethys. The flow of heated and enriched asthenospheric matter, bound from the superplume, accelerated the movement of separated Gondwana fragments northeastward in the direction of Eurasia. There, the Tethyan oceanic lithosphere subducted and fragments of Gondwana attached themselves to Eurasia; therefore, subduction zones shifted to their rear (in relation to Eurasia) parts. Thus, in place of the future Alpine–Himalayan Belt, there appeared a series of microplates divided by structural–material manifestations of various stages of the development of Tethys. By analogy with the current structure of the belt's Indonesian segment, we may assume that, to the west of it, the Tethys subduction zones also transferred to BMWs, from which, eventually, a significant part of the mantle's transition layer was formed under the future orogenic belt.

With the closure of the Tethys, the process of subduction and BMW formation gave way to the collision of the lithospheric plates of Eurasia and the Gondwana series. This slowed down their rapprochement, but asthenospheric flows from the Ethiopian–Afar superplume, probably, continued their previous movement and spread gradually below the entire orogenic belt. The fact that this happened gradually, at least in the Arabian–Caucasian segment of the belt, as A.V. Ershov and A.M. Nikishin mentioned, is indicated by the northward rejuvenation of volcanism associated with mantle sources. The sharp thinning of the flow below the Greater Caucasus could be caused by the fact that, before the Middle Miocene, the Caucasian troughs of the Paratethys subducted, according to M.G. Leonov's data, under the Lesser Caucasus, and subduction hindered the northward penetration of the flow.

During their movement, the hot upper-mantle flows processed the previous structure of the belt's upper mantle, including the transition layer at depths of 400–700 km, which had important geological consequences. Study of magmatic rocks of mantle origin indicates extremely low water contents in magmatic sources, decreasing from subduction zones to oceanic spreading zones [13]. According to the experimental data, in the transition layer, olivine with a rhombic syngony transfers into its varieties with a spinel structure—wadsleyite and, deeper, ringwoodite, and, approximately at the same depth, clinopyroxene transforms into wadsleyite and stishovite. The crystal-chemical structure of wadsleyite and ringwoodite allows the replacement of a part of oxygen atoms with hydroxyl groups [24, 25]. Their source can be subducted slabs that contain not fully dehydrated amphibolites and metasedimentary rocks and that transfer into BMWs, as well as inflows of deep-seated hydrogen. The presence of fluids at such depths is indicated by the strong attenuation of S waves under a weak change in their velocity [26] and the increased electrical conductivity [27]. The water content in the transition layer can reach 2–3%, and the transition layer is viewed as the main source of water fluids in the mantle [28]. Deeper than 670–700 km, minerals of the transition layer are probably replaced with perovskite-like phases, whose share in the underlying mantle's volume is ~80%, and their water potential is significantly lower.

The heating of the transition layer with upper-mantle flows led to the separation of fluid sources in it and their concentration in the flows themselves, causing their activity. The thus-activated asthenosphere affected the belt's lithosphere primarily with fluids. Magma chambers appeared in sections of local decompression, and these chambers in the Pamir–Himalayan segment of the belt manifested themselves in grand granite formation, which continued until the Miocene. Under the effect of the mobile component of the activated asthenosphere, metamorphic transformations could occur, as well as the softening of the lithosphere, which made its intense deformation possible [29]; the tectonic layering of the lithosphere increased, ensuring the appearance of lateral dislocations [16]. Deformation of the crust caused the appearance of topographic uplifts, as a rule, not higher than medium-altitude mountains.

By the second stage of mountain building, these processes had led to the consolidation of the crust. Asthenospheric matter under it began to replace laminated and destructed fragments of the lithospheric mantle [19, 29]. This found expression in the decreased V_P averages of the mantle's upper parts across all mountain systems of the belt, except for the Himalayan–Tibetan part of the region. The decrease in the mean velocities may be interpreted as lithospheric thinning at the expense of the asthenosphere and/or the deconsolidation of the lithospheric mantle and the lower parts of the crust under the influence of the asthenosphere. Under High Asia, where the lithosphere is most thickened by Cenozoic deformations, a high-velocity layer up to 300 km thick is occasionally preserved under the layer of reduced V_P values. Partial replacement of the lithospheric mantle with asthenospheric matter and the retrograde metamorphism of mantle and highly metamorphosed protocrustal rocks could cause deconsolidation of the mantle's upper parts and the crust's lower parts under the influence of cooled asthenospheric fluids, which supplemented the uplift caused by collisional shortening and became the main factor of surface rise, leading to the formation of the contemporary mountain relief.

Thus, the increased uplift of mountain systems in the Pliocene–Quaternary, unexplainable within the theory of plate tectonics, was caused by the activation of hot upper-mantle flows that spread from the Ethiopian–Afar superplume.

MANTLE MATTER FLOW AND PLATE TECTONICS

The presented overview of the Mesozoic–Cenozoic development of the Tethys and Alpine–Himalayan orogenic belt allowed us to make the following conclusions: the Ethiopian–Afar superplume is a region of ascending heat and mass transfer from the lower parts of the mantle; lateral upper-mantle flows, which, owing to viscous friction on the boundary of the asthenosphere and lithosphere, relocated lithospheric plates, spread from the superplume; in the conditions of plate collision, which set in after the closure of the Tethys, the flows spread below its northern margin; the enrichment of the flows with fluids could cause an active effect of the asthenosphere on the lithosphere, which eventually strengthened vertical movements and led to the formation of the contemporary mountain systems.

In other orogenic belts of the Earth, an increase in ascending movements was also noted in the Pliocene–Quaternary [20, 21, 29]. In order to understand whether the proposed model is applicable to other regions, let us consider the recent justifications of the ascending, lateral, and descending branches of mantle convection.

W. Morgan introduced into geological discourse the concept of mantle plumes—jets of matter and heat that ascend from the lower mantle, melt through lithospheric plates, and manifest themselves as volcanism ("hot spots") on the surface. This idea was subject to criticism [1, 3]. Sorokhtin [1] stressed that it was incompatible with the concept of mantle convection as the cause of plate flow. Nevertheless, the idea of plumes as the source of intraplate magmatism gained acceptance among geologists [4].

The geochemical data available do not contain signs of magma formation deeper than 700 km [2]. This does not prove that the material cannot come from larger depths and only means that, if it comes in, it loses the marks of previous depths because of processing. Therefore, the only source of information about the flow of matter in the lower mantle can be seismic tomography data. They helped to identify several superplumes, in addition to the Ethiopian–Afar one, that can be traced from the lower parts of the mantle. The largest of them is the meridionally elongated Pacific superplume, which is upwardly divided into several jets (Fig. 6). It does not reach the lithosphere, transferring into upper-mantle flows that spread eastward to the spreading zones of the East Pacific Rise. An ascending flow, smaller in area, is projected on the region of the Cape Verde Islands, west of Africa. It also loses its independence in the upper mantle, transferring into a lateral flow, which spreads westward and reaches the rift zone of the Mid-Atlantic Ridge. In the north of the Atlantic, a similar flow was found; it is inclined eastward, reaching the surface near Iceland (Fig. 7). In addition to these and some other similar through structures, less clearly expressed by reduced velocities of seismic waves, no other signs of mantle-through ascending convection branches were detected. We think that the superplumes revealed serve as their manifestations.

According to seismic tomographic data, lateral upper-mantle flows spread from the superplumes. Owing to viscous friction between the asthenosphere and the lithosphere, the flows displace lithospheric plates. The location of a spreading zone above a superplume is, most probably, an exception rather than a rule. Only the Icelandic superplume stands out in the profile along the Mid-Atlantic Ridge, while "hot" regions under the remaining parts of the spreading zone, clearly expressed at the level of the lithosphere and the upper parts of the asthenosphere, disappear at depths down to ~200–300 km (see Fig. 7). The origin of spreading zones is caused by the heterogeneity of the lithosphere and the existence of weakened zones in it. The formation of magma chambers, which eject basalts in spreading zones, is not related to deep-seated plumes. It is the reaction to plate divergence due to the uneven adhesion of the plates to the moving upper-mantle flow, caused by adiabatic melting of the

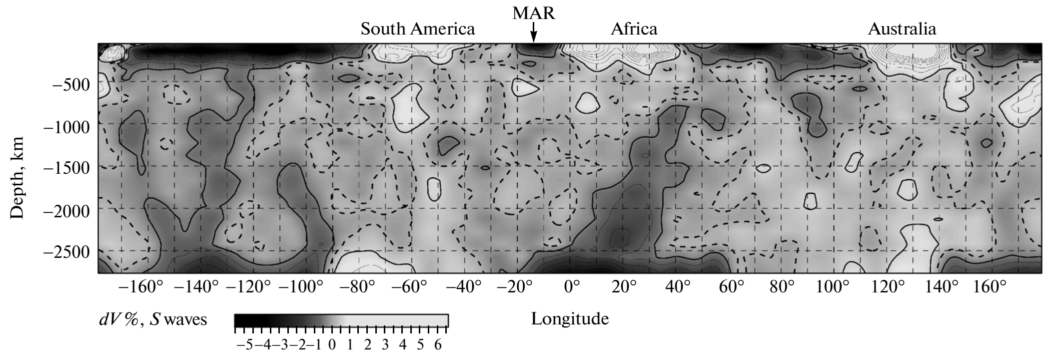

Fig. 6. Seismic tomographic profile of the mantle by *S* waves along 22° S. On the left is the "branchy" Pacific superplume, and in the center is the Ethiopian–Afar superplume; lateral flows spread from both superplumes at the level of the upper mantle. Compiled by S.Yu. Sokolov by cross-sectioning the data of global 3-D model NGRAND [17, 19]. The contours are drawn through 0.5%; the dashed line shows zero values; and MAR is the Mid-Atlantic Ridge.

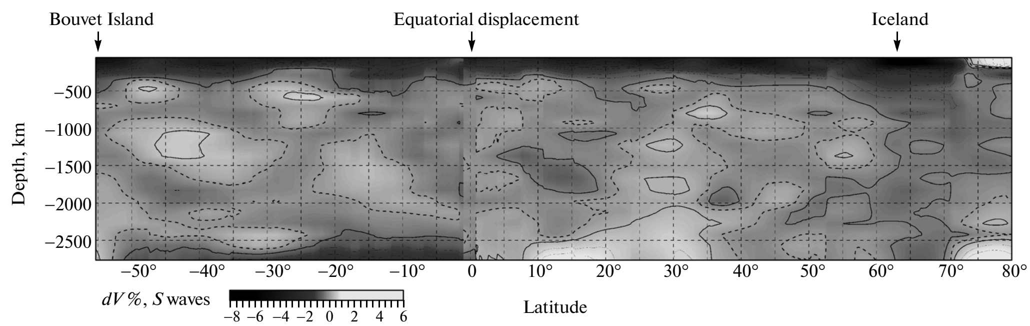

Fig. 7. Seismic tomographic profile of the mantle by *S* waves along the Mid-Atlantic Ridge. The Icelandic superplume stands out on the right; under other parts of the ridge is an area with reduced velocities of seismic waves, covering the lower strata of the lithosphere and the upper strata of the sublithospheric mantle and degenerating at depths down to 200–300 km. Compiled by S.Yu. Sokolov by cross-sectioning the data of global 3-D model NGRAND [5, 22]. The contours are drawn through 0.5%, to 1% through 0.3%. The dashed line shows zero values, and the bold solid isolines show the limits ±0.3%.

upper parts of the sublithospheric mantle and the lithosphere during stretching; therefore, these chambers are not deep.

The majority of subduction zones investigated are transformed fully or partially into subhorizontal BMWs at the level of the mantle's transition layer. The study of them in the northeast of Asia has led researchers to the conclusion that there exists upper-mantle convection associated with them, causing the rise of mantle diapirs and intraplate volcanism [2, 4, 23]. Convective shifts of the upper mantle could cause a deformational thickening of the earth's crust on the edge of the continent, which, in combination with crustal deconsolidation under the effect of fluids coming from BMWs, predetermined the uplift of contemporary mountain systems [21]. In the Alpine–Himalaya Belt, as was shown above, the processing of fluid-saturated BMWs by sublithospheric flows from the Ethiopian–Afar superplume activated these flows, and their action led to the deconsolidation of the upper parts of the mantle and the lower parts of the crust, triggering increased uplifts and mountain building. These processes were manifested most vividly in Central Asia, where the lithosphere was especially thickened by collisional deformities and enriched by relics from the previous oceanic lithosphere of the Tethys. In the Mediterranean part of the belt, where the lithosphere has preserved significant heterogeneities, ridge uplifts were combined with trough sinks. Their origin is assumed to be associated with mantle diapirism, which, in turn, also depends on lateral upper-mantle flows. Some particular specifics of the Alpine–Himalayan Belt's recent tectonics may also be associated with them, for example, the anomalously fast movement of the Anatolian Plate and the high volcanism of the Armenia Highlands [16], as well as intracontinental mantle seismic focal zones like the Hindu Kush and Vrancea foci [30], which have found no satisfactory plate-tectonic explanation.

Taking into account the fact that most subduction zones transform into BMWs at the level of the mantle's transition layer, the sinking of the remaining portions of subducted slabs into the lower mantle hardly compensates for the growth of the lithosphere in spreading zones. Most likely, the sinking of slabs is supplemented by the sinking of highly metamorphosed and, therefore, compacted fragments of the lithosphere under collision zones and ancient continental cores below the mantle's transition layer (see Figs. 4–6).

Thus, a new tectonic model, more general than that of plate tectonics, is taking shape, and we call it *the tectonics of mantle currents*. The source of plate flow is the current of upper-mantle matter within general mantle convection. Its ascending branches are expressed by mantle superplumes, and its descending branches cover not only part of subducted slabs but also certain regions under collision zones and ancient continents. Plate rupturing and faulting in some places and the sinking of a part of the lithosphere in other places occur because of differences in the velocities and directions of upper-mantle flows and their interference.

Plate tectonics is not the only result of upper-mantle currents. It is supplemented by tectonic processes caused by phase mineral transformations of mantle and crustal rocks, the development of large mantle wedges, and the related fluid saturation of the mantle's transition layer. Therefore, the tectonic model of mantle currents, fully embracing the theory of lithospheric plate tectonics, interprets a number of geological facts unexplained by this theory, in particular, the strengthening of vertical movements and mountain building processes in the Pliocene–Quaternary.

ACKNOWLEDGMENTS

This work was supported by program no. 6 of the RAS Division of Earth Sciences, program no. 4 of the RAS Presidium, and the Russian Foundation for Basic Research (project nos. 11-05-00628-a and 14-05-00122).

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Translated by B. Alekseev