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Peculiarities of Subduction in the Junction of the Kuril–Kamchatka and Aleutian Island Arcs

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Abstract—The peculiarities of the junction between the Kuril–Kamchatka and Aleutian island arcs are studied using different techniques and experimental data. The models of medium structure that were obtained by using surface wave tomography and studies of *S*-wave anisotropy in the asthenosphere beneath the subduction plate detected an ascending asthenospheric flow of hot material and fluids along the northern boundary of the lithospheric plate. The presence of the ascending asthenospheric flow in the junction zone has been recently confirmed by detailed body-wave seismic tomography. Additional feeding of the Klyuchevskoi volcanic group from the asthenospheric flow explains the great difference in the eruptive activity of these volcanoes in comparison to other volcanoes located in the Eastern volcanic belt of Kamchatka. Comparative study of Quaternary volcanoes lying in the Eastern volcanic belt has revealed a strongly pronounced decreasing productivity from north to the south, i.e., with distance from the end of the subduction plate. This reduction is likely related to a depletion in the invasion of magmatic melts along the subduction plate from the asthenospheric flow in the junction of the Kuril–Kamchatka and Aleutian island arcs.

Keywords: asthenosphere flow, seismic tomography, junction of the Kuril–Kamchatka and Aleutian island arcs, subduction, lithospheric plate

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Subduction in the Kuril–Kamchatka volcanic belt is caused by the interaction between lithospheric plates: the Pacific oceanic plate dips beneath the Eurasian (North American?) continental one. Detailed study of the structure of the Kamchatka subduction zone allowed determination of the main characteristics of the zone along the contact between interacting plates [1]. The age of the dipping oceanic plate gradually decreased from 104.5 Ma in the south (at about 50° N) to 77 Ma in the north (at about 56° N); the maximum depth of earthquakes decreases from 500 to 100 km, and the extent of the seismoactive portion in the subduction zone decreases from 700 to 230 km. The angle of slab dipping in the Kamchatka segment

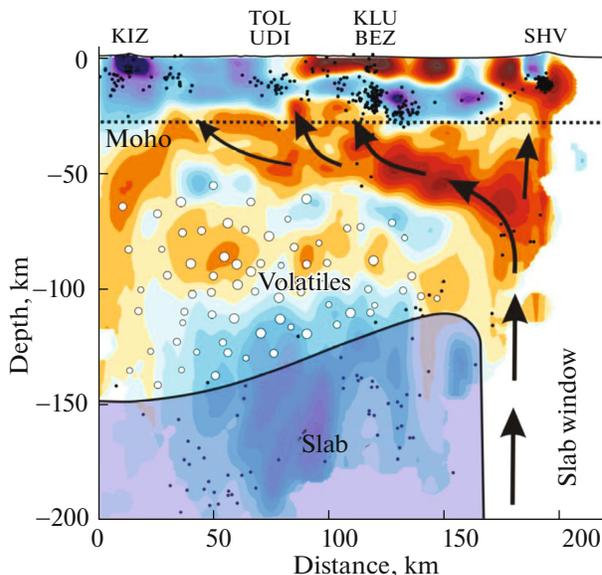


Fig. 1. Schematic distribution of magmatic melts from the asthenospheric flow at the boundary of the Pacific lithospheric plate. Zones of higher and lower (related to melt and fluid volumes) *S*-wave velocities are marked blue and yellowish red, respectively. Black dots denote earthquake hypocenters. Empty circles denote fluid flows from the upper boundary of the plunging slab. Black arrows show the possible directions of the asthenospheric flow material. The dotted horizontal line corresponds to the Moho.

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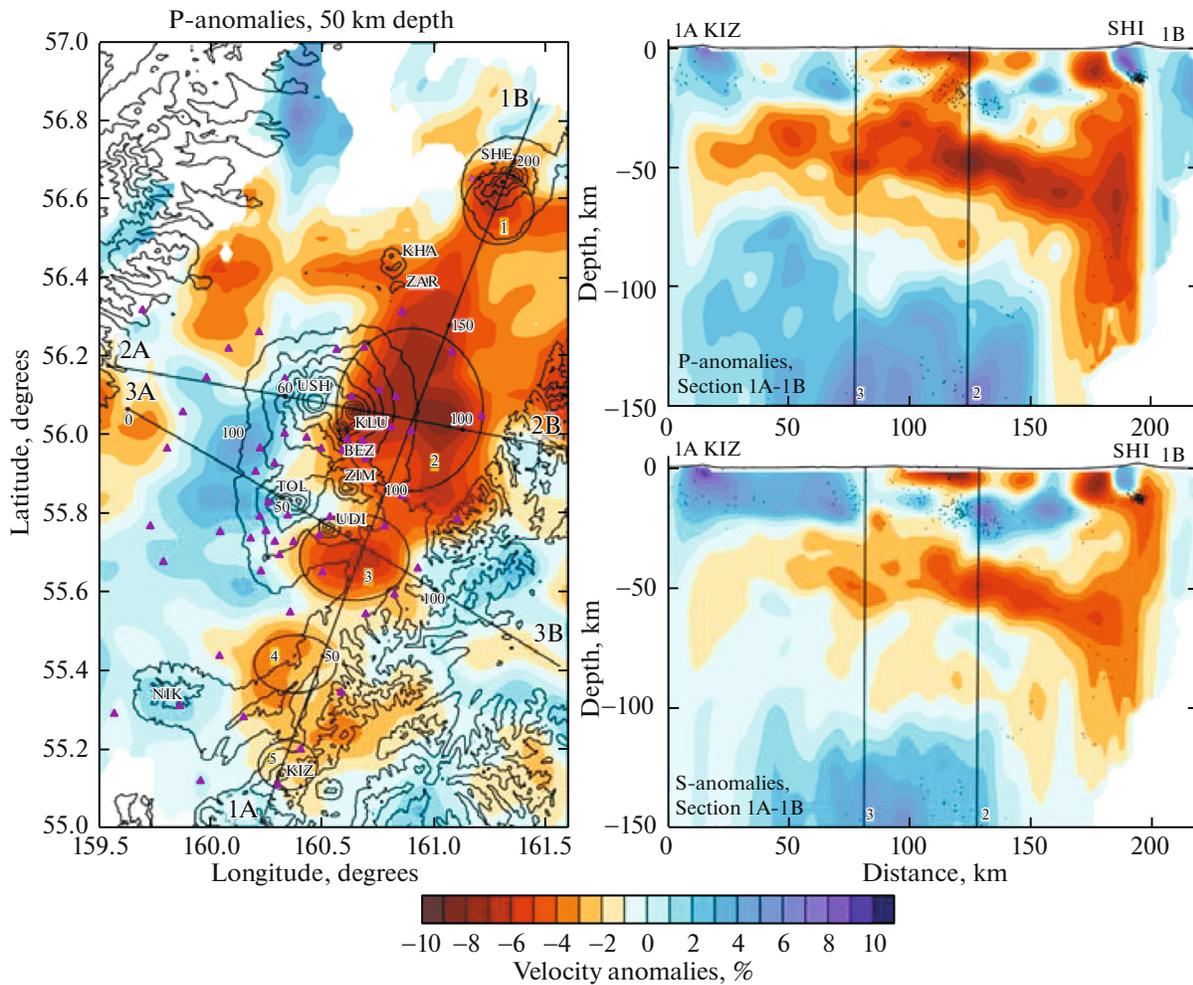


Fig. 2. In the left panel, the structure of *P*-wave velocity anomalies beneath the Klyuchevskoi volcanic group at a depth of 50 km is shown. In the right panel, *P*- and *S*-wave velocity anomalies (right top and right bottom, respectively) are along the deep tomographic section of the 1A–1B profile (Kizimen volcano (KIZ) to Shiveluch volcano (SHE)). Dots in the sections indicate earthquake hypocenters beneath volcanoes and in the subduction zone.

of the Kuril–Kamchatka arc (from 50° N to 55° N) is almost constant (about 55°). Further north, in the portion up to the junction between the Kuril–Kamchatka and Aleutian island arcs, the structure of the subduction zone changes: to the south of 55° N, the maximum depths of earthquake hypocenters gradually reduces from 500 to 300 km, while to the north of this latitude an abrupt change from 300 to 100 km is reported, with the dip angle of the slab reducing to 35°. The volcanic front is of almost linear outline at the latitudes of 50°–55°, but shifts to the northwest to the north of there; notably, the Pacific Plate bends in the same direction and disappears in the zone of junction between the Kuril–Kamchatka and Aleutian island arcs, at a latitude of about 56.5°. As was shown earlier [2–4], an ascending asthenospheric flow forms at the northern boundary of the lithospheric plate. The presence of this ascending asthenospheric flow was determined from the results of surface-wave tomography

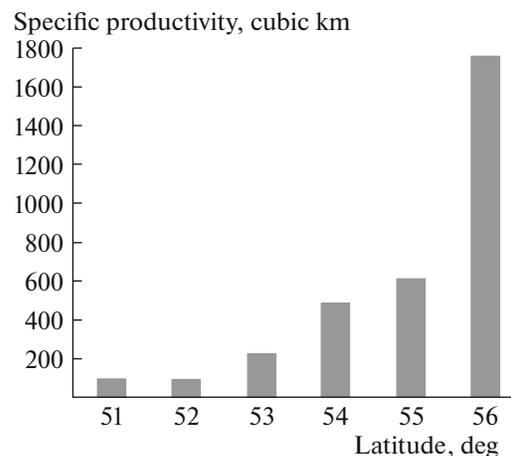


Fig. 3. Dependence of the specific productivity on latitude for volcanoes of the Eastern volcanic belt.

Table 1. Volcanoes of the Eastern volcanic belt of Kamchatka

Number	Volcano name	Height, m	Volume, km ³	Latitude	Longitude
1	Ebeko	1152	4.8	50°58'	156°02'
2	Alaid	2339	40.2	50°51'	155°33'
3	Kambalny	2156	31.47	51°18'	156°54'
4	Koshelevskii	1812	18.68	51°21'	156°45'
5	Dikii Greben	1079	3.94	51°27'	156°59'
6	Il'inskii	1578	12.34	51°30'	157°12'
Sum			111.43		
7	Zheltovskaia	1953	23.39	51°35'	157°20'
8	Kellya	940	2.61	51°39'	157°21'
9	Ksudach	1079	3.94	51°49'	157°32'
10	Khodutka	2090	28.67	52°04'	157°42'
11	Priemysh	1202	5.45	52°04'	157°42'
12	Piratkovskii	1322	7.25	52°07'	157°51'
13	Zheltyi	885	2.18	52°20'	157°55'
14	Asacha	1909	21.85	52°21'	157°50'
15	Mutnovskii	2323	39.36	52°27'	158°12'
Sum			134.75		
16	Gorelyi	1829	19.21	52°33'	158°02'
17	Zhirovskoi	1125	4.47	52°37'	158°15'
18	Vilyuchinskii	2173	32.22	52°42'	158°17'
19	Kozelskii	2189	32.94	53°14'	158°53'
20	Avacha	2751	65.37	53°15'	158°51'
21	Koryakskii	3456	129.6	53°17'	158°34'
22	Arik	2156	31.47	53°22'	158°40'
23	Aag	2310	38.7	53°24'	158°38'
Sum			237.04		
24	Zhupanovskii	2958	81.27	53°35'	159°08'
25	Dzendzur	2159	31.6	53°38'	159°05'
26	Zhupanovskie vostryaki	1707	15.62	53°47'	159°18'
27	Ditmara	1301	6.91	53°52'	159°33'
28	Bakening	2278	37.12	53°55'	158°05'
29	Belyankina	1144	4.7	53°56'	159°25'
30	Krainyi	1198	5.4	53°57'	159°20'
31	Akademii nauk	1100	4.18	53°59'	159°28'
32	Karymskii	1486	10.3	54°03'	159°27'
33	Dvor	1489	10.37	54°05'	159°27'
34	Malyi Semyachik	1560	11.92	54°08'	159°40'
35	Sobolinyi	1131	4.54	54°09'	159°27'
36	Kruglenkii	1122	4.43	54°16'	159°52'
37	Tsentrallyi Semyachik	1294	6.8	54°17'	159°56'
38	Bolshoi Semyachik	1739	16.51	54°19'	160°01'
39	Burlyashchii	1164	4.95	54°20'	159°58'
40	Vostochnyi Baranyi	1425	9.09	54°20'	159°53'
41	Kikhpinych	1552	11.74	54°29'	160°14'
42	Uzon	1591	12.65	54°30'	159°55'

Table 1. (Contd.)

Number	Volcano name	Height, m	Volume, km ³	Latitude	Longitude
Sum			289.31		
43	Taunshits	2353	40.9	54°32'	159°48'
44	Krashennikova	1856	20.08	54°35'	160°16'
45	Unana	2192	33.07	54°39'	159°45'
46	Kronotskii	3528	137.88	54°45'	160°30'
47	Shmidta	2038	26.58	54°55'	160°37'
48	Gamchen	2576	53.67	54°58'	160°42'
49	Vysokii	2153	31.34	55°04'	160°46'
50	Komarova	2070	27.85	55°04'	160°00'
51	Konradi	1892	21.27	55°06'	160°34'
52	Prihodchenko	1138	4.63	55°08'	160°44'
53	Sokol	1654	14.21	55°10'	160°33'
54	Kizimen	2485	48.18	55°12'	160°19'
55	Iult	1856	20.07	55°14'	160°36'
56	Tumrok	2103	29.2	55°23'	160°53'
Sum			508.93		
57	Malaya Udina	1945	23.1	55°45'	160°37'
58	Plosky Tolbachik	3085	92.19	55°49'	160°25'
59	Gorny Zub	2242	35.39	55°51'	160°42'
60	Ovalnaya Zimina	3081	91.83	55°52'	160°37'
61	Ostraya Zimina	2744	64.88	55°52'	160°37'
62	Bolshaya Udina	2923	78.42	55°56'	160°45'
63	Ostryi Tolbachik	3682	156.74	55°57'	160°24'
64	Bezymiannyi	2882	75.16	55°58'	160°36'
65	Kamen	4575	300.68	56°01'	160°45'
66	Klyuchevskoi	4750	336.52	56°03'	160°39'
67	Dal'naya Ploskaya	3943	192.49	56°04'	160°29'
68	Blizhnaya Ploskaya	4057	209.67	56°07'	160°30'
69	Zarechnyi	754	1.35	56°23'	160°34'
70	Kharchinskii	1400	8.62	56°26'	160°34'
71	Shiveluch	3283	111.1	56°39'	161°21'
Sum			1708.14		

and from the shear-wave anisotropy in the asthenosphere beneath the subducting plate. The fact that the subducting plate disappears in the junction between the peninsula of Kamchatka and the Aleutian arc is related to the presence of a mantle plume that ascends to the surface from depths of more than 1000 km [5]. As was supposed in [3], the ancient slab that formed during subduction of the Commander (Komandorskii) Basin lithosphere disappeared in the period from 10 to 5 Ma ago; about 2 Ma ago, the northern segment of the Pacific lithospheric plate separated and submerged into the mantle. Thus, a window appeared in the junction between the Kuril–Kamchatka and Aleutian island arcs. Moreover, the mantle plume

effect induced partial melting of the subducting plate in the western part of the Aleutian arcs to form a zone (so-called slab portal) in which the subducting plate is absent [6]. The presence of the ascending asthenospheric flow in the junction between the Kuril–Kamchatka and Aleutian island arcs has been verified recently by modeling on the basis of body-wave seismic tomography [7]. The reconstruction of mantle melt supply at the boundary of the subducting plate is shown in Fig. 1.

As was shown in [8], additional feeding of volcanoes belonging to the Klyuchevskoi group by the mentioned asthenospheric flow allows for a considerable difference in the productivity of these volcanoes com-

pared to the other volcanoes in the Eastern volcanic belt of Kamchatka. This low-velocity anomaly can be traced clearly at a depth of 50 km from Shiveluch volcano to Kizimen volcano (Fig. 2). This anomaly can be considered as an intrusion of magmatic melts along the subduction zone from the vertical asthenospheric flow at the boundary of the subducting slab.

The pattern of the velocity structure presented in [7] could be obtained only for the Kizimen volcano area. The observation system used did permit construction of seismotomographic models for volcanoes of the Eastern volcanic belt of Kamchatka, which were located to the south of Kizimen. However, we can suppose that the influence of the asthenospheric flow might have been identified for these volcanoes further south. In order to verify this hypothesis, we calculated the specific productivity of all the Quaternary volcanoes of the Eastern volcanic belt of Kamchatka. The value of the productivity was estimated from the volume of the volcanic edifice. Of course, such a method of estimating the volume of erupted products may not include the explosive part; however, this is compensated by the fact that ash clouds released during explosive eruptions usually transport an insignificant part of the total volume of erupted products. On the contrary, majority of the explosive eruption products settles as scoria and volcanic bombs to form the volcanic edifice.

Table 1 lists the volcanoes of the Eastern volcanic belt of Kamchatka, for which the volumes of erupted products were calculated.

The specific productivity of volcanoes was calculated for the portions of the subduction zone; the extent of each portion was one degree of latitude. Figure 3 presents the column chart of specific productivity for volcanoes of the Eastern volcanic belt of Kamchatka at latitudes from 51° N to 56° N.

It is obvious that the productivity of volcanoes of the Eastern volcanic belt decreases from north to south, i.e., with movement from the boundary of the subducting plate. This reduction is most likely related to the less intensive supply of magmatic melts from the asthenospheric flow along the subducting plate, in the junction of the Kuril–Kamchatka and Aleutian island arcs. Propagation of the asthenospheric flow along the subduction zone can be caused by predominant diffusion in the heated medium; in turn, diffusion is favored by the presence of melts and fluids ascending from the upper boundary of the subducting plate. It can be noted that the productivity of volcanoes does not decrease to the south of 52° N. The distance between this latitude and the northern limit of the lithospheric plate is about 500 km. Hence, for a period of about 2 Ma when the slab portal existed at the junction between the Kuril–Kamchatka and Aleutian arcs [3], magmatic melts propagated for as far as 500 km. The average rate of heat flow diffusion is 25 cm/yr. The north-to-south decrease in productivity of volca-

noes of the Eastern volcanic belt is exponential. Because the heat conductivity of a solid medium depends on the temperature of this medium and decreases exponentially as the temperature drops, the value of heat energy also decreases exponentially as the heat flow penetrates into the solid medium. Assuming such a mechanism of heat flow propagation, the volumes of the melts formed are expected to decrease exponentially along the direction of heat flow propagation.

The peculiarities of the feeding system of volcanoes revealed in the Eastern volcanic belt can explain differences in the compositions of erupted rocks between the northern and southern parts of the Kamchatka subduction zone. The composition of erupted rocks in the Eastern volcanic belt changes from predominantly mafic in the north to predominantly felsic in the south, and this may have been caused by partial melting of the crustal material [9].

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