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Magnetotelluric Sounding of Kamchatka

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Abstract—The MTS data acquired in Kamchatka during the last 30 years have been analyzed and summarized. Our interpretation is based on curves oriented along and across Kamchatka. Longitudinal and transverse curves can be affected by local geoelectric inhomogeneities. These were suppressed by conformal averaging. A bimodal interpretation of average longitudinal and transverse curves yielded a deep geoelectric model, which can be adopted as a starting point to be subsequently refined by 3D numerical modeling. The model involves a crustal conductive layer extending along central Kamchatka. In the east of the peninsula this layer is connected with crustal transverse conductive zones as wide as 50 km. Those zones have extensions toward the Pacific Ocean. Major centers of present-day volcanism occur in the transverse zones. The upper mantle contains an asthenospheric conductive layer forming an uplift beneath the present-day volcanic belt of Kamchatka.

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INTRODUCTION

Kamchatka is of great interest for the study of deep structure in the transition region between the continent and the Pacific Ocean, because that region distinctly shows dynamic processes, which are expressed in high seismicity, present-day volcanism, and geothermal activity. Previously, the available knowledge of the deep structure for the region was largely based on data supplied by seismology, gravimetry, and aeromagnetic surveys. This information was unfortunately quite inadequate. The 1970–1980 magnetotelluric investigations in Kamchatka have been very helpful for elucidating the deep structure. By now much of Kamchatka has been covered by magnetotelluric sounding surveys. Tools for interpretation, numerical and physical modeling were applied to this large factual material to derive maps of electrical conductivity in the volcanogenic sedimentary cover and deeper crustal layers and the deep geoelectric models for Kamchatka, and some areas of present-day volcanism [3].

In spite of the successes achieved, there remains some dissatisfaction, which can be summarized as follows. The coverage is extremely nonuniform, especially in areas of present-day volcanism. Analog instruments were used for the measurements, which has affected the quality of MTS curves. The interpretation relied on a single mode only, i.e., quasi-longitudinal MTS curves. It was only at the preliminary stage of analysis that quasi-transverse curves were used.

In recent years several MTS lines have been measured in Kamchatka across the peninsula. Digital electrical prospecting stations were used at steps of 2 to 5 km. The range of periods was between a few tenths of a second to 1000 s or greater. These curves constitute a sizable addition to the magnetotelluric information obtained previously. Results from MTS interpretations carried out by these authors for some areas of Kamchatka showed the existence of major transverse conductive zones that produce deep-seated 3D heterogeneities [6, 7]. For this reason an interpretation that relies on a single mode may lose essential information, or possibly distort our notions of electrical conductivity at depth.

In view of these new data, it is necessary to generalize and analyze the MTS data for all of Kamchatka using advanced methods, which take into account possible distortions of MTS curves by geoelectric heterogeneities. It is important to analyze the two modes simultaneously in order to reveal the main features of deep conductivity structure in Kamchatka. When combined with other geological and geophysical data, the results will help identify deep-seated faults and magma supply zones in major volcanic areas, thus providing more information on the dynamics of ongoing deep processes. This problem will be treated in several publications. The present study focuses on a summary and interpretation of MTS data at a qualitative level for developing a preliminary model of Kamchatka, which is to be subsequently refined using 3D numerical modeling.

The map of MTS lines is shown in Fig. 1. Nearly all of the area is covered by the soundings. However, there are some areas that have been left out of MTS areal surveys. These areas are poorly accessible because of mountain relief or the severely swampy nature of the terrain. The northern and southern parts of the area are covered by MTS surveys on a grid of about 10 by 15 km. These MTS data were obtained in previous years. The range of periods is 10 to 1000 s. The MTS lines measured in recent years cover the peninsula in a uniform

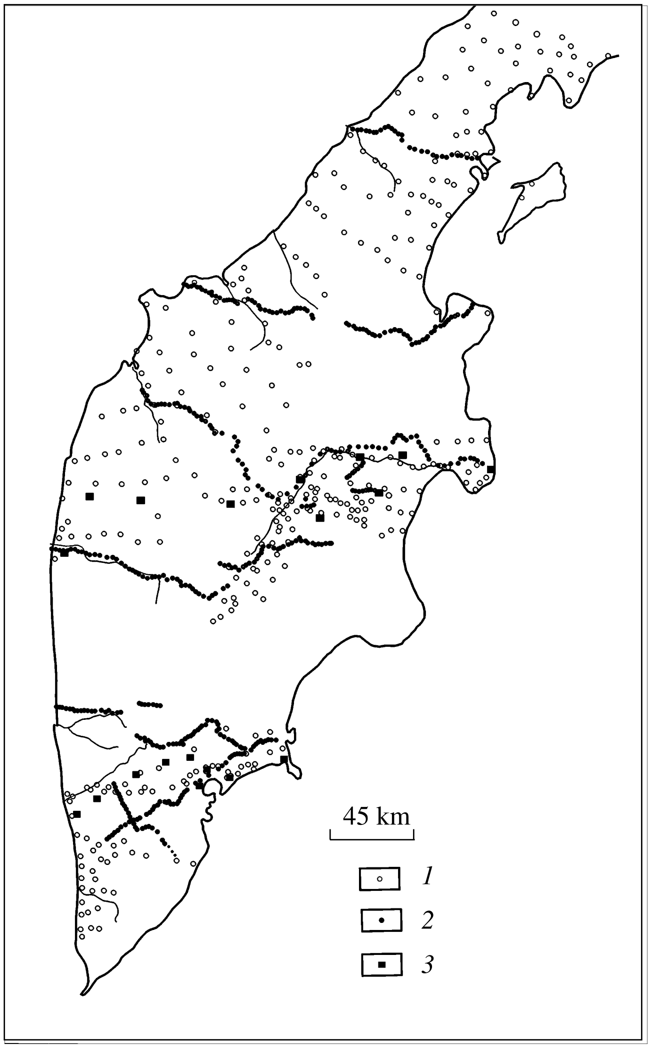

Fig. 1. A map of MTS surveys in the range of periods (*1*) 10 to 1000 s, (*2*) 0.1 to 1000 s, (*3*) 1500 to 15 000 s.

manner. The step is 2 to 5 km. The MTS measurements were made by digital electrical prospecting stations with a period range of 0.1 to 1000 s. We also have several MTS surveys at longer periods, 1500 to 15000 s. The MT field was recorded along and across the major tectonic zones of Kamchatka. These measurements were made by the Eastern Geophysical Trust Company, the PGO Kamchatgeologiya, the PGO Sakhalingeologiya of the RSFSR Ministry of Geology, and by the Institute of Volcanology of the Far East Division of the Russ. Acad. Sci.

A Brief Geological and Geoelectrical Description. Kamchatka is a young folded area, part of the Pacific mobile belt which formed during Late Cretaceous and Cenozoic time. It contains pre-Cretaceous, Cretaceous, Tertiary, and Quaternary formations. The oldest metamorphic rocks are exposed in the form of uplifts (the Srednii, Kamchatskii, and Ganaly ones) [3]. The lower part of the sedimentary-volcanogenic complex is composed of Upper Cretaceous rocks, which divide into two sequences, a terrigenous and an upper volcanogenic-cherty one. Cenozoic deposits are widespread in Kamchatka. They are used as indicators to establish the existence of the West Kamchatka, Central Kamchatka, and East Kamchatka structural facies zones (Fig. 2).

The West Kamchatka structural facies zone is roughly identical in position with the West Kamchatka Depression, with several smaller features being identified within the latter. The sedimentary–volcanogenic complex is composed of Paleogene–Neogene deposits, which are terrigenous in origin, with it only being in some isolated areas that effusive rocks are present.

The Central Kamchatka structural facies zone is an inner volcanic arc. Its evolution is thought to be related to the existence of the Main Kamchatka Fault. That zone includes the Sredinnyi Kamchatka Massif, the Ganaly uplift, the Kamchatka–Koryak and South Kamchatka anticlinoria.

The East Kamchatka zone is classified [1] as belonging to the outer volcanic arc. It includes the Khavyven metamorphic elevation, the East Kamchatka anticlinorium, the Central Kamchatka and East Kamchatka depressions, and uplifts of the volcanic peninsulas.

Intrusive and effusive magmatism widely occurs in Kamchatka. The magmatic processes have been the most active in the Central Kamchatka zone, which G.M. Vlasov classifies as an inner volcanic arc [3]. The volcanogenic rock sequences in this area are to a great extent saturated with intrusive formations. The magmatic rocks in eastern Kamchatka mostly concentrate in the eastern volcanic peninsulas. As to western Kamchatka, intrusive rocks are extremely rare there, being mostly confined to faults that bound some uplifts.

Volcanism manifested itself widely in Kamchatka during Cenozoic and Quaternary time. Researchers have identified the Central Kamchatka and East Kamchatka volcanic belts (Fig. 2), which formed during the Paleogene–Quaternary and Neogene–Quaternary time, respectively. The East Kamchatka volcanic belt is unconformably superposed upon various tectonic features and extends parallel to the Kuril–Kamchatka deep-sea trench. The volcanic deposits within the belt are composed of basic and intermediate calc–alkali rocks. Volcanism is also going on at present in the area. Most present-day active volcanoes of Kamchatka are concentrated there, their areal effusions being mostly of basaltic composition.

The geoelectric section of the region can be described as follows [4]. The top is composed of sedimentary and volcanogenic formations with their electrical resistivities varying within a wide range, from a 1
few hundreds to a few thousands of ohm-meters. Their thickness is between a few hundreds and 1000 m or greater in the area of the volcanoes. Lower resistivities 1

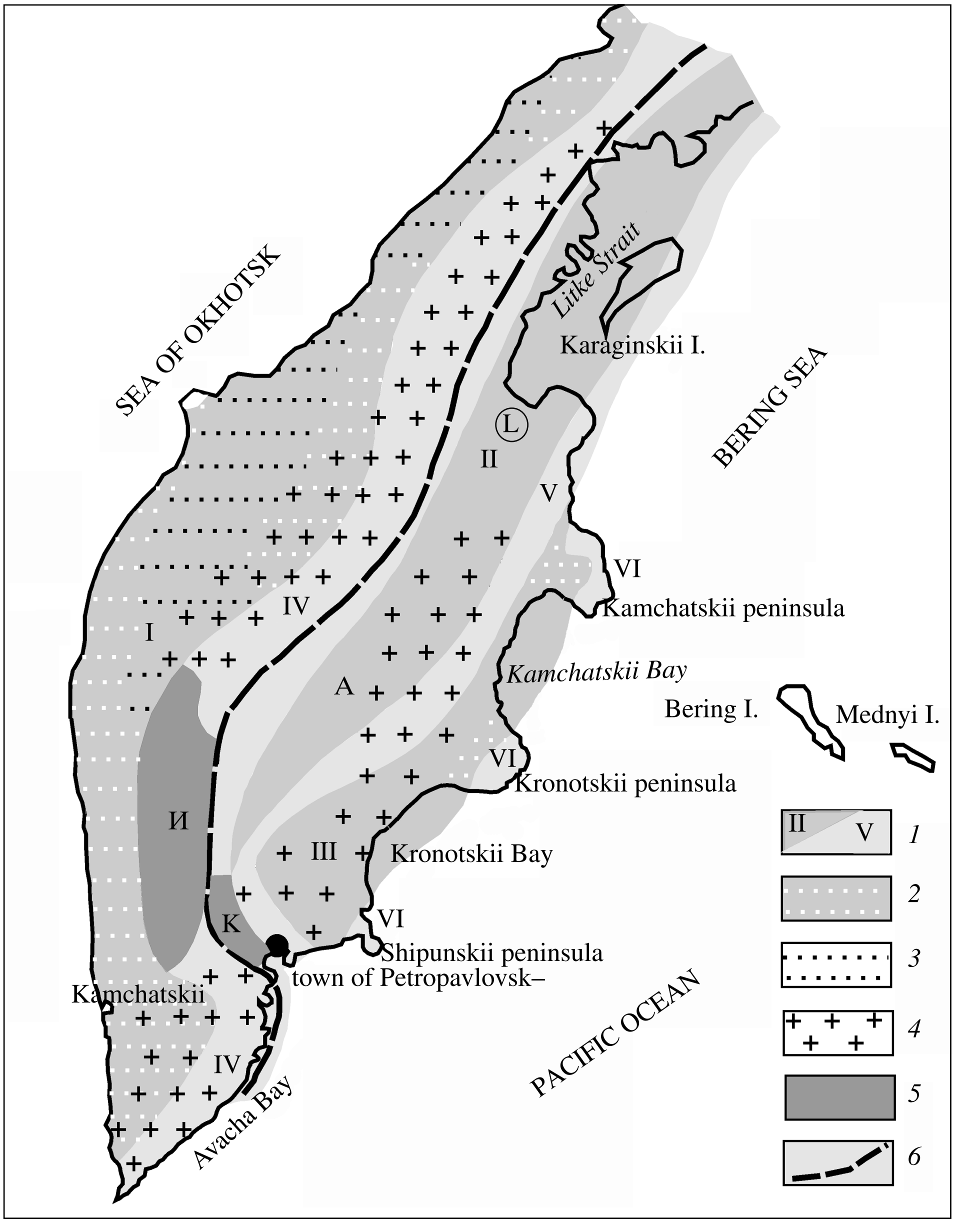

Fig. 2. Tectonic regionalization of Kamchatka: (*1*) features of the first order. Depressions: (I) West Kamchatka, (II) Central Kamchatka, (*3*) East Kamchatka; Anticlinoria: (IV) Kamchatka–Koryak, (V) East Kamchatka, (VI) uplift zone of volcanic peninsulas; (*2*), (*3*) features of the second order: (*2*) depressions, (*3*) uplifts; (*4*) superposed volcanic belts, (*5*) highs of older rocks (I stands for Sredinnyi Kamchatskii, K for Gannaly, L for Khavyven highs), (*6*) hypothetical Central Kamchatka deep-seated fault.

are typical of basins in the West Kamchatka Depres-
1 sion, higher resistivities occur in volcanic zones and the volcanic peninsulas. This is underlain by a Cenozoic sequence with a resistivity between a few to a few tens of ohm–meters and a thickness within a few kilometers
1 in the basins. Cenozoic formations with higher resistivities are typical of anticlinoria and peninsula uplifts, where the section is saturated with effusive and intrusive magmatic formations to a greater degree. The Cenozoic sequence with lower resistivity corresponds to depressions and basins, where the section is dominated by terrigenous rocks. The lowest resistivities of a few 1
ohm–meters are typical of areas with an increased thickness of low ohmic Miocene deposits. Such deposits are much more abundant in young superposed basins. The Paleogene rocks are characterized by higher resistivities. Because of their dominance in the 1
section, the mean resistivity of the Cenozoic sequence is as high as 10–20 ohm–meters or greater.

The Cenozoic sequence is underlain by rocks of the Upper Cretaceous complex. Two zones are identified as having substantially different conductivities in the

Upper Cretaceous rocks. One of these has a low resistivity, a few tens of ohm–meters. That zone includes the west coast of Kamchatka and the Koryak Upland. The lower resistivity is due to the terrigenous formations which prevail in the section. This is borne out by outcrops of terrigenous Cretaceous rocks in the Koryak Upland, the Lesnovo uplift, and Cape Omgon, as well as by deep drilling data. The resistivity of the Cretaceous complex is increasing eastward to values as great as a few hundreds of ohm–meters or more, which is thought to be due to an increasing role of volcanogenic formations.

The Mesozoic–Cenozoic sedimentary–volcanogenic complex is underlain by a metamorphic basement exposed in the Sredinnyi Massif, the Ganaly outcrop, and the Khavyyven elevation. A key high ohmic geoelectric horizon having a resistivity of a few hundreds to a few thousands of ohm-meters is confined to the basement. The crust and upper mantle involve layers of increased conductivity that are thought to be due to fluids.

THE ANALYSIS METHOD

MTS data processing was used to determine the components of the impedance tensor as reflecting the geoelectric structure. The components were found by the least squares method. The accuracy to which they can be determined throughout the period range of 0.1 to 1000 s is different for analog and digital methods of recording. When analog records are used, the accuracy is 5–10% for the impedance modulus and 3°–5° for the phase. The respective figures for digital records are 3–5% and 1°–3°. For longer periods ($T > 1500$ s) the accuracy is 10–20% for the impedance modulus and about 10° for the phase. The processing gave polar impedance diagrams. These allow assessment of the degree of lateral earth variability. The variability was also assessed analytically using Eggers' method [8]. We determined the principal directions and principal values of the impedance tensor. Analysis shows that the horizontal geoelectric variability at low frequencies can in a majority of cases be treated as quasi-2D, except for the eastern peninsulas, where the two-dimensionality of the geolectric medium is violated at higher frequencies.

The quasi-2D distribution of the geoelectric medium at lower frequencies is due to the fact that the Kamchatka Peninsula and the associated major tectonic zones (depressions and anticlinoria) have elongate shapes. Kamchatka and its tectonic zones can be approximated by quasi-2D geoelectric models at lower frequencies, as has been proved by these authors previously with the help of numerical and physical modeling [5]. The interpretation is based on curves along and across the main Kamchatka trend. The curves along Kamchatka were called longitudinal and those across it, transverse. This allows us, already at the first stage of analysis, to identify the influence of the "coast effect" along these two directions; the effect is due to a dramatic contrast in conductivity between the media in contact on the coasts of the Pacific Ocean and of the Sea of Okhotsk.

The MTS curves for Kamchatka are strongly affected by lateral heterogeneities due to magmatic bodies, faults, features of the sedimentary-volcanogenic cover, the seas and the ocean that surround the peninsula. A formal interpretation of individual MTS curves in order to extract information concerning deeper structure is meaningless. The ρ effect [2] is especially strong in MTS curves. It has affected both longitudinal and transverse curves. The effect is related to shallow subsurface heterogeneities, shifting the curves of apparent resistivity along the resistivity axis throughout the frequency range used. For this reason the curves can only be interpreted quantitatively after normalization for the purpose of diminishing the influence of near-surface heterogeneities. There are several ways to smooth out the distortions due to the ρ effect, all being based on the fact that deep-seated conductors produce surface anomalies of a few tens of kilometers, while local near-surface heterogeneities are expressed in more intensive local anomalies of a few kilometers. The problem of identifying information relevant to deeper structure therefore reduces to detecting a regional component in the background of local noise. The problem can be solved by spatial filtering. That method has long been in use in gravimetry and is widely employed for interpretations of the Kamchatka magnetotelluric field. Later, we used this method to study deep conductivity in Kamchatka [4].

The present paper uses the older method for averaging curves that have similar shapes. Our basic assumption is that the shape of a curve corresponds to a definite type of geoelectric section. The ρ effect makes MTS curves divergent by their level of resistivity while retaining the shape. It follows that MTS curves that have similar shapes are due to similar deep geoelectric sections. The above principle has been used to derive a geoelectric model for Kamchatka. Organizing all MTS curves into families using that principle, we thereby regionalize Kamchatka into zones of different deep sections. This work has been done for longitudinal and transverse MTS curves.

Kamchatka has been divided into 34 zones, each having its own shape for longitudinal and transverse curves (Fig. 3). The zones have areas of 5000 to 10 000–15 000 sq. kilometers or greater. The number of curves in a zone is 15 to 30. All curves for each zone cannot conveniently be shown in a figure. We provide an example in Fig. 4, showing longitudinal and transverse amplitude and phase curves for zone 15. It is seen that the amplitude curves have resistivity levels that differ by almost an order of magnitude, while retaining their shapes. At the same time, the phase curves are all similar, especially at lower frequencies. This demonstrates the dominance of the galvanic effect for the distortions due to near-surface heterogeneities. Conformal averaging was used to smooth out these effects [1]. The mean values of apparent resistivity were calculated as geometric means. The mean phases were arithmetic means.

The resulting mean longitudinal and transverse apparent resistivity curves are shown in Figs. 5 and 6 along with phase curves. The latter are known to show the effect of a layer at higher frequencies compared with the longitudinal curves and supply substantial additional information on deep conductivity in a restricted low frequency range. Many amplitude and phase MTS curves, both longitudinal and transverse, exhibit a minimum in the period range of 10–30 to 200 s, indicating a low resistivity layer in the crust. The MTS curves have been organized into sets with differing visibilities of the minimum.

Consider the longitudinal MTS curves. They are in the sets A, B, and C. The curves of apparent resistivity in set A have ascending asymptotic branches on the right approaching a maximum (Fig. 5). At the same time, the phase curves involve a well-pronounced maximum and descending branches which, as will be shown below, are due to a conductive asthenospheric layer. We thus come to the conclusion that the conductive crustal layer is not visibly expressed in the longitudinal curves of set A.

Consider the longitudinal curves in set B (Fig. 5). That set is the most numerous, so it has been divided into three families. The apparent resistivity curves in this set mostly have a minimum on the right, which is thought to be due to a conductive crustal layer. It is only some individual curves that have descending asymptotic branches on the right. Nearly all the phase curves involve a well-pronounced minimum that corroborates the existence of a layer of increased conductivity. Comparing the families of apparent resistivity, we must note that the minima in the MTS curves for western Kamchatka that characterize the crustal layer (6a, 6b, 8, 9, 11, 12) are less pronounced. This may be related to increased conductivity in the sedimentary cover or to a relatively low conductivity of the crustal layer. The crustal layer is better expressed in the MTS curves for the middle part of Kamchatka. This is shown in the family of curves 14a, 14c, 16, 18, 10, and 13–19. These curves are related to the Kamchatka–Koryak anticlinorium with a superposed volcanic belt, which is confined to a deep-seated fault hypothesized for that location. In the third family of set B it only the amplitude curves 21 and 22, which show poorly expressed minima at periods of 400–600 s, are found. The other curves have descending branches for lower frequencies related to the existence of a conductive layer. This is indicated by the low frequency minima in the phase curves.

Consider the set C (Fig. 5). That set includes two families of curves. In the family (24–26, 28, 33), the amplitude curves for lower frequencies have a maximum preceding a descending branch, which is related to the conductive asthenospheric layer, as will be shown below. The maxima are better expressed in the phase curves. The amplitude curves in the family (27, 30–32, 34) have more complex forms. Several curves (34, 37, 30) involve flattish portions at lower frequencies. Curve 32 is represented by an ascending asymptotic branch. Curve 31 has a poorly expressed maximum. This behavior of MTS curves in this family is largely controlled by 3D effects due to the complicated outline of the eastern peninsulas of Kamchatka [5, 6]. One is entitled to conclude that the crustal layer of increased conductivity is not seen in the set C curves.

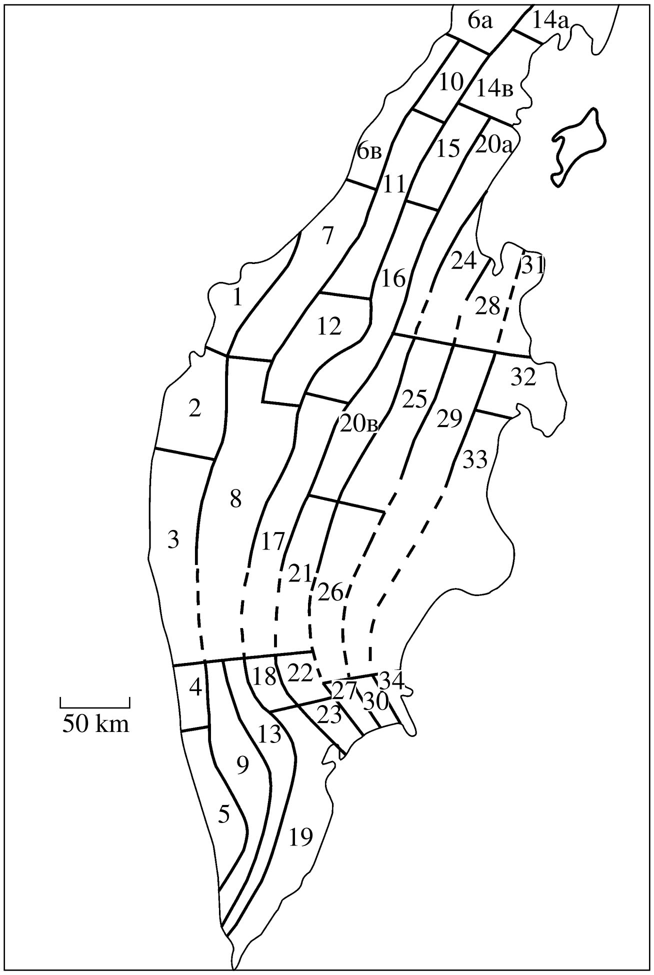

Fig. 3. A map of families of longitudinal and transverse MTS curves. Numerals denote the regions corresponding to the mean curves in Figs. 4 and 5.

Consider the transverse MTS curves (Fig. 6). They have been arranged into five families in the sets D, E, and F according to how the crustal layer of increased conductivity shows up. The set D contains curves 1–5 and 9. The amplitude curves are tending toward a maximum on the right. The maximum exhibits itself in a

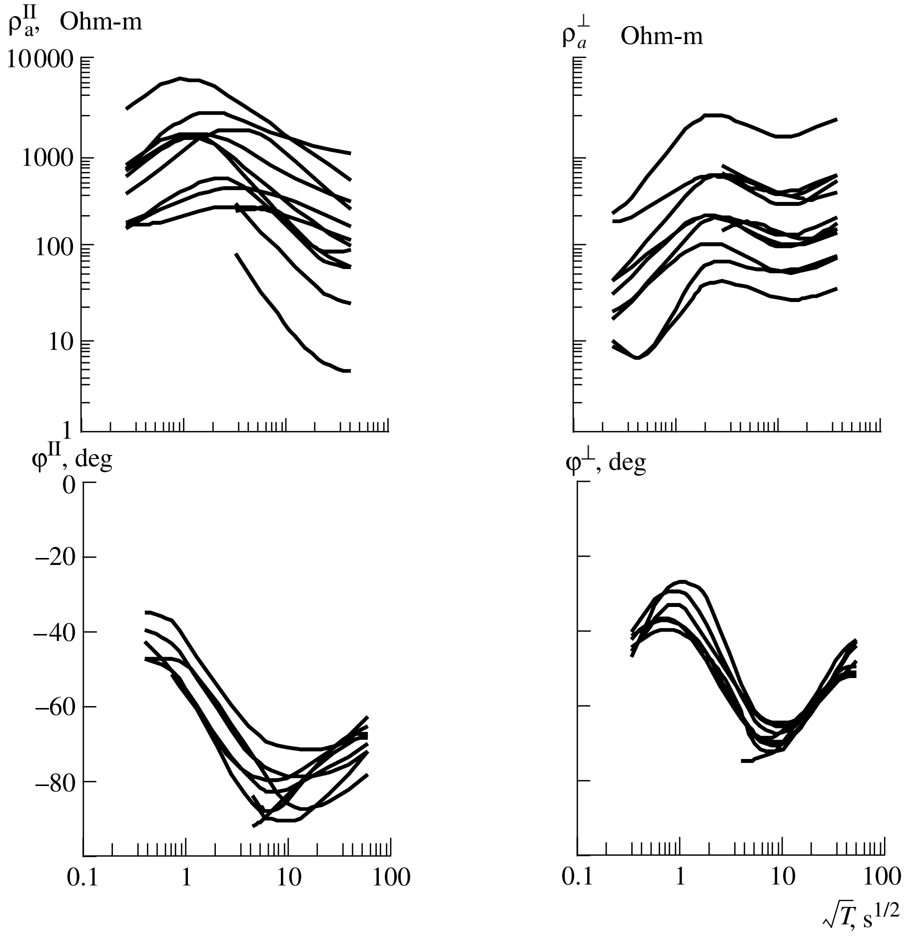

Fig. 4. Families of longitudinal and transverse individual MTS curves for region 15.

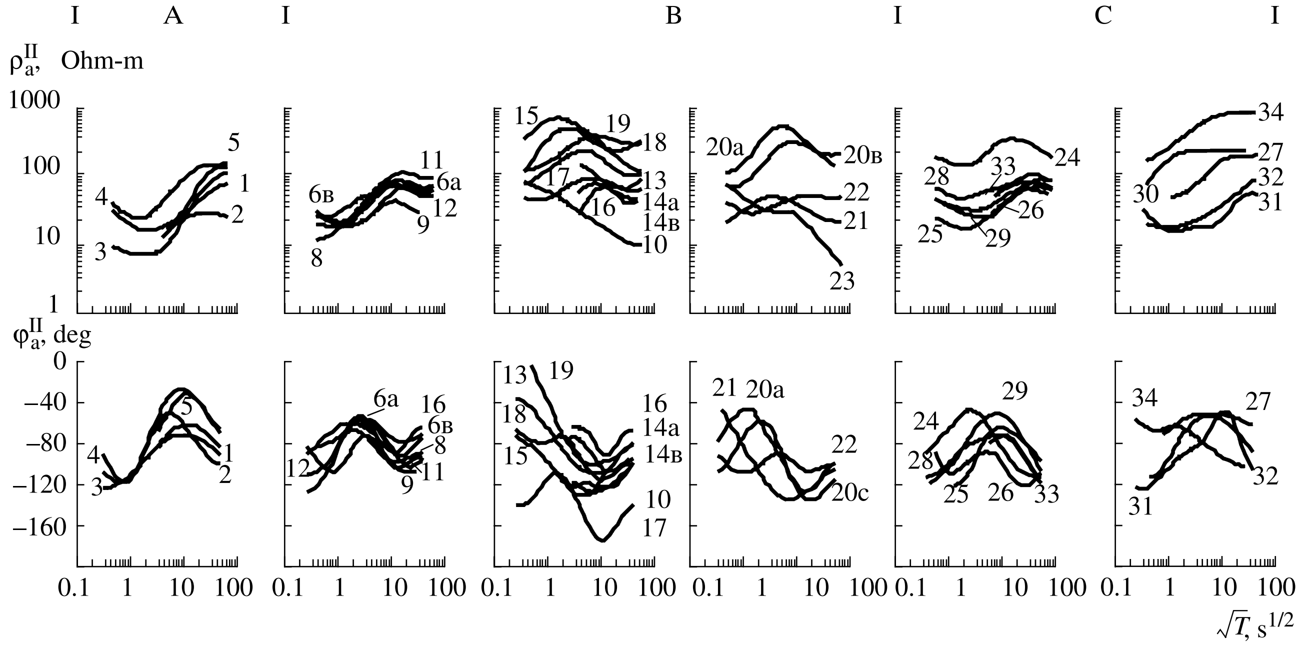

Fig. 5. Families of mean longitudinal MTS curves. The numbering of the curves is in correspondence with the regions in Fig. 3. A, B, and C denote the families relevant to the regions in Fig. 7.

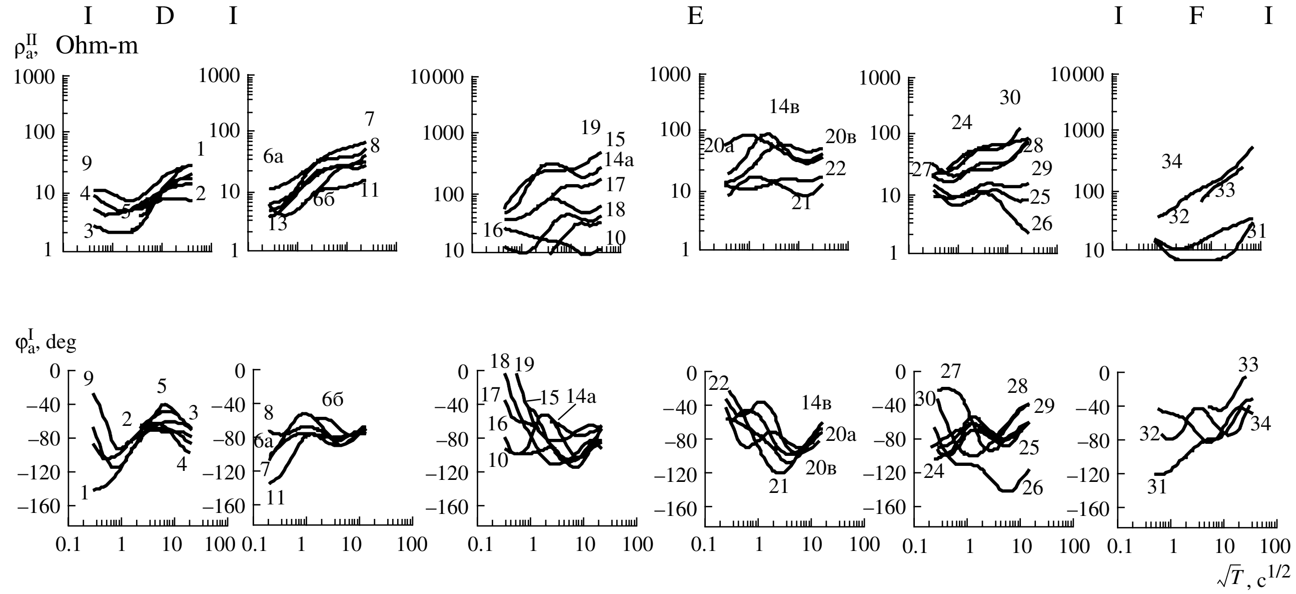

Fig. 6. Families of mean transverse MTS curves. The numbering of the curves is in correspondence with the regions in Fig. 3. D, E, and F denote the families relevant to the regions in Fig. 8.

more pronounced form in the phase curves. The curves in this set are similar to the longitudinal curves of set A. The curves of set D have not either been affected by the crustal layer of increased conductivity.

Set E contains three families of curves. The crustal layer is expressed in the amplitude curves of the family (shown in 6a, 6b, 7, 8, 11, 13) in the form of a minor minimum and flattish branches at lower frequencies. The layer is better expressed in the phase curves in the form of a minimum. The amplitude or phase curves of these families (10, 14a, 15–19) and (20–22, 14c) have the crustal layer in the form of well-pronounced minima, no matter what the conductivity of the sedimentary cover is. Most amplitude curves in the family shown in 24–30 involve a minimum on the right. Curve 26 has a descending asymptotic branch. The phase curves have a well-defined minimum at periods of 100 to 200 s, corroborating the existence of the conductive crustal layer.

The set F is represented by the family in curves 31–34. The amplitude curves have ascending asymptotic branches at lower frequencies, which is due to the coastal effect. The phase curves do not invariably match the amplitude curves in this family, which seems to be related to the violation of the dispersion relations due to the 3D heterogeneities caused by the eastern peninsulas of Kamchatka. The effect of the crustal layer is not seen in this set of curves.

RESULTS AND DISCUSSION

The preceding analysis yielded maps showing the occurrence of the conductive crustal layer, which is expressed in the form of minima in the longitudinal and transverse MTS curves (Figs. 7 and 8). The regions A and D, where the conductive crustal layer is not seen in the longitudinal and transverse MTS curves, are practically identical over most of the area. Some difference between the two regions can be noted in southwestern Kamchatka only, where region D occupies a larger area compared with region A, covering nearly half the southern extremity of the peninsula. The absence of minima in the longitudinal and transverse MTS curves can be accounted for by two factors. In the first place, the conductive crustal layer may be altogether missing in western Kamchatka. Secondly, it should be noted that the west coast of Kamchatka where regions A and D are situated has thicker low ohmic terrigenous sediments. Tectonically speaking, the West Kamchatka Depression is prominent there. Assuming the conductive crustal layer to be available, its conductivity must be either lower than or similar to that of the sedimentary cover. If that is the case, the layer will not produce a minimum in the MTS curves. Both of these hypotheses should be tested by numerical modeling.

Consider region B as identified from the longitudinal curves (Fig. 7). The crustal layer is conspicuous here in the MTS curves. It is also well expressed in the transverse curves. We are therefore entitled to assert that the conductive crustal layer is available throughout region B. The region is situated in the Kamchatka–Koryak anticlinorium with a superposed volcanic belt. A formal interpretation of the longitudinal MTS curves for the region helps identify a zone that is as shallow as 15–20 km depth (the areas 10, 13, 14a, 14c, 15–17, 19, 22, 23). That zone is situated where the Main Kamchatka Fault occurs (Fig. 2). The nature of the zone

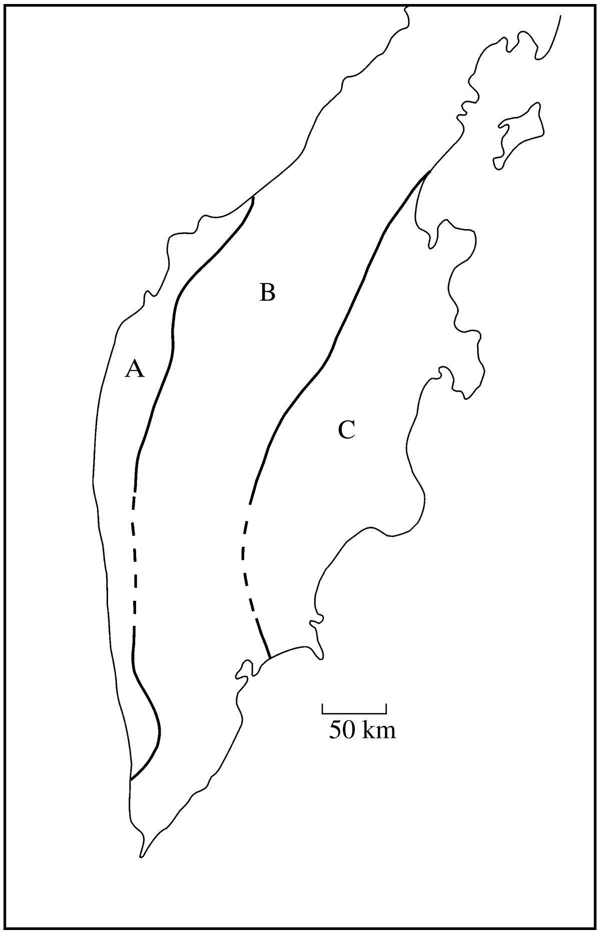

Fig. 7. Areas where the influence of the crustal layer is felt in longitudinal MTS curves. A and C: the crustal layer is not seen, B: the crustal layer is seen as a minimum in amplitude or phase curves.

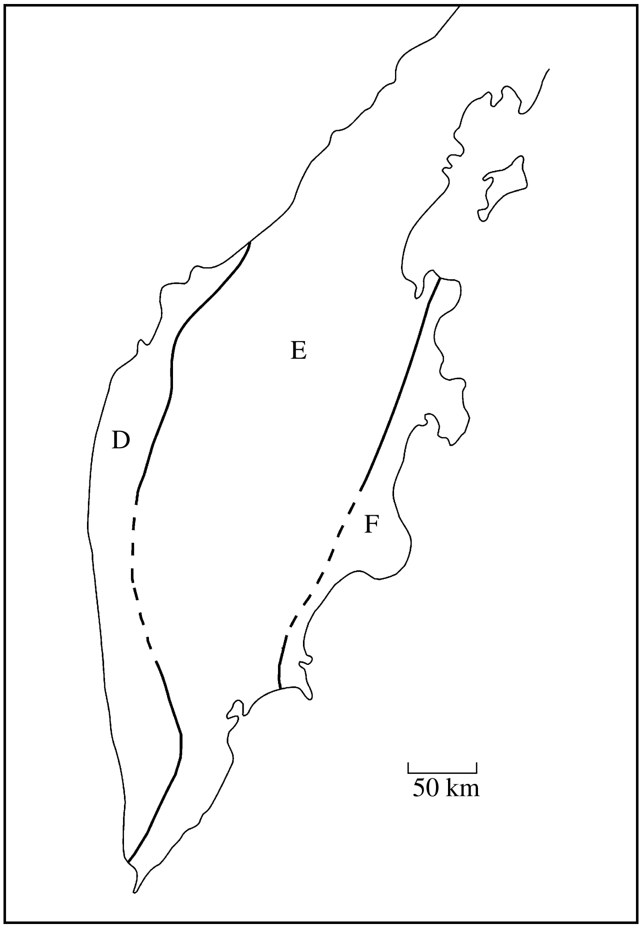

Fig. 8. Areas where the influence of the crustal layer is felt in transverse MTS curves. D and F: the crustal layer is not seen in the curves, E: the crustal layer is seen as a minimum in amplitude or phase curves.

could possibly be related to hydrothermal solutions and magma melts.

We now consider region E, where the conductive crustal layer is identified from the longitudinal curves (Fig. 8). The region covers much of the peninsula and is broader than region B. The difference calls for explanation. It is a known fact that the resolution capabilities of longitudinal and transverse curves in relation to deep conductors are different. The longitudinal curves have a greater resolution for deep conductors overlain by screening high ohmic crustal rocks. The curves are subject to the inductive influence of electric currents concentrating in a deep conductor. That influence affects the formal interpretation of longitudinal MTS curves in that the inferred crustal conductor is broader than that based on the transverse curves. In the case we are considering we have a reversed picture, the crustal layer derived from longitudinal curves being narrower than that based on the transverse curves.

A more graphic presentation is provided by Fig. 9 showing the difference between the maps of the crustal layer based on longitudinal and transverse curves. Two zones of difference can be seen. The one lies in the southwestern part of the area, while the other is identified as a band about 200 km wide in eastern Kamchatka. The former zone typically has minima in the longitudinal curves and no minima in the transverse ones. The difference is explainable by the induction effect caused by electric currents concentrating in the Golygino depression, which is filled with thicker low ohmic sediments [3]. The latter zone is characterized, as was noted above, by the presence of low frequency minima in the transverse curves and an absence of such minima in the longitudinal ones. Such a situation could arise in the lithosphere model for eastern Kamchatka involving transverse conductive zones [6, 7]. It is also necessary for the effect that the conductive zones should have extended shapes, i.e., their lengths should be a few times their widths. However, the zones should have limited widths, so they would not be seen in the

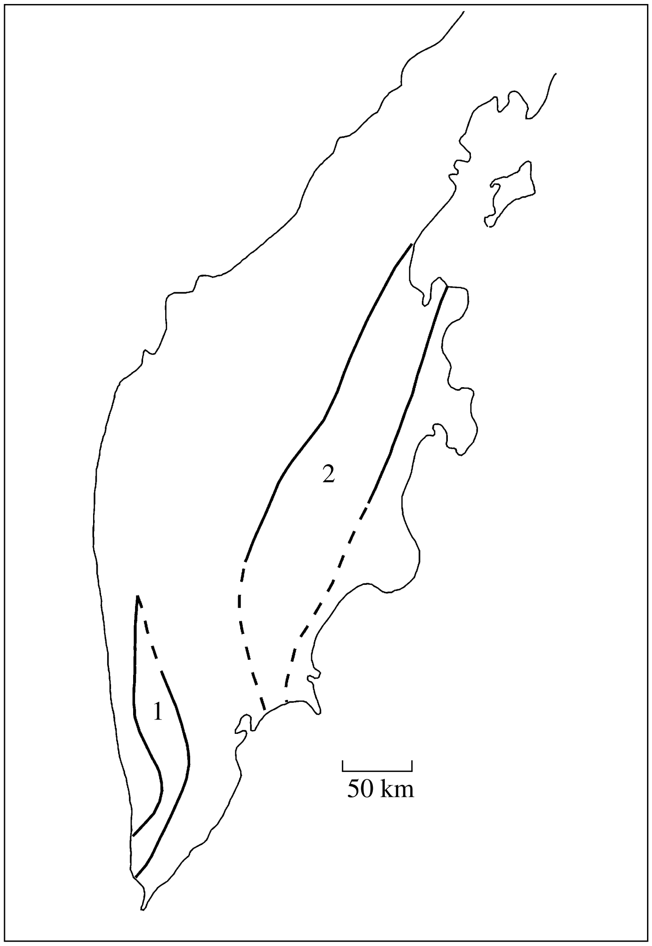

Fig. 9. Zones where the crustal layer is seen differently in longitudinal and transverse MTS curves: (*1*) the crustal layer is only seen in longitudinal curves, (*2*) only in transverse curves.

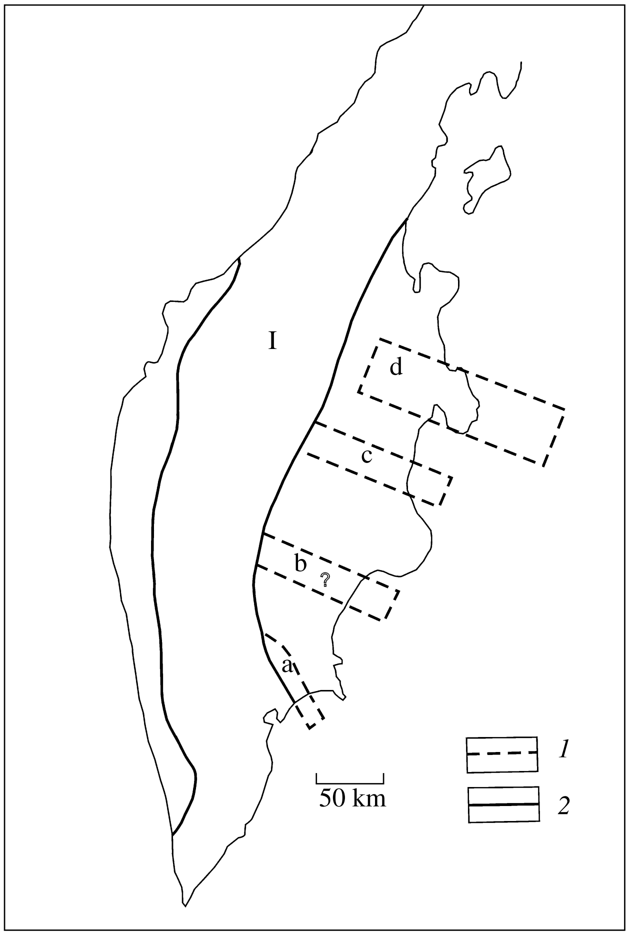

Fig. 10. A map of the influence of the crustal layer in longitudinal and transverse curves: (*1*) boundaries of area where the crustal layer is seen (*I*) in longitudinal and transverse curves, (*2*) boundaries of zones where the crustal layer is seen (*a*, *b*, *c*), the same for the lithospheric layer (*d*) in transverse curves.

longitudinal curves. Estimates based on 3D numerical modeling [7] show that the width should not exceed 50 km. With this width, the conductive zones must extend toward the east coast and beyond into the ocean. However, the transverse curves for zone F do not involve as well-pronounced minima as those for zone E. Numerical modeling has shown that this circumstance is due to distortions in the curves arising from the coast effect and because electric currents flow round the complex shapes of the eastern peninsulas of Kamchatka. It is due to these factors that the crustal layer is not seen in the transverse curves. We thus arrive at a model which involves the crustal layer (region B) extending along central Kamchatka, the layer being in contact with transverse conductive crustal zones (a, b, c) that have extensions into the ocean (Fig. 10). Somewhat to the north is the lithospheric conductive zone D, which has an oceanward extension for 200 km. That zone is situated on the extension of the Aleutian island arc [7]. The geoelectric model outlined above can be assumed as a starting point for inversion using 3D numerical modeling.

Now let us examine the effects of the asthenospheric conductive layer in the MTS curves. We have low frequency MTS surveys carried out along two lines in the period range between a few minutes and a few hours (Fig. 1). The mean curves of the regions where the low frequency MTS has been carried out are supplemented with apparent resistivity values in the period range 1500 to 15000 s. The low frequency branches have been displaced along the resistivity axis to make them coincide with the high frequency curve obtained by statistical averaging. We thus have composite longitudinal and transverse MTS curves that are free from local galvanic distortions. The low frequency branches of the composite longitudinal and transverse curves may have been affected by the *S* effect and a number of other effects. Especially great distortions occur in the curves situated near coastlines of complicated shape. The inter-

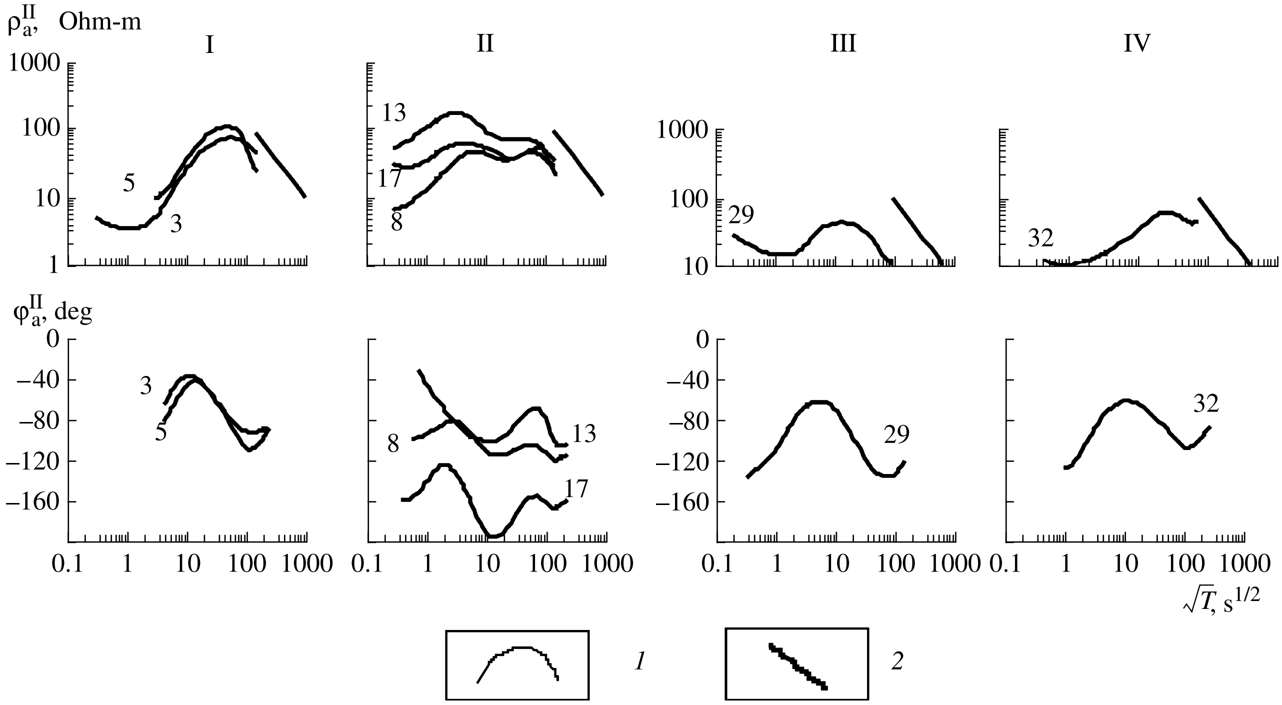

Fig. 11. Composite longitudinal curves when made to coincide with the standard curve of apparent resistivity. (I), (II), (III), (IV) denote curves relevant to zones with different deep conductivities: (*1*) MTS curve, (2) normal curve of apparent resistivity.

pretation of such MTS curves can only be possible by using 3D numerical modeling. Dealing with a qualitative interpretation so far, we have selected some individual longitudinal curves that are less subject to distortion at lower frequencies. To do this we used the numerical modeling of the Kamchatka MT field reported in [5].

The MTS curves are shown in Fig. 11. They are related to zones I, II, III, and IV, having differing conductivities at depth (Fig. 12). The amplitude curves for all these zones have for their right parts a descending branch that occasionally reaches a minimum. These low frequency branches are below the standard MTS curve. It is important that the phase curves have a minimum throughout the range of periods considered, which favors the existence of a conductive asthenospheric layer. The behavior of the top of that layer can roughly be assessed from the amplitude curves. The top ascends from 150 km depth in zone I to 70 km in zone III and descends toward eastern Kamchatka. This high of the asthenospheric layer is confined to an area of present-day volcanism. The asthenospheric layer is thought to be related to partial melting of ultrabasic rocks.

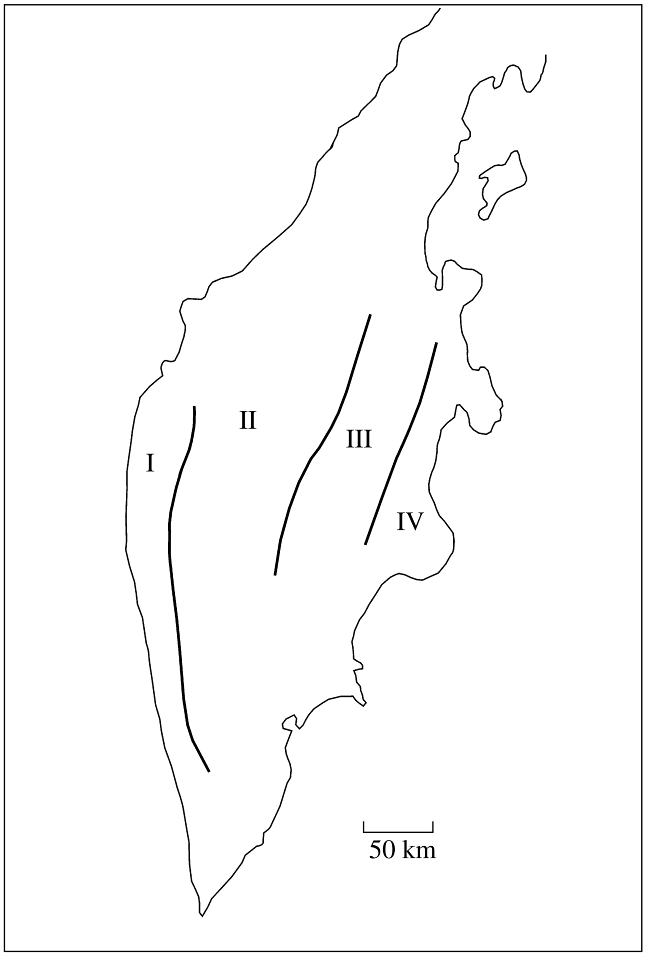

Fig. 12. Zones with differing depths to the conductive asthenospheric layer: (I) 150, (II) 100, (III) 70, and (IV) 120 km.

CONCLUSIONS

Our interpretation of MTS curves along and across the Kamchatka peninsula allows the separation of the induction and the *S* effect related to a high conductivity contrast in the upper layer by several orders of magnitude between the land and the ocean. The longitudinal and transverse amplitude curves are subject to a strong influence of local geoelectric heterogeneities. We have managed to suppress the influence of these heterogeneities with the help of conformal averaging.

A qualitative bimodal interpretation of mean longitudinal and transverse MTS curves was used to regionalize Kamchatka into regions having different crustal conductivities. The crustal layer is not seen in the MTS curves obtained in western Kamchatka. A region about 200 km wide and 1200 km long has been identified in central Kamchatka with the crustal layer affecting both longitudinal and transverse curves. There is a zone in the middle of that region where the crustal layer is located as little as 15–20 km below the ground surface and has an increased conductivity. That zone is confined to the Kamchatka–Koryak anticlinorium with the superposed volcanic belt at the base of which is the Central Kamchatka deep-seated fault. A region has been identified in eastern Kamchatka where the crustal layer is only seen in the transverse curves. The crust of the region is supposed to contain transverse conductive zones as wide as 50 km extending into the Pacific. Large areas of present-day volcanism occur in such zones. A conductive asthenospheric layer has been identified from mean longitudinal MTS curves, with the top of the layer rising the highest beneath the area of present-day volcanism, as inferred from some rough estimates.

This qualitative analysis of longitudinal and transverse MTS curves thus yields a model in which large centers of present-day volcanism in Kamchatka coincide with transverse conductive crustal zones and with the high of the asthenosphere extending along Kamchatka. The results of qualitative MTS interpretation call for some refinement using 3D numerical modeling of the magnetotelluric field.

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REFERENCES

1. Berdichevskii, M.N., Van'yan, L.L., Kuznetsov, V.A., et al., A Geoelectric Model for the Baikal Region, in *Geologo-geofizicheskie i podvodnye issledovaniya ozera Baikal* (Geological, Geophysical, and Underwater Studies of Lake Baikal), Moscow: In-t Okeanol. AN SSSR, 1979, pp. 126–141.
2. Berdichevskii, M.N., Dmitriev, V.I., Novikov, A.D., and Pastutsan, V.V., *Analiz i interpretatsiya magnitotelluricheskikh dannykh* (The Analysis and Interpretation of Magnetotelluric Data), Moscow: Dialog-MGU, 1997.
3. *Geologiya SSSR. Kamchatka, Kuril'skie ostrova. Geologicheskoe opisanie* (The Geology of the USSR. Kamchatka, Kuril Is.: A Geological Description), vol. 31, Moscow: Nedra, 1974.
4. Moroz, Yu.F., *Elektroprovodnost' zemnoi kory i verkhnei mantii Kamchatki* (The Electric Conductivity of the Crust and Upper Mantle in Kamchatka), Moscow; Nauka, 1991.
5. Moroz, Yu.F. and Kobzova, V.M., Physical and Numerical Modeling of the Kamchatka Magnetotelluric Field, *Vulkanol. Seismol.*, 1994, no. 2, pp. 86–98.
6. Moroz, Yu.F., Nurmukhamedov, A.G., and Moroz, T.A., A Deep Geoelectric Model for the Petropavlovsk Geodynamic Test Site, Kamchatka, *Fizika Zemli,* 2001, no. 6, pp. 58–66.
7. Moroz, Yu.F. and Nurmukhamedov, A.G., A Deep Geoelectric Model for the Junction Region between the Kuril–Kamchatka and Aleutian Island Arcs, *Fizika Zemli*, 2004, no. 6, pp. 54–67.
8. Eggers, D.E., An Eigenstate Formulation of the Magnetotelluric Impedance Tensor, *Geophysics*, 1982, vol. 47, pp. 1204–1214.

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