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Physical Modeling of the Magnetotelluric Field in the Petropavlovsk Geodynamic Site, Kamchatka

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The effects of surface resistivity inhomogeneities on magnetotelluric sounding (MTS) curves under the complex geologic conditions of the Site were examined. Three-dimensional models were used to imitate a resistivity structure close to the real one and to reveal the basic features in the MTS curves caused by the "coast" effect, by a transverse conductivity structure in the sediments, by the complex coastline, and by the presence of volcanoes. It is shown that MTS curves oriented along Kamchatka should preferably be used to study deep electric conductivity in the Site area. However, these curves are also affected by surface resistivity inhomogeneities. Low frequency distortions of MTS curves were estimated for different geoelectric conditions at the Site. These results can be used in the interpretation of practical MTS curves.

INTRODUCTION

The Petropavlovsk Geodynamic Site is one of the areas of high earthquake hazard in Kamchatka. Much detailed magnetotelluric sounding (MTS) work was done lately in this area to develop a resistivity model of the lithosphere which could serve as a basis for developing an optimal network of monitoring the electromagnetic field with a view to predicting large earthquakes and volcanic eruptions. The chief difficulty of interpreting MT soundings is to identify and correct possible distortions of the curves of apparent resistivity caused by surface geoelectric inhomogeneities. The Petropavlovsk Site includes the Pacific coast with its complicated shoreline including Shipunskii Peninsula and the Gulf of Avacha. There is a prominent transverse feature in the upper crust within the Site area, namely, the Avacha graben syncline filled with sediments of high conductivity [2].

Besides, there are several active volcanoes in the Site area: Avacha, Koryakskii, and others. Physical modeling was used to study the effects of the geoelectric inhomogeneities mentioned above on the behavior of the magnetotelluric field. Experiments were made using a tank facility of the Carpatian Division, Institute of Geophysics, Ukraine.

Two models were investigated because of the limited capacity of the facility. The models consisted of 22×15 cm concrete plates 7 cm thick. The plates were arranged in a "chessboard" pattern as compactly as possible in six rows on the metal bottom of the tank (five rows under the "sea"). The tank was filled with a salt solution for one model and with common water for the other. The plate layer had resistivities of 7 and 150 Ω m, respectively. The layer simulated the lithosphere. Where "land" should be, the plates were covered with a thin cement layer (1.5–2 cm) having a resistivity of about 5 Ω m. This layer simulated the sediments. The conductive sedimentary layer in the Avacha graben syncline was simulated by a layer of salt solution 0.07 m thick with a varying concentration. The solution had a resistivity of 0.2 Ω m in the first model and 1.3 Ω m in the second. The land had conical highs up to 0.03 m in height and 0.1–0.15 m in diameter; they simulated Avacha, Koryakskii, and other volcanoes. The seafloor topography in the oceanic part of the model was made in concrete. The basin was filled with a salt solution having a specific resistivity of 0.2 Ω m. A metal sheet to simulate a deep-seated conductor was placed at the base of the model at a depth of 44 cm.

In accordance with [1], the similarity factors were $K_L = 10^5$, $K_\rho = 1$, $K_T = 10^{10}$, and $K_S = 10^5$, where K_L, K_ρ, K_T, and K_S were scale factors for the size, resistivity, period, and conductivity, respectively. We simulated electromagnetic variations of periods between 1000 and 80 000 s using this installation whose frequency range was 0.1–8 MHz. The models simulated the sections in which the sediments had a resistivity of 5 Ω m and the water, 0.2 Ω m. The first model had a resistivity of 7 Ω m for the lithosphere and 0.2 Ω m for the conductive sedimentary layer in the graben syncline. The respective values in the second model were 150 and 1.3 Ω m.

These models were used to find out how MTS curves are distorted by the ocean, complicated coastline (Gulf of Avacha and Shipunskii Peninsula), a great resistivity contrast at the land–sea boundary, a conductive zone in the sedimentary-volcanogenic cover (Avacha graben syncline), and volcanic structures. The electromagnetic field was recorded at the stations marked in the map of Fig. 1. Electric and magnetic components were recorded for the *E* and *H* cases of a polarized field when the model was excited longitudinally (along Kamchatka) and transversely (across Kamchatka), respectively. In both of these cases we recorded a "background" MTS curve far from geoelectric inhomogeneities, i.e., nearly in a laterally homogeneous earth. Our "background" curves for *E*- and *H*-polarizations differed by 10–15%, which seems to have been caused by differences in the aerials that excited the electromagnetic field. Electromagnetic components were measured to within 5-7%.

The MTS curves generated with the first model clearly showed a rising left branch, a maximum, and a downgoing branch, produced by the sediments, the poorly conducting

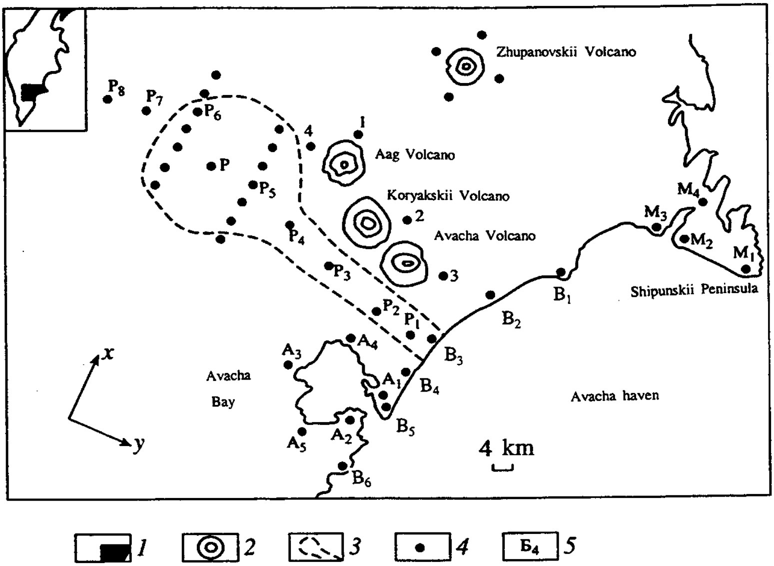

Figure 1 Location of magnetotelluric stations: *1* - Petropavlovsk Geodynamic Site in Kamchatka; *2* - volcanoes; *3* - outline of the Avacha graben; *4* - magnetotelluric stations; *5* - station code.

lithosphere, and the deep-seated conductor, respectively. The curves of this model yielded more information on the effects of surface geoelectric inhomogeneities, but this model simulated a resistivity structure that was significantly different from the real one. The second model was more optimal in this respect. Unfortunately, however, stable results were obtained in this model only for the downgoing low-frequency branches of MTS curves because of the limitations of the tank facility. In this frequency region the curves also provided information on the effects of geoelectric inhomogeneities in the upper layer. Comparison of MTS curves between the two models revealed that the results were qualitatively similar for the lower frequencies. For this reason we will discuss the data obtained with the first model in order to fully illustrate possible distortions in the MTS curves observed at the Site.

AVACHA GRABEN SYNCLINE

This feature was studied using the data acquired on two transverse and one longitudinal lines (Fig. 1). The example in Fig. 2 shows the curves of apparent resistivity measured

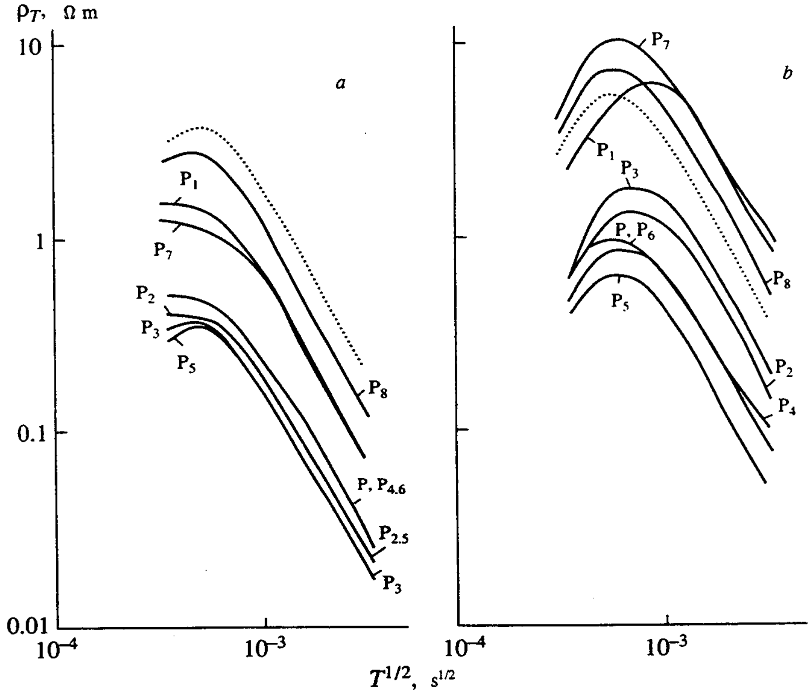

Figure 2 MTS curves (1) in the Avacha graben-syncline: *a*, *b* – longitudinal and transverse curves, respectively; 2 – "background" (normal) curves. The numbers of the curves correspond with the MTS station codes in Fig. 1.

along the longitudinal line. It is obvious that where *E*- and *H*-polarizations are present (longitudinal and transverse curves, respectively), most of the curves lie below the "background" (normal) ones. An exception is the transverse P_1 curve for the coastal zone which has higher resistivity relative to the "background" curve at lower frequencies. Also, resistivities higher by factors of 1.5–2 occur in the transverse curves recorded beyond the graben syncline at P_7 and P_8 stations. It should be noted that the longitudinal MTS curves in the graben syncline (except for curve P_1) are similar among themselves to within a few tens of percent. However, their resistivity in the downgoing branch is nearly an order below the "background" apparent resistivities, while the transverse MTS curves differ by factors of 1.5–2 in resistivity level. It is important to note that the phase curves for low frequencies are similar, even though both longitudinal and transverse amplitude curves are significantly divergent. The phase curves usually differ to within the measurement error.

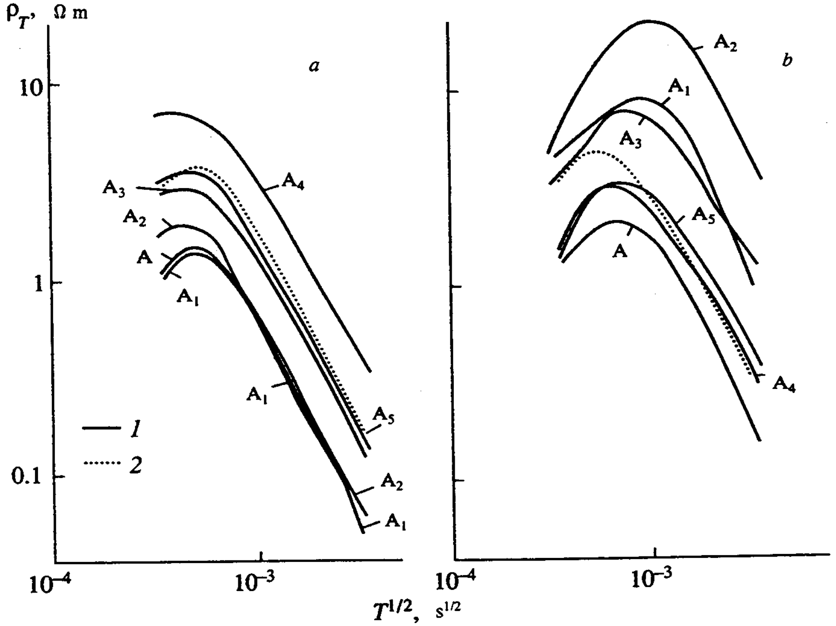

Figure 3 MTS curves in the Avacha Bay area. Notation as in Fig. 2.

This shows that the distortions in the curves are due to galvanic effects, a substantial contribution being apparently due to the S effect in the first place. However, neither a concentration of electric current in the conductive zone nor other effects can be ruled out. Especially noticeable is the "coast" effect in the transverse curves. This effect makes the apparent resistivity curves to be drawn upward along the S line, the maximum being displaced toward the lower frequencies. The "coast" effect is the most noticeable in the P_1 curve close to the ocean. It follows from the results of our physical modeling that the deep conductivity in the Avacha graben syncline area can best be studied using longitudinal MTS curves, which are less subject to the "coast" effect. It should however be remembered that a formal interpretation of these curves for both models may cause errors in deep conductivity reaching nearly an order of magnitude.

AVACHA BAY

The longitudinal and transverse MTS curves recorded in Avacha Bay are shown in Fig. 3. Their shapes vary notably. The transverse curves have their maxima displaced toward lower frequencies owing to the "coast" effect. Typically, the longitudinal MTS curves are less different in resistivity in the low frequency region. They are not more than 30% above or below the "background" curve. The transverse curves are more prone to the effect of the bay. We did not notice any regular patterns in the behavior of the amplitude curves relative to the bay position. The phase curves recorded there also point to the predominance of galvanic effects. These effects include the concentration of electric current in the bay. The study of deep conductivity in this area too should preferably rely on longitudinal MTS curves.

GULF OF AVACHA COAST

The MTS curves recorded along the coastline are presented in Fig. 4. The longitudinal curves lie both above and below the "background" resistivity, the discrepancies reaching 50%. This behavior can be explained by the galvanic effects caused by local changes in the coastline (the phases are within not more than 10–15% from the "background" curve, i.e., within the uncertainty of determination).

The transverse curves generally have higher low-frequency resistivities compared with the "background" curve, the differences being by factors of a few times. The maximum is displaced toward the lower frequencies. This behavior is related to the "coast" effect. However, the differences in resistivity level are probably due to local inhomogeneities, like in the case of the longitudinal curves. It seems that deep-seated conductivity in coastal areas is best studied using *E*-polarization curves as well. It should be borne in mind when doing so, however, that they may be distorted by local inhomogeneities. Distortions in this case can be as high as a few tens of percent, as can be judged from the second model.

SHIPUNSKII PENINSULA

The observations on the Shipunskii Peninsula were carried out at four stations (Fig. 1). The resulting longitudinal and transverse MTS curves are shown in Fig. 5. The longitudinal curves are seen to exceed the "background" curve by nearly 150–200% in resistivity level in the low frequency region. The transverse curves were affected by the "coast" effect, their maxima being displaced toward the lower frequencies. The curves are differently positioned relative to the "background" curve and do not show any regular pattern. The longitudinal and transverse curves involve a merely slight internal scatter. Here too, one may hypothesize the significant influence of galvanic effects. These include the electric currents flowing around the Shipunskii Peninsula and the *S* effect. The latter is clearly seen in the amplitude curves for the case of longitudinal excitation in the model (*E*-polarization), the Shipunskii Peninsula then acting transversely to the electric current. It can be seen from the second model, which is more realistic, that a formal interpretation

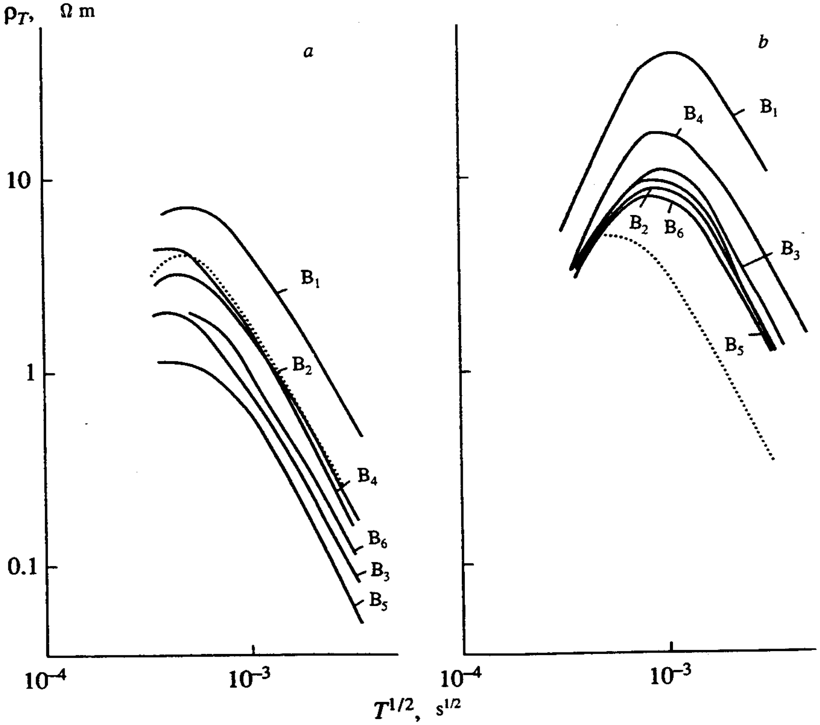

Figure 4 MTS curves for the coast of the Gulf of Avacha. Notation as in Fig. 2.

of longitudinal apparent resistivity curves will overestimate the depth to a crustal (upper mantle) conductor by factors of 3–5. Therefore the *E*-polarization curves for the Shipunskii Peninsula should be corrected by this amount of resistivity before interpretation.

VOLCANOES

MT sounding was carried out at distances of a few kilometers from the volcanoes (Fig. 1). Here, the transverse curves were influenced by the "coast" effect, as is the case of the other Site areas. The MTS amplitude curves near Zhupanovskii Volcano differ by a few tens of percent from the "background" curve, possibly owing to the effect of the volcanic edifice [3].

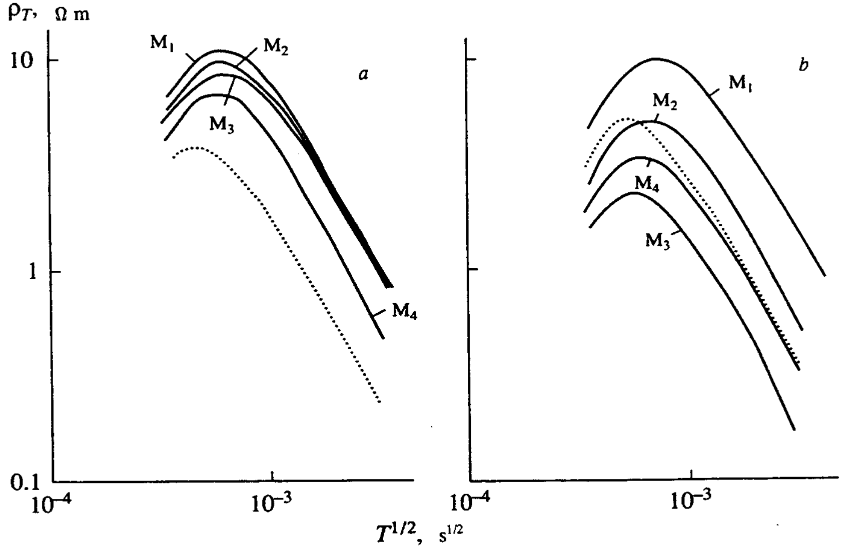

Figure 5 MTS curves for the Shipunskii Peninsula. Notation as in Fig. 2.

Consider the behavior of the MTS curves in the area of the Avacha-Koryakskii volcanic group (Fig. 6). Here, the longitudinal curves are less distorted. Curve 3, the nearest to the coastline, departs from the "background" more than the others. This departure might have been caused by the induction effect of electric currents in the shelf zone. The transverse curves show a greater distortion. Most of them lie below the "background" curve by resistivity values of 30-50%. This distortion was probably due to the induction of electric currents in the Avacha graben syncline. It follows from this present analysis that MTS longitudinal curves are more suitable for the study of deep conductivity in areas with volcanoes.

CONCLUSION

The results of our physical modeling of the magnetotelluric field show that crustal and upper mantle conductivity in the Site area should be studied using MTS longitudinal curves, which are less subject to the "coast" effect. The following features should be borne in mind.

1. The low frequency branches of MTS longitudinal curves within the Avacha graben syncline are below the "background" curve by nearly an order of magnitude in the Avacha

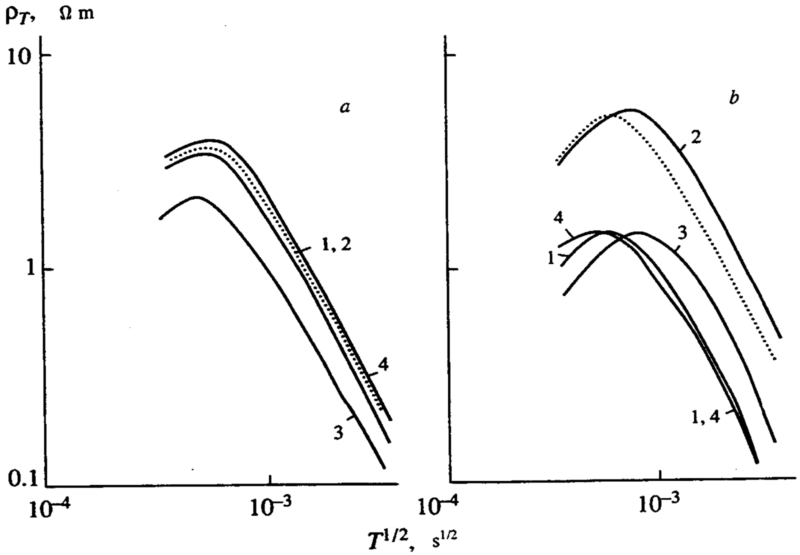

Figure 6 MTS curves for the Avacha-Koryakskii volcanic group. Notation as in Fig. 2.

graben and by factors of 3–5 on the Shipunskii Peninsula.

2. MTS longitudinal curves in the Avacha Bay area differ by not more than 30% from the "background" (normal) curve.

3. Near the coast the MTS longitudinal curves may be affected by geoelectric inhomogeneities related to local coastline changes to depart by nearly 50% from the "background" (normal) curve.

4. MTS longitudinal curves are very slightly distorted in the area of volcanoes. Here, the low frequency branches depart from the "background" (normal) curve by amounts well within the accuracy of apparent resistivity measurements.

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