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Maps of geoelectric sections of Turkey, Iran, Afghanistan, Pakistan, Korea, and Japan

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Abstract. Results of geoelectric mapping of some Asian countries with high seismic activity are presented. The methodology of the geoelectric mapping is considered, and the corresponding maps of geoelectric sections of Turkey, Iran, Afghanistan, Pakistan, Korea, and Japan are constructed on a scale of 1:5 000 000.

1 Introduction

Investigation of the electric properties (conductivity σ and dielectric permittivity ε) of Earth's crust of seismoactive areas is an important component of seismoelectromagnetism. This is because earthquakes as pulsive mechanical processes always occur in the Earth's crust or the upper mantle. They are accompanied or anticipated by mechanoelectromagnetic processes and the phenomena which are a subject of studies in seismoelectromagnetism. The electrical properties of rocks depend on many factors, such as the lithological and mechanical compositions, water content, temperature, and groundwater mineralization; therefore, it is unlikely to evaluate these parameters by theoretical calculations. They can be determined rather accurately by means of special in-situ measurements.

Electric properties (conductivity or geoelectric sections) maps of continents and countries constructed on various scales according to certain criteria can be regarded as initial information for models of the electrical condition of the upper crust. Well-known are the effective conductivity maps of continents (Morgan and Maxwell, 1965); the United States, Canada, Finland, Italy, Japan, and other countries (Fine, 1954; Ireland, 1961; Eliassen, 1957; Dosho et al., 1967; Tsydypov et al., 1979), which systematize basic data on the electrical properties of rocks in terms of a homogeneous model of the medium. These maps are made with the results of measurements of field strength of LF-MF broadcasting stations. They may be true at concrete frequencies of separate radio stations, but cannot be used in a wide range of frequencies. Works on the preparation of similar maps demand the presence of widely developed network of radio stations and greater expenses.

The electric inhomogeneous geological medium distorts the amplitude-phase structure of an electromagnetic field. As bedding of the Earth's crust exerts a significant influence on the structure and level of an electromagnetic field there was a necessity of taking account of this factor. An essential increase in accuracy of calculations of the electromagnetic field in a wide frequency band (from VLF and up to MF-SF) became possible with the use of predictive maps of geoelectric sections (GES), that account for the layered structure of the underlying medium. These maps reflect the areal distribution of various GES types, with the electrical resistivity ρ_j (one is the inverse of the conductivity $\sigma_j=1/\rho_j$), dielectric permittivity ε_j and thickness h_j specified for each layer of GES. These parameters enable the calculation of values of surface impedance δ, attenuation function W and field strength E in a wide range of frequencies. These values are necessary for the prediction of electromagnetic wave propagation conditions.

The conductivity map of the world, compiled by Morgan and Maxwell (1965), now fails to meet practical requirements because it is constructed using the model of a homogeneous underlying medium. Significant divergences of conductivity values from their map with measurements are actually observed in some areas (Bashkuev, 1996), with electrical boundaries not coinciding with real electrical and geological boundaries. This calls for the construction of a new predictive map of geoelectric sections of continents of the world. So the purpose of this paper is to construct the maps

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of GES of Turkey, Iran, Afghanistan, Pakistan, Korea, and Japan, necessary for calculations of propagation of wideband electromagnetic emissions.

2 Method of geoelectric mapping and processing of the information on electric properties of rocks.

By a geoelectric model of the underlying medium we usually understand its description via a family of parameters. They are expressed by the functions of coordinates convenient for the calculations of the electromagnetic field. The elementary geoelectric model of the underlying medium is the model, in which its different regions are characterized by its own effective conductivity σ (effective resistivity $\rho_\sim$) not dependent on depth. The model with horizontally layered structure of the separate regions is more realistic. This model of the underlying medium at a local point describes the GES differentiated in terms of the electrical resistivity ρ_j, permittivity ε_j, and thickness h_j of each layer (Tsydypov et al., 1979; Bashkuev, 1996). It is realized in the form of maps of parameters of GESs. Different geoelectric models of the underlying medium, depending on purpose, frequency and criterion of accuracy, are constructible from the map. The effect of the underlying medium on the electromagnetic field is usually incorporated through the complex value of the surface impedance δ, which is defined by the electrical parameters and the structure of the rocks.

The construction of a predictive map of GES parameters is meant here as the determination of the surface distribution of various GES types and the estimation of the resistivity ρ_j and thickness h_j of individual layers of the section throughout the mapped area on the basis of a limited amount of filed (archival) geological data or measurement results. The problem reduces to the determination of the GES type (e.g., $\rho_1>\rho_2$ or $\rho_1<\rho_2$) of a homogeneous region and its boundaries and to the statistical estimation of the parameters ρ_j and h_j. The GES map provides a generalized image of the real geological situation, and its reliability depends on the detail of observations and their generalization in accordance with the chosen scale. (In cartography, the term "generalization" refers to the selection of the most essential features and their generalization (sensu lato) in accordance with the purpose, subject, and scale of the map).

The main source of information on the parameters ρ_j and h_j of upper crust horizons were vertical electrical soundings (VES) data. The extensive use of VES method in the geoelectric mapping was favored by good agreement between values of the surface impedance modulus and phase obtained by direct measurements by a method of radioimpedance sounding (RIS) and VES-derived calculations, as well as by the absence of frequency dispersion of the conductivity of thawed rocks in a frequency range of up to 5 MHz (Bashkuev, 1996). The convergence of the VES and RIS results confirms the validity of combining these methods for investigating the electrical parameters of the layered underlying medium in the VLF-LF-MF ranges of electromagnetic waves. As a result, it is possible to use numerous archival VES data, thereby significantly accelerating GES prediction within large regions and reducing their cost (Tsydypov et al., 1979; Bashkuev, 1996; Dorzhiev et al., 1987).

The initial data when constructing the predictive GES maps are,

1. the geological map of Eurasia of scale 1:5 000 000 under Markovsky's edition (1975)
2. archival and published materials of geoelectrical researches in Turkey, Iran, Pakistan, and Afghanistan, in deserts of Central Asia, in mountain ranges Pamir and Caucasus
3. and also results of the electroprospecting works carried out on analogues of territories of Japan and Korea - island Sakhalin and the south of Primorski Krai (Dosho et al., 1967; Tsytsyshivili, 1980; Homilius, 1969; Beljaevsky, 1961; Kobayashi, 1959).

When preparing the GES maps, archival geophysical materials of industrial geological association "Abroad Geology", the geology departments of Georgia, Turkmenistan, Tadjikistan are widely used.

These maps incorporated the data derived from experimental investigations by VES and RIS methods in the territory of Asia in 1971–2007 in Buryat Scientific Center of the Siberian Branch of the Russian Academy of Sciences.

The Geological Survey of Russia (the former USSR) has the All-Russian Geological Fund, and in its archives they store all reports on the geological-geophysical works, performed by the Russian experts in the territory of Russia and other countries. On each planetable of scale 1:1 000 000 there is a scheme of geological-geophysical investigations of territory with the indication of the geological report number. In each report there is the section of geophysical works containing materials of electroprospecting works with an exact topographical locating of VEZ profiles and curves of apparent resistivity ρ_a. As a rule, curves of ρ_a have been interpreted in terms of 2–4 layered horizontal-layered model of medium, and the geological description of complexes of rocks is also resulted. Thus, in geological reports there are a large number of already interpreted VES results topographically connected to the location and geologically connected to different complexes of rocks. At the first stage the expert-geophysicist carries out collection and generalization of a large quantity of experimental data about electric properties of rocks, structure and genesis, of the specified region. At the second stage statistical treatment of parameters of geoelectric sections is performed. At that the correct geological estimation of sections and the subsequent grouping of data on complexes of rocks in view of their lithological composition, genesis and age are of decisive importance. The statistical law of distribution of electric parameters is determined for a choice of methods of processing of the input information, computation of average values, an estimation of a scale of gradation of ρ_j and h_j.

The probabilistic model of GES most fully corresponds to the nature of studied object, namely, the layered underlying medium (Yakupov, 1968; Mel'nikov, 1977; Veshev, 1980; Troyan and Hayakawa, 2002). The hypothesis about lognormal distribution law of electrical resistivity ρ_j and thickness of a layer h_j of rocks is accepted at statistical treatment of archival data about electric properties of rocks. We have checked this hypothesis in quantity of parameters of asymmetry $A_{\lg\rho_j}$ and an excess $E_{\lg\rho_j}$ on an example of the most widespread and typical lithological complexes of Asia (Table 1).

The knowledge of distribution laws of parameters of geoelectric sections ρ_j, h_j has allowed us to choose objective criteria of statistical treatment of archival VES data. In particular, the most probable values of a surface impedance δ of the layered medium are calculated by estimations of the average of distribution of parameters ρ_j and h_j of geoelectric section layers. On the basis of the presented results it is possible to recognize that the use of logarithmic scales at constructing of predictive maps of GESs is valid.

Studying the influence of various factors on electric properties of rocks in a wide range of frequencies is an important problem at predicting of GES parameters and constructing of maps of underlying medium electric properties of the large regions.

As a result of the analysis and generalizations of a large quantity of VES data received in the territory of Asia, we have revealed regularities in the distribution of electric properties of rocks depending on a geological structure, age, jointing and porosity of rocks, water saturation and a mineralization of underground waters.

GES parameters of mesozoic and cenozoic sediments are basically defined by granulometric composition, a degree of water saturation and a mineralization of underground waters (Table 2).

Quorternary sediments are developed in middle latitudes of Asia almost everywhere. Their composition is various and includes pebblestones, crushed rocks, sands, sandy loams, loams and rarely clays and silts of various genesis. Eolian sands compose fields of the significant sizes in arid deserted-steppe areas of Asia. They are mainly light- and medium-grained sands and sandy loams. They compose barchans, dunes and hillocks. Thickness of sands reaches 15–20 and more meters. GES of eolian sands are two-layered with the relation $\rho_1 > \rho_2$. The top layer is presented by dry sands, and bottom layer – by damp sands. Resistivity of dry sands varies from 470 up to 2500 Ω·m at the average value equal to 1000 Ω·m. Resistivity of damp sands changes from 50 up to 290 Ω·m and on the average 120 Ω·m. Average thickness of the top horizon of dry sands is 3.5 m, and one of the bottom horizon of damp sands is about 10–13 m. Electric properties of loose sediments are defined basically by their granulometric composition, a degree of humidity and a mineralization of underground waters. Electric properties of crystal rocks (metamorphic and magmatic) practically do not depend on their petrographic composition, and they are defined by a degree of jointing of rocks, their water content and a mineralization of underground waters. The crystal rocks possessing a generality of structural position and hydro-geological conditions, have, as a rule, close values of electrical resistivity, as is shown in Table 3. The most widespread crystal rocks of middle latitudes of Asia are granitoids, composing large massifs within the area of mountain structures. GES of granitoids are mostly three-layered type ($\rho_1 < \rho_2 < \rho_3$), where the top horizon is composed by loose eluvial-diluvial formations, average horizon – by fractured, sometimes water-bearing granites, and bottom horizon – by monolithic rocks.

Table 1. Results of check of a hypothesis about lognormal distribution of ρ_j values of rocks.

Lithological complexes	$\overline{\lg\rho_j}$	$A^*_{\lg\rho_j}$	$E^*_{\lg\rho_j}$	$\frac{A_{\lg\rho_j}}{\sqrt{6/M^*}}$	$\frac{E_{\lg\rho_j}}{2\sqrt{6/M}}$
Quorternary sediments	2.32	0.19	−1.04	0.55	−1.44
Coal-bearing sediments	1.7	0.67	1.14	1.85	1.58
Volcanogenic formations	2.51	0.19	−1.17	0.52	−1.63
Mesozoic granites	2.51	0.32	−0.62	0.88	−0.86
Paleozoic granites	3.0	0.58	−0.13	1.61	−0.19

* $A_{\lg\rho_j}$, $E_{\lg\rho_j}$ – asymmetry and an excess of data sampling of ρ_j, M – amount of sampling.

The GES parameters of key sites (individual rock types) were estimated from a limited data sample on the basis of statistical processing of the initial ρ_j and h_j data set. The construction of ρ_j and h_j histograms enabled the determination of the ρ_j and h_j distribution patterns and in several cases allowed us to eliminate blunders in their estimation. The GES map was constructed on the basis of a limited amount of initial data that are very irregularly distributed over surface, which precluded formal interpolation and extrapolation with the required degree of detail and accuracy. In such a situation, we used the method of analogies, which is common in the Earth sciences. Prediction of ρ_j and h_j values relied on the study of geoelectric features in a particular region and detailed examination of the key and prediction areas. The work was done in the following order. The most probable ρ_j and h_j parameters of upper crust were determined in a key area. The similarity between the key and prediction areas suggested from their geological and geophysical characteristics allowed us to extend the ρ_j and h_j values obtained at the key site to the entire study area with similar properties.

Table 2. Electrical resistivity of volcanogenic-sedimentary formations of middle latitudes of Asia.

Lithologic structure	Number of measurements	Limits of changes ρ, Ω·m	Average value $\overline{\rho}$, Ω·m
Alluvial sediments			
1. Pebblestone	33	180–5000	984
2. Sand with gravel and pebble	45	100–530	225
3. Argillaceous sand	66	40–300	98
Quorternary sediments			
1.Gravel, pebble	135	120–3000	510
2. Sand with gravel	73	20–1390	270
3. Argillaceous sand	66	18–275	70
4. Sandy clay	48	18–75	35
5. Clay	36	12–30	20
Neogene sediments			
1. Gravel, pebble	49	23–700	210
2. Sand	53	60–3000	310
3. Argillaceous sand	89	20–300	70
4. Sandy clay	75	10–110	28
5. Clay	62	2–26	9
Mesozoic sediments			
1. Coal-bearing Cretaceous sediments	74	20–192	51
2. Volcanogenic-sedimentary strata	23	20–690	150
3. Triassic-Jurassic volcanogenic complex	132	100–1620	325
4. Terrigeneous Cretaceous sediments	226	2–520	34

Table 3. Electric resistivity of crystalline rocks of middle latitude of Asia

Degree of jointing	Composition of sediments, age of intrusions	Number of measurements	Limits of changes ρ, Ω·m	Average value $\overline{\rho}$, Ω·m
Paleozoic sediments				
1. Monolithic	Volcanogenic	7	930–2600	1655
	Volcanogenic-sedimentogene	19	390–2500	1140
	Terrigene	38	400–3050	1245
2. Fractured	Volcanogenic	10	200–900	365
	Volcanogenic-sedimentogene	11	120–500	270
	Terrigene	35	200–800	435
3. Fractured, water-bearing	Volcanogenic	17	40–220	85
	Volcanogenic-sedimentogene	10	90–200	135
	Terrigene	65	35–200	100
Intrusive formations				
1. Monolithic	Devonian	4	190–3000	1190
	Permian	6	1280–5000	2930
2. Fractured	Cambrian	24	230–1500	895
	Devonian	14	420–1400	690
	Permian	9	500–1500	665
3. Fractured, water-bearing	Cambrian	22	23–500	135
	Devonian	32	20–250	85
	Cambrian	6	55–185	120
	Permian	17	50–290	160

Fig. 1a. The predictive map of geoelectric sections of Turkey.

3 Maps of GES and their discussion

The subject of our study, the upper crust of territory of some countries of Asia (Turkey, Iran, Afghanistan, Pakistan, Korea and Japan), is characterized by a significant spatial inhomogeneity of electrical properties of rocks. According to seismic division into districts, territories of the specified countries of Asia are located in areas with the high degree of potential seismic danger. The vast area of territory and very wide range of geoelectric conditions required combined investigations involving scientific analysis and generalization of both published and archival data, analytical and numerical calculations, and field experiments.

The GES maps of Turkey, Iran, Afghanistan, Pakistan (on a scale of 1:5 000 000) are given on Figs. 1a, b and c, and those of Korea and Japan are presented in Figs. 2a and b. The predictive GES map of Turkey, Iran, Afghanistan, Pakistan, covering an area of 3 880 000 km^2, contains 7 GES types; the maps of Korea and Japan, covering an area of 590 000 km^2, contain 4 types of one- to four-layer geoelectric sections.
The analysis of geoelectric maps has shown that small-scale maps usually have 5–7 steps of (ρ_j, h_j), and splitting into intervals depends in many respects on experience of the researcher and is processed with the knowledge of general set and statistical laws of distribution of (ρ_j, h_j). For the territory mapped it was expedient to choose a simple enough scale of predicted parametrers (ρ_j, h_j), considering a non-uniform network of electroprospecting works and predictive character of a map.

Information on GES maps is expressed in codes defining the resistivities ρ_j and thicknesses h_j of layers on a logarithmically uniform scale. The logarithm of the discretization interval for ρ_j and h_j is 0.333. The scale of ρ_j and h_j has three gradations per decade. Denoting the step number by N and using the formulas

$$\rho_j = 10^{0.333(N-0.5)} \text{ (in } \Omega\cdot\text{m)},\ N=0 \sim 15 \quad (1)$$

$$h_j = 10^{0.333(N-3.5)} \text{ (in m)},\ N=1 \sim 15 \quad (2)$$

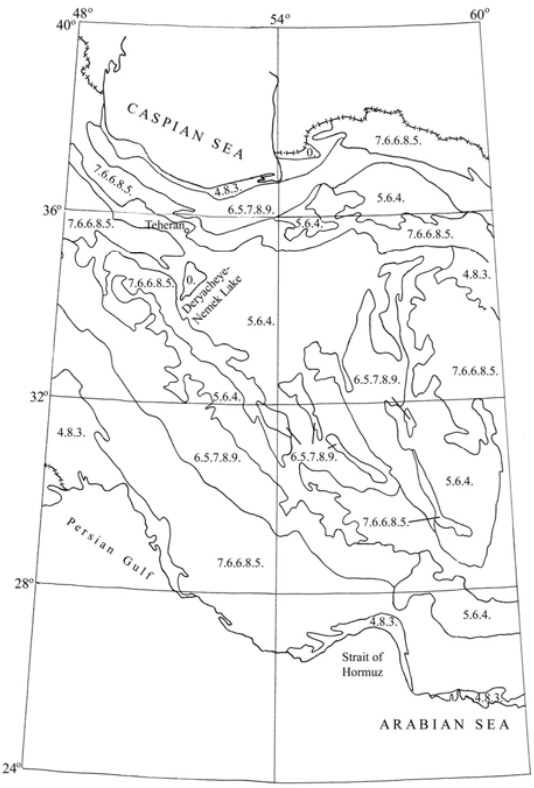

Fig. 1b. The predictive map of geoelectric sections Iran.

Fig. 1c. The predictive map of geoelectric sections of Afghanistan and Pakistan .

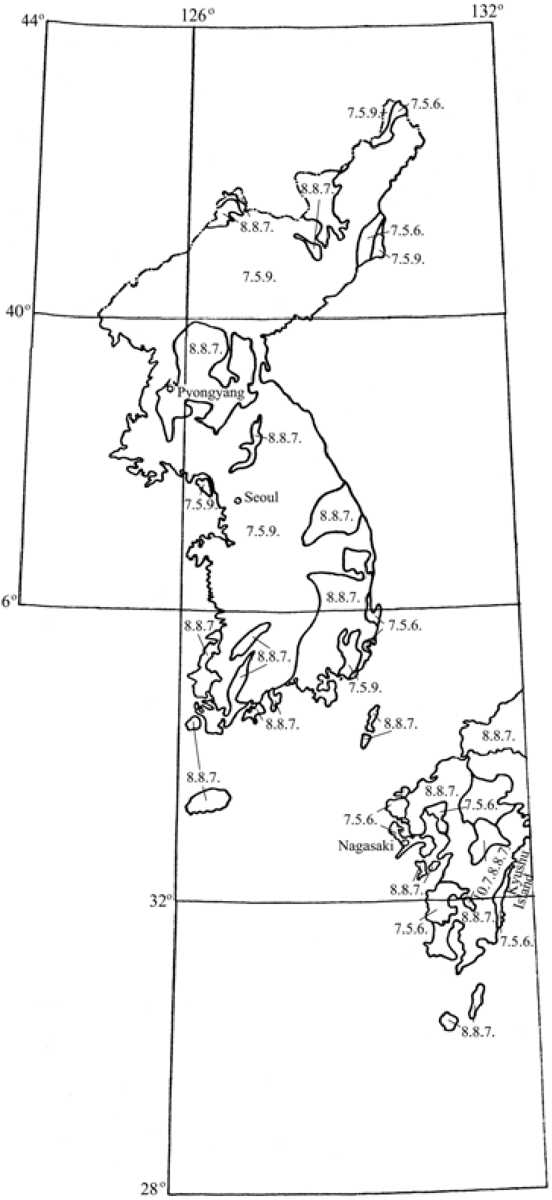

Fig. 2a. The predictive map of geoelectric sections of Korea.

we calculated the median values of ρ_j and h_j (Table 4).

Fig. 2b. The predictive map of geoelectric sections of Japan.

Due to the limited amount of experimental data, the GES maps were constructed on a small scale (1:5 000 000). As a basis, we used the geological 1:5 000 000 map of Eurasia and the map of Morgan and Maxwell recommended by the International Radio Consultative Committee (CCIR). According to the map by Morgan and Maxwell, Turkey, Iran, Afghanistan, and Pakistan have only two conductivity $\sigma\,(\sigma=1/\rho)$ gradations. The general background of territories of these countries is $3{\cdot}10^{-3}$ S/m (ρ=333 Ω·m). Japan has two gradations (10^{-2} and $3{\cdot}10^{-3}$ S/m) (ρ=100 Ω·m, ρ=333 Ω·m), with the general background of its territory being 10^{-2} S/m (ρ=100 Ω·m). Korea also has two gradations (10^{-2} and 10^{-3} S/m) and a general background of 10^{-3} S/m (ρ=1000 Ω·m). Frequency dependences of the surface impedance in the range 10–1000 kHz for inferred geoelectric sections have calculated asmaps. Figure 3a and b illustrates the frequency dependences of the modulus δ and phase φ_δ° of the surface impedance on the GES maps data. The surface impedance of an n-layer medium was calculated with the formula $\delta^{(n)}=\delta_1\cdot Q^{(n)}$, which is convenient for numerical calculations (Tsydypov et al., 1979; Bashkuev, 1996). Here, δ_1 is the surface impedance of a homogeneous medium with the parameters of the first layer, and $Q^{(n)}=F(f,\rho_j,\varepsilon_j,h_j)$ is the correction factor accounting for the underlying crustal layers. The expression for the correction factor is,

$$Q^{(n)}=\frac{1-R_{12}^{(n)}\cdot\exp\left(-i2k_{1z}h_1\right)}{1+R_{12}^{(n)}\cdot\exp\left(-i2k_{1z}h_1\right)}, \tag{3}$$

where

$$R_{j(j+1)}^{(n)}=\frac{\delta_j\alpha_{j+1}^{+}-\delta_{j+1}\alpha_{j+1}^{-}}{\delta_j\alpha_{j+1}^{+}+\delta_{j+1}\alpha_{j+1}^{-}}$$

Table 4. The map codes (e.g., 9.7.8. . . .) signify the following: the first number denotes the step on the resistivity scale for the first layer (defining its ρ_1 value), the second number denotes the step on the layer thickness scale (h_1), the third and subsequent numbers denote the same parameters for the second and subsequent layers. The permittivity of the layers was set at ε_j=10.

Step number	Median value ρ_j, Ω·m	Median value h_j, m
0	0.68	–
1	1.47	0.147
2	3.16	0.316
3	6.8	0.68
…	…	…
10	1470	147
11	3160	316
…	…	…

is the coefficient of reflection on the interface between the layers with numbers of j and j+1;

$$\alpha_j^{\pm}=1\pm R_{j(j+1)}^{(n)}\exp(-i2k_{jz}h_j);$$

$$k_{jz}=k_0\sqrt{\varepsilon_{jk}-\sin^2\Theta};$$

$$k_0=2\pi/\lambda;$$

$$\delta_j=\sqrt{\varepsilon_{jk}-\sin^2\Theta}/\varepsilon_{jk},$$

for

$$j=n\ R_{n(n+1)}^{(n)}=0,\quad \alpha_n^{\pm}=1;$$

$$\varepsilon_{jk}=\varepsilon_j+i60\lambda\sigma_j$$

is related complex dielectric permittivity; h_j is thickness of layer number j; Θ is angle of incidence of the plane vertically polarized wave on the "Earth-air" interface. The monochromatic electromagnetic wave is assumed to vary with time as $\exp(-i\omega t)$. Recurrent expressions showed above allow calculating frequency dependences of surface impedance of multi-sectional media. The GES maps with frequency independent parameters of individual layers are found to be convenient for the interpolation of a surface impedance on frequency. They form a basis for constructing maps of the surface impedance δ, which enable us to calculate electromagnetic fields in the VLF-LF-MF ranges. The coordinates dependence of δ is chosen in the form of piece-homogeneous function. In this case the problem of calculations of an electromagnetic field from GES map is reduced to finding the boundaries of inhomogeneities and δ values on homogeneous sites. The analysis of the impedance modulus $|\delta|$ and phase φ_δ° shown in the GES maps reveals a significant range of their variation. For example, the values of $|\delta|$ at a frequency of 10 kHz vary from 0.001 to 0.014, and the impedance phase, from −30° to −57°; the respective variation ranges at 1000 kHz are 0.006 to 0.207 and −17° to −50°. With taken account of the topography and woods, the GES maps make it possible to determine such an important characteristic of the electromagnetic wave process as the field attenuation function W within a wide range of electromagnetic waves. The W values in the model of a multisection impedance propagation path are determined by solving numerically the Hufford or Feinberg integral equation (Dembelov, 2003). The accuracy of predicting the electromagnetic field strength is ±(15∼30)% (Tsydypov et al., 1979; Bashkuev, 1996; Dorzhiev et al., 1987).

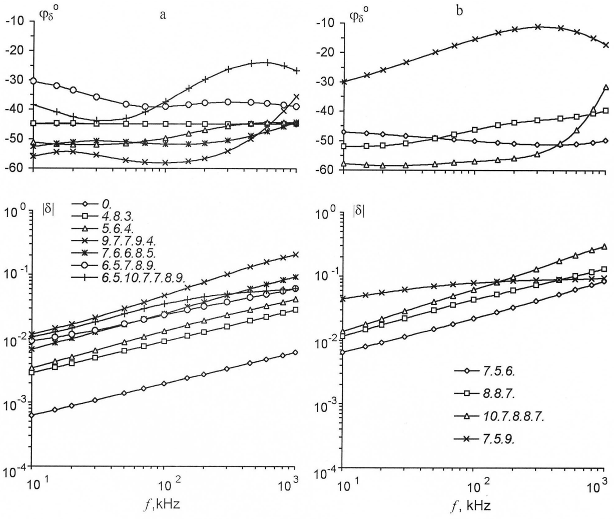

Fig. 3. The frequency dependences of the modulus $|\delta|$ **(a)** and phase φ_δ° **(b)** of the surface impedance for GES types in Turkey, Iran, Afghanistan, Pakistan, Korea and Japan.

Geoelectric mapping showed that the transition from one geological section to another is accompanied by a change in electrical properties, i.e., geoelectric and geological boundaries usually coincide. Therefore, the outlines of areas with the same GES at times change so unusually over the map area. The explanation of this phenomenon is simple: geoelectric boundaries are drawn along geological boundaries of basic complexes of rocks. The majority of the boundaries coincide with the geological boundaries and are reliably delineated; some boundaries are indistinct and drawn tentatively because they fall within wide zones of gradual transition from one GES type to another.

As regards the amount of available empirical data, our GES maps on a scale of 1:5 000 000 covering an area of 4 470 000 km^2, fall under the category of predictive or schematic maps. They share all the features inherent in small-scale maps. When working with them, one should keep in mind the resolution of small-scale maps and their inability to image some, occasionally essential, details of the geoelectric situation that are clearly visible in maps of larger scales. One should consider that the contours bounding a given GES type always include little areas of a different GES type.

The predictive maps comprehensively characterize the regional patterns of spatial distribution of areas with different GES types on the territory of the middle-latitude seismoactive belt of Asia. These are general maps as regards their scale and specialized maps with respect to their content. The maps generalize the vast and diverse empirical data. They show that their underlying premises and the method of their construction ensure an adequate reflection of the relationship between the electrical properties of the upper crust and various geological structures.

4 Conclusions

We try to summarize several important points of this paper in the followings.

1. There exists a regular connection between resistivity and lithological and hydrogeological parameters of rocks, their structure, and the GES spatial variation pattern. The resistivity of a particular rock type is a random quantity with a lognormal distribution. The contours of the areas with similar electrical properties coincide with geological boundaries.

2. On the basis of objective classification of geoelectric structures of the Eart's crust and the interpretation of the vertical electrical sounding data, a new effective method of physical-statistics prediction of the geoelectric sections of layered natural media basic types are developed.

3. The outcomes of the research of electrical properties of natural layered media by complex radio- and geophysical methods as a whole have led to the creation of a new generation of maps of electrical properties of separate countries of Asia, which take into account a layered structure of terrestrial crust. The maps of GES of Turkey, Iran, Afghanistan, Pakistan, Korea and Japan of scale 1:5 000 000 are created. The area distribution of various types of geoelectric sections with the indication of a electrical resistivity ρ_j and thickness h_j of each horizon is reflected on the GES maps.

4. The GES maps can find an application in calculating the propagation of VLF-L F-MF electromagnetic emissions, for solving the tasks of the seismoelectromagnetic prognosis of earthquakes. Taking into account the layered structure of the underlying medium, these maps are capable of increasing the accuracy in electromagnetic field calculations by 1.5–3 times as compared to the Morgan-Maxwell map.

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