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MIGRATION OF THE SCALAR COMPONENTS OF THE ELCTROMAGNETIC FIELD IN GEOELECTRIC PROBLEMS[1]

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In previous papers [1-4] we have developed a method of electromagnetic migration, which is a generalization of previous methods of seismic migration [5-8] to the case of variable electromagnetic fields. The migration transformations can be used to transform the electromagnetic fields observed at the ground surface into a "geoelectric image" of the geological section, as well as to identify the positions of conductive bodies associated with hydrothermal phenomena or the presence of potential ore-containing zones. In the two versions of the method presented in our earlier papers [1-4], in order to perform the migration transformations it is necessary to measure all the components of the electromagnetic field at the ground surface in the areal version, or to determine three components (E_x, H_y and E_z or H_x, E_y and H_z) in the vertical section version. However, in geoelectrical investigations in the field, one only measures a single component of the electromagnetic field (either electrical or magnetic). It is thus very important to develop migration transformation methods based on a single component of the field, which we will attempt to do in the present paper.

2. The electromagnetic migration technique involves the extension of the electromagnetic field into the lower half-space in the inverted time $\tau = T - t$, where t is the ordinary (forward) time and T is the field observation time interval on the ground surface. To construct a migration procedure based on a single field component, we first consider the problem of extension of the scalar field components, known at the boundary S of a uniform region D, into the interior of this region. We assume that the quasisteady-state electromagnetic field E, H is generated by a source located outside region D, which has constant electrical conductivity σ and magnetic permeability μ. Then any scalar component U of the electromagnetic field within region D will satisfy the equation

$$\Delta U - \mu\sigma \partial U/\partial t = 0. \tag{1}$$

We multiply the left and right sides of the Eq. (1) by the fundamental Green function G^d for the diffusion equation [4, 9], satisfying the equation

$$\Delta G^d + \mu\sigma \frac{\partial G^d}{\partial t} = \delta(\mathbf{r} - \mathbf{r}')\delta(t - t'), \tag{2}$$

where δ is the delta function.

We integrate these products over the time from $-\infty$ to $+\infty$ and over the entire region D and use the second Green formula to convert the volume integral to a surface integral over the boundary S of the region. Then, by virtue of Eq. (2), we obtain

$$U(\mathbf{r}', t') = \int_{-\infty}^{\infty} \iint_S \left(U \frac{\partial G^d}{\partial n} - G^d \frac{\partial U}{\partial n} \right) dS dt, \tag{3}$$

where $\mathbf{r}' \in D$, and n is the exterior unit vector normal to the surface S,

$$G^d = G^d(\mathbf{r}, t \,|\, \mathbf{r}', t') = -\frac{(\mu\sigma)^{1/2}}{8\pi^{3/2}(t' - t)^{3/2}} \exp\left(-\frac{\mu\sigma |\mathbf{r} - \mathbf{r}'|^2}{4(t' - t)} \right) \kappa(t' - t). \tag{4}$$

where κ is the Heaviside function.

Note that Eq. (3) remains valid if instead of the function G^d in the expression under the integral on the right side of Eq. (3) we use the sum of G^d and an arbitrary solution g, of the homogeneous equation in region D,

$$\Delta g + \mu\sigma \frac{\partial g}{\partial t} = 0, \quad \mathbf{r} \in D. \tag{5}$$

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We thus may write

$$U(\mathbf{r}', t') = \int_{-\infty}^{\infty} \iint_{S} \left(U \frac{\partial(G^d + g)}{\partial n} - (G^d + g) \frac{\partial U}{\partial n} \right) dS dt. \tag{6}$$

Equation (6) is the basis of our theory of migration transformations of the scalar components of the electromagnetic field.

3. Consider the following geoelectrical problem. Assume that some scalar component U^0 of the electromagnetic field generated by an arbitrary unsteady-state source switched on at instant $t = 0$ is specified on the horizontal ground surface $z = 0$, in the time interval from 0 to T. The soil is assumed to have a constant conductivity σ except in some anomalous region D with an excess conductivity $\Delta\sigma(\mathbf{r})$. The magnetic permeability is everywhere equal to that of a vacuum, μ_0. As noted above, we neglect displacement currents, i.e., we are dealing with a quasisteady field model. The problem is to define the anomalous region D, with excess conductivity $\Delta\sigma > 0$, can be determined by migration transformations of the anomalous values of the electromagnetic field vectors. But we find that this problem can also be solved in terms of the individual scalar components of the field.

We make the following definition. The migration field U^m for a given scalar component U^0 of an anomalous electromagnetic field is the field that satisfies the conditions

A) $U^m(\mathbf{r}, \tau)\big|_{z=0} = \begin{cases} U^0(\mathbf{r}, T-\tau)\big|_{z=0}, & 0 \leqslant \tau \leqslant T, \\ 0, \quad \tau < 0, \ \tau > T, & \end{cases}$

where $\tau = T - t$;

B) $\Delta U^m(\mathbf{r}, \tau) - \mu\sigma \dfrac{\partial U^m(\mathbf{r}, \tau)}{\partial \tau} = 0$ for $z \leqslant 0$;

C) The field $U^m(\mathbf{r}, \tau)$ tends to zero rather rapidly at infinity in the lower half-space; $U^m(\mathbf{r}, \tau) \to 0$ (the rate at which the field U^m must drop off will be determined below).

Thus, the problem of finding the migration field reduces to the extension of the anomalous field U^m from the horizontal ground surface ($z = 0$) into the lower half-space in inverted time τ.

To solve this problem, we designate an arbitrary point $\mathbf{r}'$ in the lower half-space and construct a sphere of radius R around it. We denote by O_R the part of the sphere lying in the lower half-space, by S_R the part of the plane $z = 0$ falling within the sphere, and by D_R the region bounded by the surfaces $S_R \cup O_R$.

We can find the field $U^m(\mathbf{r}', \tau')$ from Eq. (6) by converting from the forward time t to the inverse time τ:

$$U^m(\mathbf{r}', \tau') = \int_0^{\tau'} \iint_{O_R \cup S_R} \left(U^m \frac{\partial(G^d + g)}{\partial n} - (G^d + g) \frac{\partial U^m}{\partial n} \right) dS d\tau, \tag{7}$$

where G^d is the green function for the diffusion equation,

$$G^d = G^d(\mathbf{r}, \tau \mid \mathbf{r}', \tau'). \tag{8}$$

We assume that the auxiliary function g tends to zero at infinity along with U^m in such a way that the integral over the part of the sphere O_R also tends to zero as $R \to \infty$, while the integral over S_R tends to the value of the integral over the entire horizontal plane $z = 0$. Thus, taking the limits as $R \to \infty$, we obtain

$$U^m(\mathbf{r}', \tau') = \int_0^{T} \iint_{-\infty}^{+\infty} \left(U^m \frac{\partial(G^d + g)}{\partial z} - (G^d + g) \frac{\partial U^m}{\partial z} \right) dS d\tau. \tag{9}$$

The right side of Eq. (9) contains both the migration field on the earth's surface, which we know from condition A), and its vertical derivative $\partial U^m/\partial z$, which we have not specified. To eliminate the need to specify $\partial U^m/\partial z$ on the earth's surface, we follow the usual procedure of seismic holography [5, 6] and choose an auxiliary fucntion g such that

$$(G^d + g)\big|_{z=0} \equiv 0. \tag{10}$$

For this purpose, we need only to specify g in the form

$$g(\mathbf{r}, \tau \mid \mathbf{r}', \tau') = -G^d(\mathbf{r}, \tau \mid \mathbf{r}'', \tau') = \frac{(\mu\sigma)^{1/2}}{8\pi^{3/2}(\tau' - \tau)^{3/2}} \exp\left(-\frac{\mu\sigma \mid \mathbf{r} - \mathbf{r}'' \mid^2}{4(\tau' - \tau)} \right) \kappa(\tau' - \tau), \tag{11}$$

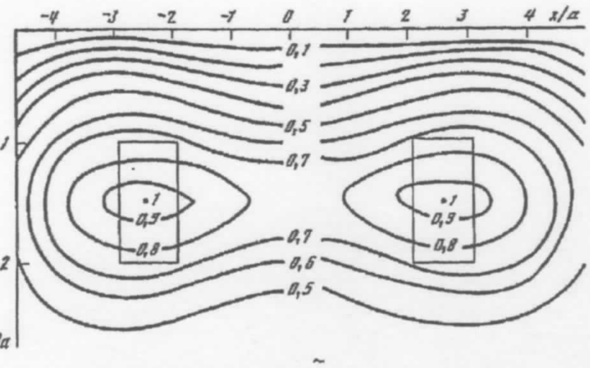

Fig. 1. Diagram of migration field $\tilde{H}_x$ in vertical plane.

where the point r'', in which the function G is defined, is positioned symmetrically to r' with respect to the ground surface $z = 0$.

Thus, on the right side of Eq. (9), the second term in the expression under the integral vanishes, and, by virtue of condition A) we obtain

$$U^m(\mathbf{r}', \tau') = \int_0^{\tau'} \iint_{-\infty}^{+\infty} U^0(\mathbf{r}, T - \tau) K(\mathbf{r}, \tau \mid \mathbf{r}', \tau') dS d\tau, \tag{12}$$

$$K(\mathbf{r}, \tau \mid \mathbf{r}', \tau') = \frac{(\mu\sigma)^{3/2} z'}{8\pi^{3/2}(\tau' - \tau)^{5/2}} \exp\left(-\frac{\mu\sigma \mid \mathbf{r} - \mathbf{r}' \mid^2}{(\tau' - \tau)}\right) \kappa(\tau' - \tau). \tag{13}$$

Let us replace the variable τ in Eqs. (12) and (13) with T-t; then,

$$U^m(\mathbf{r}', T - t') = \int_{t'}^{T} \iint_{-\infty}^{+\infty} U^0(\mathbf{r}, t) \tilde{K}(\mathbf{r}', t' \mid \mathbf{r}, t) dS dt, \tag{14}$$

where $\tilde{K}$ is the function conjugate to K:

$$\tilde{K}(\mathbf{r}', t' \mid \mathbf{r}, t) = K(\mathbf{r}', -t' \mid \mathbf{r}, -t) = K(\mathbf{r}, t \mid \mathbf{r}', t').$$

We have thus derived an integral equation that enables us to perform migration transformations of any scalar components of the electromagnetic field. It is readily seen that the migration fields that we have derived have all the properties of the so-called "pseudomigration" fields that we introduced earlier [4, 10], provided there is suitable choice of the migration parameter $\sigma^m = c^m\sigma$, where c is the migration constant equal to 0.25. The most important of these properties is that the extrema of the migration fields define the location at depth of the region — with excess electric currents in the conductivity nonuniformity D.

As an example, we consider a two-dimensional model generated by a planar E-polarized field in the quasisteady approximation. A homogeneous half-space with a conductivity σ_n = 0.01 (ohm·m)$^{-1}$ contains two local nonuniformities of square cross section $a \times a$ and of conductivity σ_a = 1 (ohm·m)$^{-1}$ located at the same depth $h = a$ and at a distance l = 4 a from each other. It will be seen from Fig. 1 that the extrema of the migration field $\tilde{H}_x^m$ calculated for the migration parameter $\sigma^m = 0{,}25\sigma_n$ at the optimum time, overlap exactly the centers of the nonuniformities. The choice of the optimum time is made by the standard procedure [3, 4].

Thus, we have developed a migration method for scalar components of the electromagnetic field that can be used to reconstruct the locations of geoelectric nonuniformities from the measured components of the magnetic or electric field.

This method decreases the number of needed observations significantly below that required in the general method of electromagnetic migration. The latter also requires measurements of vectors of the unsteady-state electromagnetic field. The method can be used to interpret electromagnetic soundings made with a powerful pulse current generator and to process standard geophysical investigations by transient field sounding technique.

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A MODEL OF TWO-SCALE, TWO-LEVEL PLATE TECTONICS AND INTRAPLATE CRUSTAL DEFORMATION[1]

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The theory of plate tectonics, which has successfully explained many global patterns of the structure and evolution of the lithosphere, encounters serious difficulty in the discussion of regional-scale geological processes. This is true in particular of the problem of intraplate and interplate deformations occurring in zones of collision of large continental plates. In essence, the entire Alpine-Himalayan belt is a zone (widening from west to east) of occurrence of such intraplate deformations. To explain its existence in terms of plate tectonics, the presence of about 20 additional microplates has been invoked [1], assuming that these microplates were generated by fragmentation of the marginal zones of large continental plates during collision. The kinematics of the relative displacements of the microplates have been analyzed by the standard method, using Euler's theorem. A slightly different approach to the problem is based on the theory of plastic deformations of the marginal zones of colliding plates [2].

There are two main objections to the above method of describing deformations in the zones of collision of large plates. The first, which has been stated often in the literature, involves the existence of an obvious limit on the number of microplates into which a plate can be fragmented. Indeed, if we postulate that to be regarded as a plate of any kind (including a microplate), a segment of the lithosphere must have horizontal dimensions an order of magnitude greater than its thickness, then in the case of the continents, whose lithosphere is about 200 km thick, we cannot regard as a plate any region measuring less than 1000 km. But to explain the deformations in the western Alpine-Himalayan mobile belt, microplates measuring roughly 200 km on a

[1]Translated from: Skhema dvukhmasshtabnoy dvukh"yarusnoy tektoniki plit i vnutriplitnyye deformatsii zemnoy kory. Doklady Akademii Nauk SSSR, 1988, Vol. 302, No. 1, pp. 62-67.

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