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Classification of Archaeological Targets by the Use of Temporary Magnetic Variations Examination

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Many buried magnetized archaeological and geological objects producing significant magnetic anomalies(for instance, ancient furnaces, weapon, agricultural targets and high-magnetized basalts) may be classified without high-expensive excavations. Such a classification may be conducted on the basis of comprehensive studying temporary magnetic variations over these objects. It is especially significant for archaeogeophysical investigations in the areas of world recognized religious and cultural artifacts where all excavations are forbidden (Eppelbaum, 2010).

Yanovsky's (1978) investigations laid the foundation of the magnetic variations utilization for separation of disturbing objects with high magnetic susceptibility (not depending on intensity of the studied magnetic anomalies). However, these procedures are inapplicable for studying low-intensive and negative magnetic anomalies, where an influence of residual magnetization may be sufficient one. At the same time the approach presented below may be used for investigation of the nature of magnetic anomalies with arbitrary intensity and origin.

In the common case (we consider for simplicity that anomalous object is a sphere) the value of magnetic variations η could be estimated using the following expression (Finkelstein and Eppelbaum, 1997):

$$\eta = \frac{f\left(P\right) + \delta H_a + \delta H_o}{\delta H_o}, \tag{1}$$

where induction parameter $P = \alpha\sqrt{\kappa\gamma\omega}$ (Wait, 1951), H_o is the initial field of magnetic variations, H_a is the anomalous component of magnetic variations, κ is the magnetic susceptibility, γ is the electric conductivity, ω is the frequency of geomagnetic variations, and α is the radius of the sphere.

For the approximate estimation of possible values of anomalous geomagnetic variations (AGV) over sphere within some domain T, we will use an expression of the anomalous vertical magnetic component Z for any point M (x, y, z) in the external space (for the case of vertical magnetization) (Nepomnyaschikh, 1964):

$$Z_a = \frac{\left(\kappa_1 - \kappa_2\right) Z_0 + \left(1 + 4\pi\kappa_2\right) J_{RZ}^{e}}{1 + 4\pi\kappa_2 + N_{zz}\left(\kappa_1 - \kappa_2\right)} \cdot \frac{\partial^2}{\partial z^2} \int\limits_T \frac{d\tau}{r}, \tag{2}$$

where $\kappa_1$is themagnetic susceptibility of the object, κ_2 is the magnetic susceptibility of the host medium, $Z_0$is the vertical component of Earth's magnetic field, $J_{RZ}^{e}$is the effective component of the vector of residual magnetization, N_{zz} is the coefficient of the demagnetization, $\frac{\partial^2}{\partial z^2} \int\limits_T \frac{d\tau}{r}$ is the second derivative of the z-axis of the integral $\int\limits_T \frac{d\tau}{r}$, and $d\tau$ is the volume element of the domain T.

Taking into account that in most cases $\kappa_2$isnegligible compared with $\kappa_1$of magnetic objects, as well as the fact that the residual magnetization of J_{RZ}^{e} when exposed to an alternating field does not create additional fields, values κ_2, and J_{RZ}^{e} in Eq. (2) can be practically ignored in the evaluation of magnetic fields from objects. Then for variations of the vertical component of the magnetizing field with objects having a high content of ferromagnetic materials according to Eq. (2) we will observe abnormal values of the magnetic variations (Finkelstein et al., 2012):

$$\delta Z_a = \frac{\kappa_1 \delta Z_0}{1 + N_{zz}\kappa_1} \cdot \frac{\partial^2}{\partial z^2} \int\limits_T \frac{d\tau}{r}, \tag{3}$$

where δZ_0 is some increment (both positive and negative) of Z_0.

Solving the expression $\frac{\partial^2}{\partial z^2}\int\limits_T \frac{d\tau}{r}$ in Eq. (3) for each particular body shape, we find that the anomalous geomagnetic variations from the body of spherical form will be determined by the expression

$$\delta Z_a = \frac{4.2a^3\kappa_1\left[\left(2h^2 - x^2\right)\sin J - 3hx\cos J\right]}{\left(1+\kappa_1 N_{ZZ}\right)\left(h^2+x^2\right)^{5/2}}\delta Z_0, \tag{4}$$

where J is the angle between the magnetization vector and the horizon, a is the radius of the sphere, x is the current coordinate, and h is the depth to its center. For a spherical body the parameter N_{zz} was assumed as $\frac{4}{3}\pi$ (Nikitsky and Glebovsky, 1990).

In accordance with Eq. (4) the relationship between abnormal to normal variations (η) were calculated:

$$\eta = \frac{\delta Z_a + \delta Z_0}{\delta Z_0} \tag{5}$$

and plotted versus the magnetic susceptibility of a sphere with a radius a (Finkelstein et al., 2012).

From Eq. (5) follows that at small values of δZ_a the ratio becomes close to unity, for example granitoids - basalts, and each value of the differential function (Δ^{1-2}) of geomagnetic variations between the two points (1 and 2) will be close to the values of the background level, unless there are other factors creating AGV of different origin.

The developed methodology includes: (a) estimation of influence of electric conductivity for studied objects and surrounding medium; (b) selection of the most optimal frequencies for observation of magnetic variation effect ($f(P)$ should seek to the value less than 0.6); (c) revealing relationship between observed variations (their intensity and form) and parameters of disturbing objects (their geometric and physical characteristics); (d) calculation of magnetic susceptibility. Results obtained in the items (c) and (d) are applied (together with other available geological, archaeological, environmental and geophysical data) for classification of studied ancient targets.

These procedures have been successfully tested in several ore deposits of the Middle Asia (mainly in Kazakhstan) and Caucasus. Some preliminary experimental observations over ancient iron-containing targets were carried out in Israel (Eppelbaum et al., 2010).

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