ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 415A, No. 6, pp. 935–939. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © I.I. Glukhikh, V.I. Utkin, Yu.G. Astrakhantsev, N.A. Beloglazova, V.P. Starovoitov, 2007, published in Doklady Akademii Nauk, 2007, Vol. 415, No. 5, pp. 673–677.

GEOPHYSICS

Variations of the Geomagnetic Field in Boreholes

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Received February 9, 2007

DOI: 10.1134/S1028334X07060244

The results of monitoring of the measurements of the geomagnetic field in boreholes carried out for the first time are presented in this article. Variations (perturbations) of the geomagnetic field caused mainly by auroras were recorded in the satellite borehole of the Kola superdeep borehole SG-3. The amplitude–frequency analysis was performed, and the measurements were compared with the ground-based measurements. Similar measurements were carried out in the Ural superdeep borehole SG-4. The recorded variations are related mainly to the class of S_q variations. The performed amplitude–frequency analysis of variations measured at the surface and in the borehole allowed us to determine the depth of internal sources of high- and low-frequency components of S_q variations.

Variations of the geomagnetic field are the object of research beginning from the moment of instrumental measurements of the Earth's magnetic field [1]. Geomagnetic variations of different periods are a natural source of electromagnetic methods for studying the Earth's deep structure [2, 3, and others]. Investigation of solar–terrestrial correlations yielded a large amount of data on the correlation between geomagnetic variations and solar activity [4]. In [5, 6], geomagnetic variations are considered a source of magnetization to estimate the nature of magnetic anomalies. A large amount of research is related to variations of the geomagnetic field as forerunners of earthquakes [7]. At present, the correlation between magnetic storms and seismicity is being studied [8]. All these investigations are based on data obtained from land-based observations of the Earth's magnetic field.

A STM-120 borehole magnetometer-variometer was developed at the Institute of Geophysics, Ural Division of the Russian Academy of Sciences, for measurements of the variations of the geomagnetic field in boreholes [9]. The technical characteristics (measurements of three components, sensitivity not less than ±2.0 nT, measurement cycle 6 s, operation temperature up to 120°C) of the device are not worse than flux-gate magnetometers of the observatory type. The available software makes it possible to calculate all components and the absolute value of the magnetic field during measurements taking into account the zero offset and variations in the transformation coefficients of primary transformers. We can also average the series of measurements, correlate with the time interval, and exclude random outliers of the measurements. The device was tested in the Kola Superdeep Geolaboratory in 2000–2002 and the Ural superdeep borehole in 2004.

During the period from November 23 to 28, 2002, recording of geomagnetic field variations in the Kola Superdeep Geolaboratory was carried out in full measure near the borehole bottom and in the satellite borehole at a depth of 560 m. The borehole instrument was located in the zone of mass picrite porphyrites. The overlying sequence was mainly represented by massive diabases, picritic porphyrites, and basic tuffs with a small amount of sulfide dissemination. Magnetic susceptibility was equal to (100–150) · 10^{-5} SI u. [10]. Five perturbations of the geomagnetic field probably related to local phenomena (auroras) were recorded during this period (Fig. 1). The amplitudes of perturbations of the vertical component were equal to 350–900 nT, and perturbations of the horizontal component were equal to 500–950 nT. A comparison of the data measured in the borehole and at the surface (Fig. 1) showed that amplitudes of the vertical and horizontal components of the geomagnetic field (they are not shown in order to avoid complication of the graph) lack any significant differences. However, one can note a significant variation in declination in both amplitude and direction. This fact confirms the validity of the amplitude-spectral analysis based on the Fast Fourier Transform algorithm [11], which demonstrated the lack of any appreciable difference in amplitudes of the vertical and horizontal components of the geomagnetic fields recorded at the surface and in the borehole. Since this effect is observed over the entire frequency spectrum (from diurnal to short periods), the influence of the overlying rock sequence should be excluded. It is possible that the

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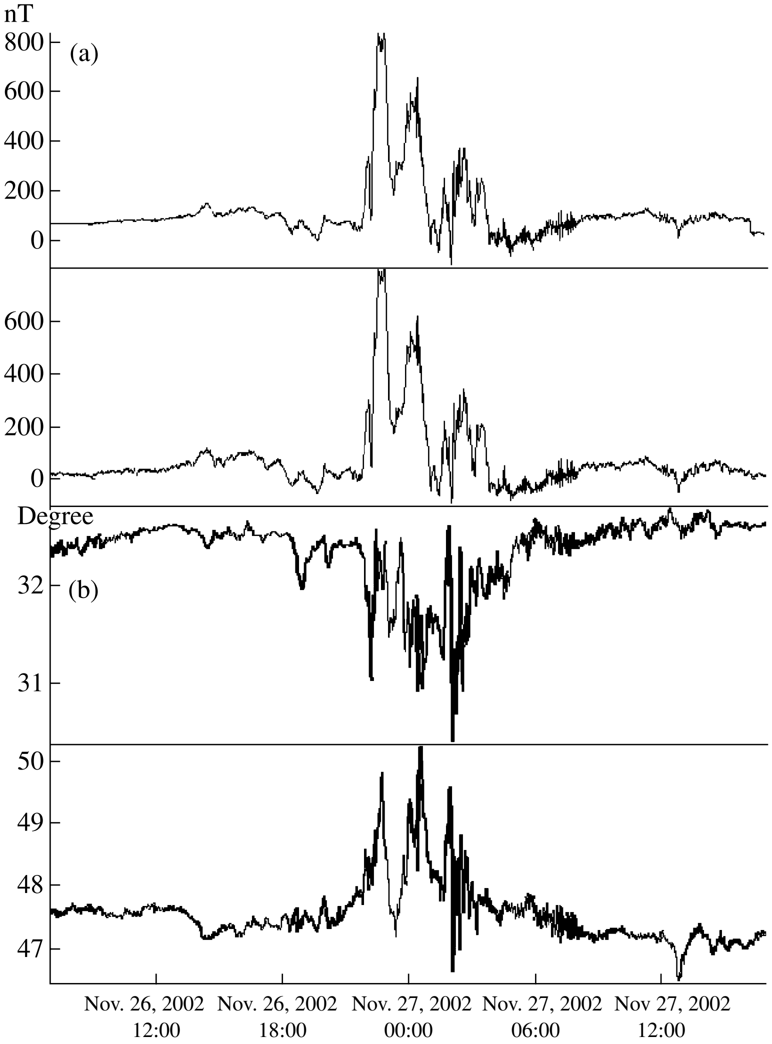

Fig. 1. Records of geomagnetic field variations November 24–27, 2002, in the Kola Superdeep Geolaboratory. (a) Comparison of the vertical component measured in the borehole and at the surface; (b) the same for magnetic declination.

structure of the aurora-mediated magnetic field at the observation point is influenced by human impact: the derrick of the satellite borehole and the adjacent case of borehole SG-3.

Variations of the geomagnetic field in the Ural superdeep borehole were measured following a similar (surface–borehole) scheme. The borehole instrument was located at a depth of 5970 m, where the surrounding material was composed of massive rhyodacites with magnetic permeability (1500–2000) · 10^{-5} SI u. [12]. Variations recorded from October 23 to 26, 2004. According to the observations at the Arti observatory, these days were calm and unperturbed. The recorded variations belong to class S_q. Figure 2 shows results of the recording of the vertical component of the geomagnetic field variations at the Arti observatory near the borehole bottom and at a depth of 5970 m. The data about the variations in the geomagnetic field components are given in Table 1.

The amplitude–frequency analysis was carried out according to the method described above (an example of the vertical component is shown in Fig. 3). The low-frequency part (the sum of harmonics from 1 to 15) of the geomagnetic field varies in the following range: the horizontal component is equal to 30 nT at the Arti observatory, 32 nT near the borehole SG-4 bottom, and 40 nT at a depth of 5970 m. The vertical component is equal to 12, 25, and 25 nT, respectively. The high-frequency part (the sum of harmonics from 16 to 40) of the variations are equal to 8, 15, and 30 nT, respectively, for the horizontal component and 3, 15, and 30 nT, respectively, for the vertical component.

We can determine the depth to the source of the internal component of variations based on the following prerequisites: application of the method and data of the discrimination of S_q variations into components

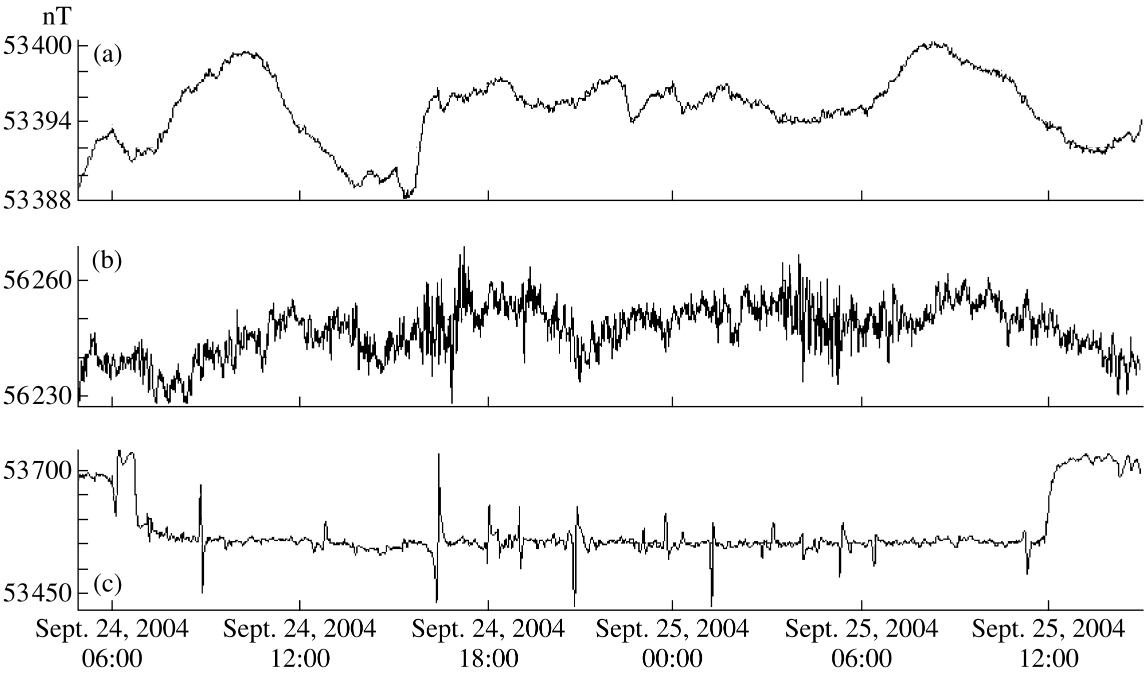

Fig. 2. Records of the vertical component of geomagnetic field variations September 24–25, 2004. (a) Arti observatory; (b) land-based instrument in Ural superdeep borehole; (c) borehole instrument in the Ural superdeep borehole, depth 5970 m.

induced by external and internal sources (with respect to the Earth's surface) based on calculations of external and internal magnetic potentials [2, 13]; application of this method to observations of the surface–borehole system assuming that a linear current is the source of internal variations.

The depth of the source is estimated at approximately 14 and 7.5 km based on the low-frequency and high-frequency components of variations, respectively. A comparison of these data with the electric conductivity of the Earth's crust in the Middle Urals [14] and data of deep seismic sounding [12] shows that a crustal conducting layer (thickness up to 12 km and electric conductivity 240 Ohm · m) is distinguished at a depth of 12 ± 2 km. A layer of low velocities is also found in this depth interval. At a depth of 8.0 km, a contact between layers with low and high velocities of P-waves is observed. The section includes a zone of tectonic distortions at a depth of 6.3–7.5 km.

During the recording of the geomagnetic field at a depth of 5970 m, we recorded two additional peculiarities of variations in the geomagnetic field, which were not found in the records by the land-based instrument. The first peculiarity is related to a sharp decrease in the vertical component on September 24 and restoration of the previous level on September 25 (Fig. 2). In this case, instrumental errors are excluded. This effect was not found in the records made at the Arti observatory. The second peculiarity is related to the recording of local perturbations over approximately 30 min, which are manifested in the records of the vertical and horizontal components (Fig. 4). A detailed analysis of the perturbations allows us to suppose that these anomalies are related to the subsidence of magnetized pieces of rocks. Interpretation of the recorded anomalies by traditional methods; their comparison with theoretical calculations from the objects with different directions of magnetization; and coincidence of the divergence of anomaly centers in terms of the magnetic field compo-

Range of recorded variations of the geomagnetic field

Parameter	Borehole, depth 5970 m			Borehole bottom			Arti observatory		
	min	max	range	min	max	range	min	max	range
Vertical component, nT	53540	53730	190	56230	56260	30	53380	53398	18
Horizontal component, nT	15150	15220	70	14595	14640	45	16285	16330	45
Declination, degree	314.2	315.0	0.8	331.6	331.8	0.2	11.3	11.5	0.2

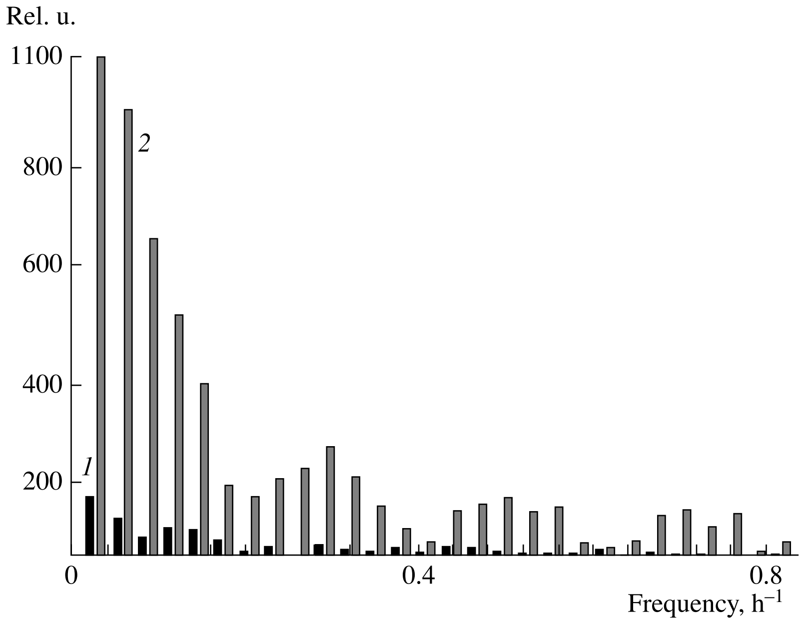

Fig. 3. Amplitude–frequency spectra of the vertical component of geomagnetic field variations in the Ural superdeep borehole. (*1*) At the surface, (*2*) at a depth of 5970 m.

nents matching the distance between the primary transformers, which measure the components of the geomagnetic field, allows us to obtain a satisfactory explanation of each anomaly. The quantitative interpretation of the magnetic anomaly shows that it was caused by an isometric magnetized object descending close to the borehole instrument at a distance of 2.0 cm from its casing with a velocity of 11.4 mm/min. It is most likely to expect that these are aggregations of magnetite crystals with magnetic permeability equal to 1.0 SI u. and Koenigsberger coefficient nearly equal to 1.0. In this case, the radius of the magnetized object is 4.0 mm. However, one cannot rule out another interpretation of such anomalies of the magnetic field, e.g., "the inertial mechanism of seismic energy transformation to the magnetic field energy" suggested and calculated by Guglielmi [15]. The magnetic signals appear during the shear displacement of rocks, which are transported together with the destruction front as a result of accelerated motion of fluid in the pores and cracks [15]. Further observations in the boreholes are necessary along with the calculations of the amplitude and duration of pulses of the appearing magnetic field in a realistic situation.

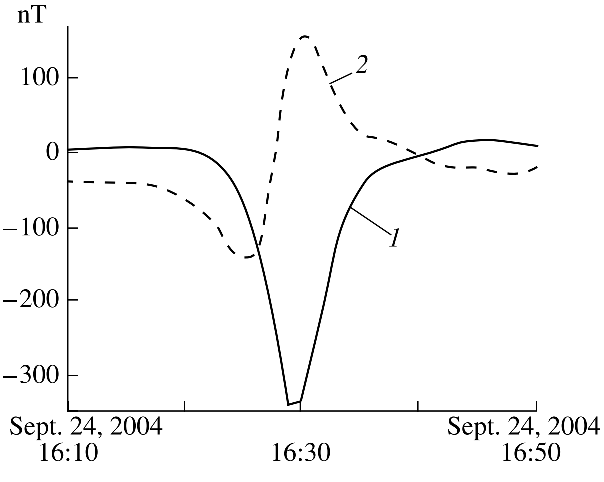

Fig. 4. Example of a record of 30-min perturbation of the geomagnetic field. Ural superdeep borehole, depth 5970 m. (1) Vertical component, (2) horizontal component.

Thus, recording of three components of the geomagnetic field by a STM-120 magnetometer–variometer in boreholes, especially in superdeep boreholes would allow us to obtain new additional information for the investigation of physical fields and the deep structure of the Earth. Integration of the magnetometer–variometer data with the data of seismic acoustic emission and electromagnetic emission would make it possible to clarify the nature of anomalous variations in the vertical component of the geomagnetic field in the borehole.

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