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Experimental evidence of the Phobos magnetic field

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The detailed analysis of the disturbances of the magnetic field near Phobos has been carried out. Two types of the force lines have been found. Some of them correspond to the force lines of the solar wind disturbed by the obstacle. Others are related to Phobos. The character and the direction of the disturbances give the strong evidence for the existence of the magnetic field and the magnetosphere of Phobos . Assuming a dipole approximation, the value of the magnetic field of Phobos on its surface is 0.6 G. It is comparable to the value of the magnetic field on a surface of the Earth.

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1. The origin of planets and planetary bodies is one of the basic problems of research of the Solar system. The research of Phobos represents the special interest. According to modern representations, Phobos refers to the seized asteroid bodies and its substance may carry the information about the origin and evolution of the Solar system.

In July 1988, two probes were launched to Phobos for studying of Mars and Phobos. It was the expansive program developed by the scientists of Soviet Union with the participation of many other countries.

In March 1989, the "Phobos-2" approached to Phobos at the distance of 180–400 km and was placed on a "quasi-synchronous" orbit. Fig.1 gives the examples of the satellite trajectory relative to Phobos. The satellite was moving along a circular trajectory. It was approaching to Phobos at the distance up to 180 km and was going away from it up to 400 km. Simultaneously, the satellite, together with Phobos, rotated around of Mars. The Fig.1 gives the scheme of the orbit around Mars and the coordinate system used. The axis X is directed to the Sun, the axis Y is opposite to the direction of movement of Mars around the Sun, the axis Z supplements the coordinate system. Thus, the satellite was approaching to Phobos 3 times per day at the distance up to 180 km from the dayside of Phobos (P). In addition, 3 times per day, the satellite was approaching to Phobos on the night side of Phobos and Mars (M). The labels P and M indicate this situation. The location of the Mars bow shock, deduced from the "Phobos-2" data, is displayed by the solid line. We will consider the magnetic events of the P field. The magnetic events relate to the vicinity of Phobos only.

Eroshenko [1] pointed out the existence of an obstacle near Phobos. The effects of local depression of a magnetic field near to an orbit of movement of Phobos were considered in the work [2]. We have made very thorough studying of the magnetic field data near Phobos and it has resulted to the unexpected conclusion. Phobos has the magnetic field. It is possible that the magnetic field of Phobos and the Mars crystal magnetism, discovered by the Mars Global Surveyor MAG/ER experiment [3], have common nature.

2. The overview of the magnetic field measurements near Phobos. Aboard the spacecraft the magnetic field measurements were carried out by the two magnetometers FGMM and MAGMA. The description of the devices and the first results can be found in [4].

The general review of the measurements of the magnetic field B on the "quasi-synchronous" orbits from March 22 until March 26 1989 is given on Fig.2. The label P marks the measurements of the magnetic field on the dayside of Phobos with approaching to it up to 180 km. The behavior itself and the value of the magnetic field attract the attention from 20 to 22 o'clock on the 22 March 1989. The measured value of the module of the magnetic field B is 17 nT at this period on the dayside of Phobos. It is a higher than the value B measured earlier in a tail of Mars.

We are passing on to the consideration of the events at time of the approaches of the satellite (CA) to Phobos up to 180 km from the dayside. Each time the magnetometers marked the distinct disturbances of the magnetic field. We can see either structured disturbances with the peculiarities or simple disturbances of the mag-

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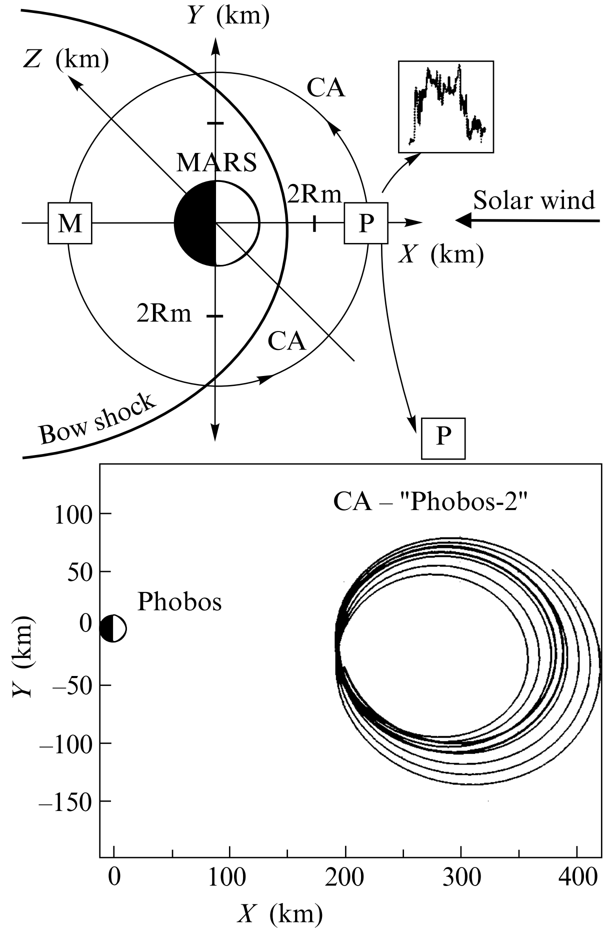

Fig.1. On the top of the figure the spacecraft trajectory (CA) is shown in the solar orbital coordinate system of Mars. At the bottom of the figure the spacecraft trajectory is shown in the centric coordinate system of Phobos. The X-axis points to the Sun

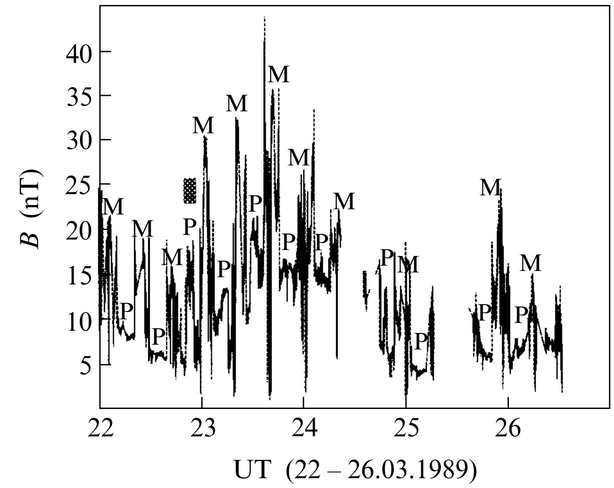

Fig.2. The overview of the magnetic field B along all "quasi-synchronous" orbits around Mars from 22 to 26 March 1989 is shown. The label P indicates the measurements near the dayside of Phobos with the approaching to him up to 180 km

netic field. The review of the magnetogrammas gives only some representation about the phenomena.

3. The analysis of the magnetic disturbances. For the best understanding of the phenomenon, we shall draw the field of gradients of the measured magnetic field at the points of the satellite trajectory. As we are limited to the framework of the short article, the consideration will be made here only in the projection onto the plane of the ecliptic. It does not bring the considerable additions into the essence of the phenomenon.

The amplitudes and the directions of the magnetic field vectors are given on Fig.3 in the plane of the ecliptic for the 3 characteristic disturbances of the magnetic field. The axis X is directed, we remind, to the Sun. Each vector of the field here is the tangent, going through the point of the trajectory at the moment when the measurement was made there, toward the force line of the magnetic field. The arrows show the location of the Phobos magnetopause. We shall make use of the magnetic field vector between the arrows for reconstruction of the Phobos magnetosphere. In Fig.4 some model of the Phobos magnetosphere relevant to this case is shown.

With the help of the Fig.3 and the magnetogrammas we shall illustrate a real picture of the interaction of the solar wind plasma with the Phobos magnetosphere. A simple set illustrates the dayside part of the Phobos magnetosphere there. We will use the force lines of the magnetic field. The results are presented in the plane of the ecliptic on Fig.5–7. On top of the figure the magnetogramma of the phenomenon and the plasma parameters (the speed V and the concentration n of the plasma) are given. At the bottom, the magnetic phenomenon is described with the help of the force lines of the magnetic field.

It is necessary to note, that the Phobos represents a small body with the sizes 18-21-27 km, therefore the interaction picture is very dynamical. Direction of the flow in the subsolar point may vary very rapidly depending on radial speed of a solar wind. And as the data are submitted here for the interval of the disturbance, the initial direction of the magnetic field may differ very much from the direction of the magnetic field of undisturbed solar wind.

We shall begin the analysis with the most interesting picture of the interaction fixed by the magnetometers on the dayside of Phobos. On Fig.5 the sharp rise of the magnetic field was observed from 20:15 o'clock until 22:00 o'clock on 22 March 1989. Except of the increase almost 5 times of the B value, the "shock-like" behaviour

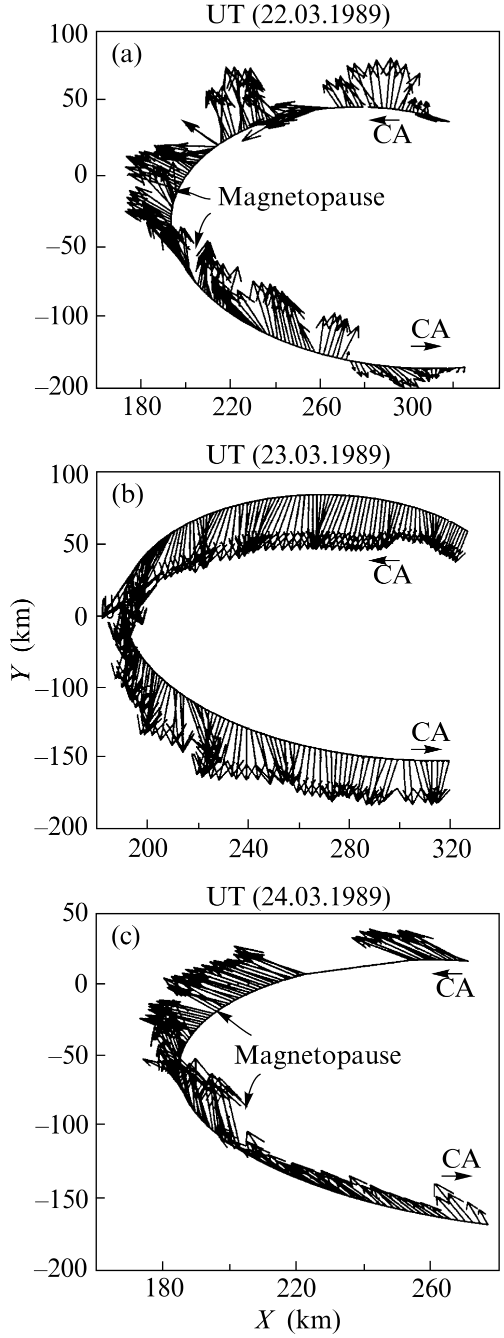

Fig.3. The amplitudes, the direction of vectors of the magnetic field (B_x/B_y) and the trajectory of satellite (CA) are given in the centric coordinate system of Phobos for 3 characteristic disturbances on the dayside of Phobos. Each vector of the field here is the tangent going through the point of a trajectory at the moment when the measurement was made there, toward the force line of the magnetic field. The panel (a) is the obtained data at 20:00–22:30 on 22 March 1989, (b) – at 11:00–14:00 on 23 March 1989, (c) – at 18:00–20:00 on 24 March 1989

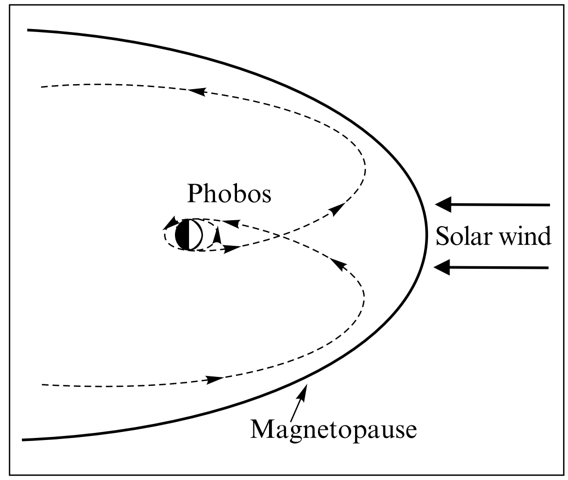

Fig.4. The model of Phobos magnetosphere deduced from the Phobos data is shown

is marked along the edges and the middle of the event. The speed V of the solar wind increased from 400 km/s up to 600 km/s. The concentration n of the solar wind increased from 2 cm^3 up to 10 cm^3 in this period. In the context of the force lines, the same picture of the interaction appears in the clearer form. First, we see the magnetic force lines of the solar wind compressed by the obstacle. Next, the force lines go to Phobos, next, the magnetometers fix the return direction of the magnetic field. In addition, the loops are extended. We cannot tell that the force lines are dipole, as the analysis has not been carried out. Next, the satellite observed again the solar wind plasma compressed by the obstacle.

Fig.6 gives the magnetic field disturbance which was observed from 11:30 until 13:20 on 23 March 1989 i.e. rather long time – almost 2 hours and practically on the same part of the satellite trajectory. There is the distinctive peculiarity of the behaviour of the magnetic field. There is no the "shock-like" behaviour. The field was 2 times increased. On 23 March 1989, a dynamic pressure of a solar wind was increased so much, that it compressed the magnetic field of Phobos. The speed V of the solar wind increased from 650 km/s up to 750 km/s. The concentration n of the solar wind increased from 5 cm^{-3} up to 7 cm^{-3} in this period. Therefore, during this period the magnetometers observed only the compressed magnetic field of the solar wind. The picture of the force lines brightly demonstrates this. The curvature of force lines has practically a spherical feature.

On 24 March 1989 the dynamic pressure of a solar wind fell. The speed V of the solar wind decreased to down 600 km/s. The concentration n of the solar wind decreased down to 1 cm^{-3} in this period. Therefore, it was possible to observe the remarkable event that we see

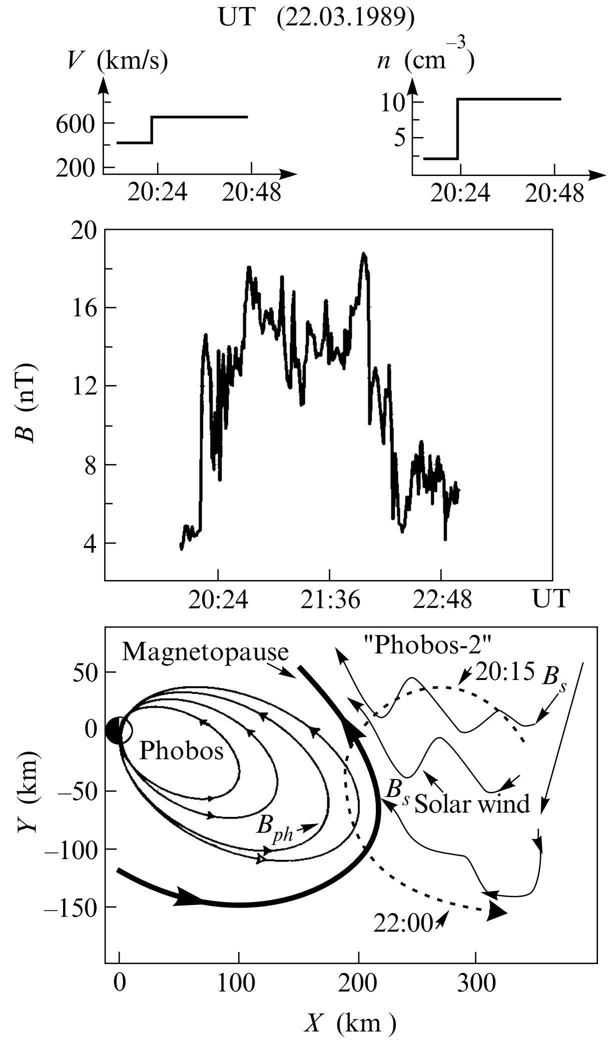

Fig.5. On the top of figure, the observed sharp rise of the magnetic field B on March 22 1989 is shown. At the bottom, the magnetic phenomenon is described with the help of the force lines of the magnetic field. The gray solid lines B_s are the force lines of the magnetic field of the solar wind. The solid lines B_{ph} are the force lines of the magnetic field of Phobos. The dashed line shows the trajectory of satellite (CA) concerning Phobos. The dark solid line marks the magnetopause of Phobos

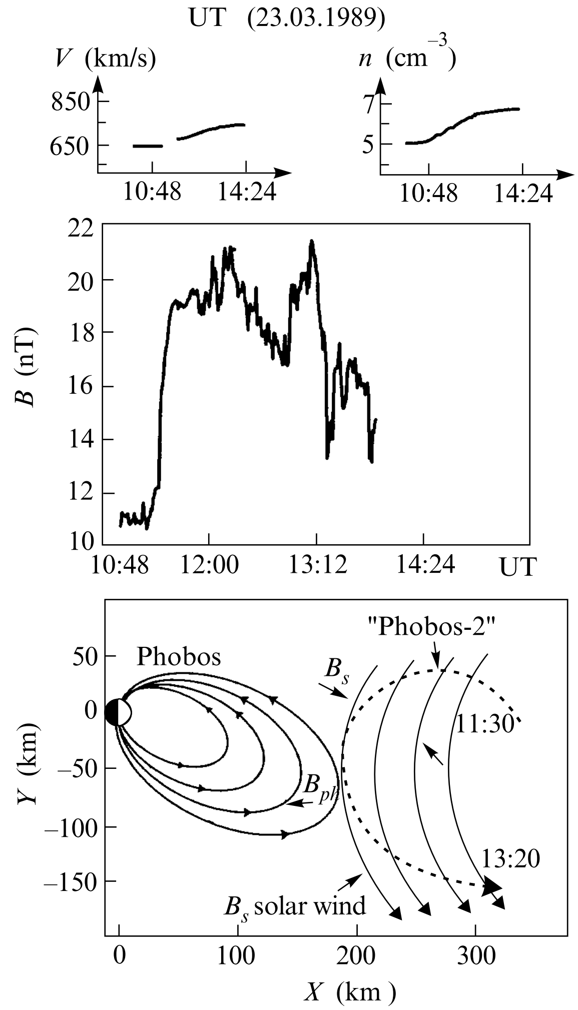

Fig.6. As Fig.5, but the magnetic phenomenon is observed on March 23 1989. The magnetopause is absent

on Fig.7. It is the magnetogramma with the characteristic "shock-like" behaviour. We shall designate it by the magnetopause. Fig.7 allows making the conclusion that the satellite has flown by under the subsolar point of the magnetosphere. During this period, the magnetic field of the solar wind turned in the opposite direction.

Finishing the analysis, it is necessary to stress that the force lines, going to Phobos and from Phobos, are observed on the same part of the trajectory. The characteristic axis of the anisotropy of the observations is deflected at the angle about 15–20 degrees from the axis X directed to the Sun for all events.

In conclusion, it is necessary to note that certainly, the magnetic field was measured only on the satellite trajectory, and it is possible to speak authentically about the direction and its value only in these points. However, near Phobos the measured force lines always go to Phobos and then do from Phobos.

4. The magnetic field of Phobos. The existence of the magnetic field of Phobos is the natural explanation of the observation of the magnetic disturbances near Phobos. We shall make the estimations of the field value on its surface. Assuming dipole character of the magnetic field of Phobos H_{ph}, it is possible to calculate its value on the Phobos surface by two independent ways from experimental data.

Firstly, we are able to calculate its value by using the measurements of the magnetic field from 18:55

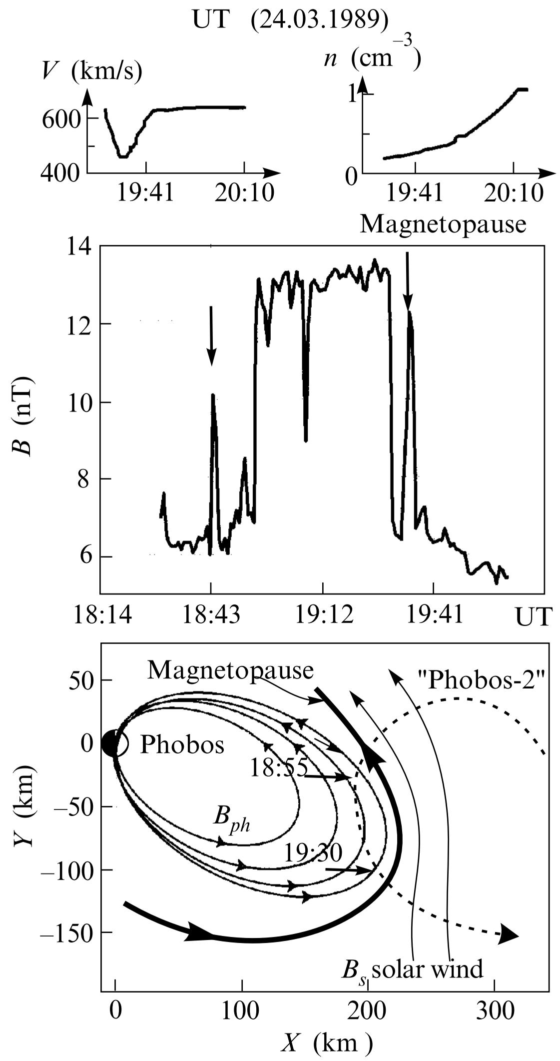

Fig.7. As Fig. 5, but the magnetic phenomenon is observed on March 24 1989. The dark solid line marks the magnetopause of Phobos

until 19:40 on 24 March 1989. For the analysis of the magnetic properties of Phobos the date are ideal. The measured magnetic field was about 13 nT (Fig.6). $H_{ph} = 13 \times (h/R_{ph})^3 = 13 \times (180/11)^3 = 0.57\,\mathrm{G}$, where R_{ph} is the radius of Phobos.

Secondly, we are able to calculate the magnetic moment M' out of the equation of the balance of pressure of the solar wind and the pressure of the dipole field of the planet on the magnetopause, and then the magnetic field of Phobos on its surface: $2nm_pV^2 = 1/8\pi\left(2M'/D^3\right)^2$ where $D = R_{ph} + h$ is the distance from the center of the planet up to its subsolar point, n, V – the concentration and the speed of the solar wind, m_p – the mass of a proton. The measured values of the concentration and the speed of the solar wind are used for estimations of the magnetic moment M'. The data are $n = 0.17\,\mathrm{cm}^{-3}$, $V = 617\,\mathrm{km/s}$ at 18:55–19:40 on 24 March 1989 [1]. Thus we assume that the satellite was in the subsolar point of the magnetosphere of Phobos at 19:30 – 19:40 on 24 March 1989 and the given picture of the force lines on Fig.7 shows that. The magnetic moment is equal: $M' = 0.8 \times 10^{18}\,\mathrm{G} \cdot \mathrm{cm}^3$, $H_{ph} = 0.6\,\mathrm{G}$.

We have received the same value. The value of the magnetic field on the surface of Phobos at 0.6 G is mystical because it is the same value as the value of the magnetic field on a surface of the Earth. The sizes of the Earth and Phobos are incommensurable. Made measurements give the value of the distance from Phobos up to the subsolar point of its magnetosphere. It is about 13–16 radiuses of Phobos. For the Earth this value is about 10 radiuses of the Earth. For Mars this value is hardly more than one radius of Mars.

5. In summary, we shall sum up of the considered results received by the magnetometers during the expedition "Phobos-2". Phobos has the magnetosphere. The distance from Phobos up to the subsolar point of its magnetosphere is about 13–16 radiuses of Phobos. The unusual behavior of the magnetic field observed near Phobos is explained in the terms of the magnetic field of Phobos. Phobos has the own magnetic field. Calculated value gives 0.6 G in the dipole approximation on its surface. Its steady anisotropy is observed.

Now the origin of the magnetic field of Phobos is not known. As the density of Phobos is $2\,\mathrm{g/cm}^3$, it seems reasonable to assume two things for the explanation. 1. The Phobos is non-uniform. There exists an immense piece of a magnetic material. 2. The Phobos consists of small pieces of a magnetic material in a low density filler. The magnetization of Phobos substance is 0.15 CGS. There are some meteorites with the magnetization up to 3 CGS [5].

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1. E. G. Eroshenko, Kosm. Issled. **38**, 127 (2000).
2. V. G. Mordovskaya, V. N. Oraevsky, and J. Rustenbach, Kosm. Issled. **39**, N5 (2001).
3. M. H. Acuna, J. E. P. Connerney, N. F. Ness et al., Science **284**, 790 (1999).
4. W. Riedler, D. Mohlmann, V. N. Oraevsky et al., Nature **341**, 604 (1989).
5. E. G. Gus'kova, *Magnetic properties of meteorites*, M.: Nayka, 1972.