IN SITU MEASUREMENTS OF THE PHOBOS MAGNETIC FIELD DURING THE "PHOBOS – 2" MISSION. V.G. Mordovskaya, and V.N. Oraevsky, *Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation (IZMIRAN), Troitsk, Moscow region, 142190 Russia, mail: valen@izmiran.rssi.ru.*

The future explorations to Mars have to take into account the Martian satellites, Phobos and Deimos, because their substance may carry the information on an origin and evolution of Mars.

The trajectory of *Phobos*-2 provided the collection of data in regions which are appropriate for an investigation of interaction of Phobos with the solar wind and have not been explored before. From March 22, 1989, to March 26, 1989, at each orbit around Mars, both *Phobos*-2 spacecraft and the Mars satellite Phobos were inside the solar wind and within the Martian magnetosphere during 3.8 h. The spacecraft was located permanently in a vicinity of Phobos at this time and the distances between them were 180–400 km. A sharp rise in the regular part of the magnetic field was observed on the circular orbits near the dayside of Phobos at distances of 180–250 km from its center when Phobos was in the unperturbed solar wind.

Figure 1 displays a sketch of the position of the *Phobos*-2 and Phobos in the projection onto the Mars ecliptic plane XoY on March 22–26, 1989. The X-axis points to the Sun; the X-Y plane coincides with the orbital plane of Mars; the Y-axis points in opposite direction of the Mars orbital velocity; the Z-axis is perpendicular to X and Y.

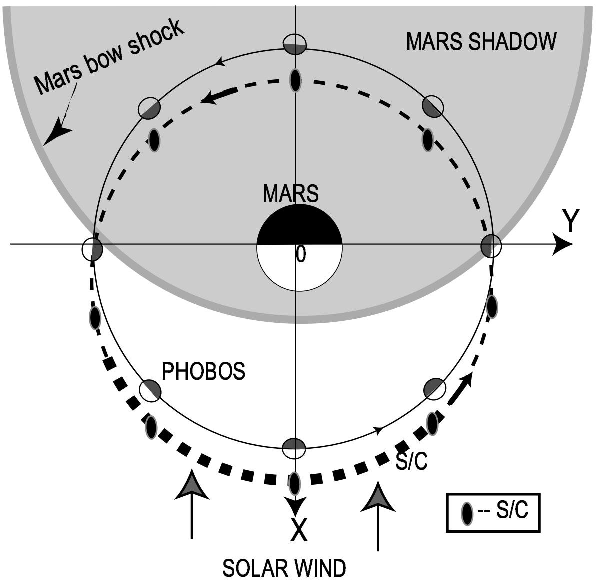


Fig. 1. View of the location of the *Phobos*-2 and Phobos on March 22–26, 1989.

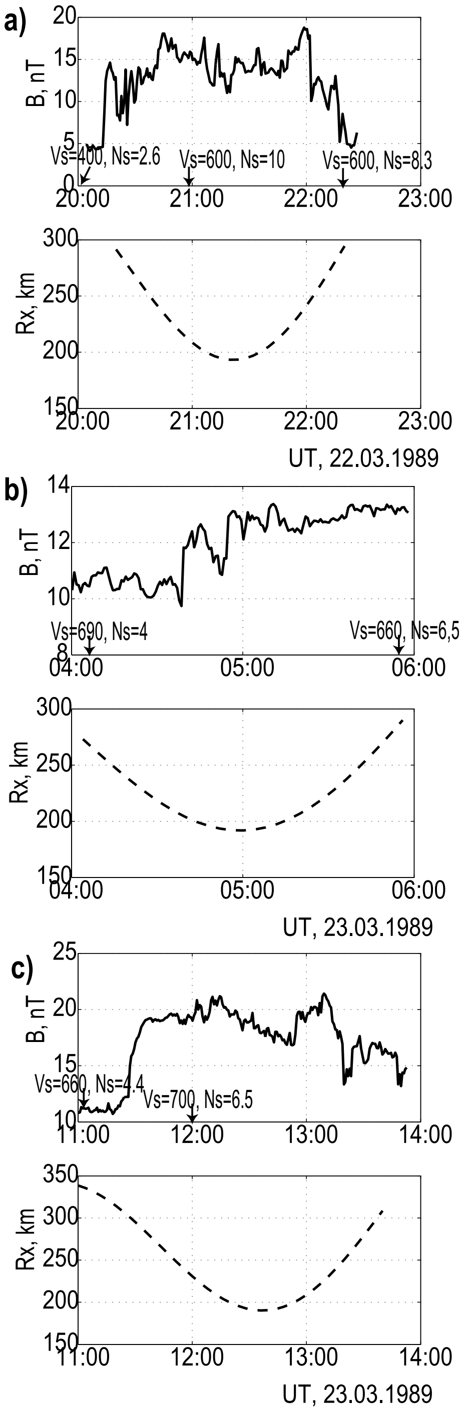
The line composed of small squares allocates the part of the spacecraft trajectory on the circular orbit around Mars where the magnetic field enhancements were observed. The magnetic field enhancement in the regular part can not be really attributed to the Mars. The S/C crossed a stationary slowly moving structure, which approached to and then moved away from the S/C accordingly with the scheme of the S/C flight. The magnetic field enhancement observed near the dayside of Phobos really attributes to the Phobos. Analyzing the data acquired aboard *Phobos*-2, Mordovskaya et al. (2001, 2002) gave evidence that Phobos has its own magnetic field and its magnetic moment is $M' \simeq 10^{15}$ A·m^2. The magnetic moment M' was estimated from pressure balance for the solar wind and the Phobos magnetic field measured at the magnetopause. The peculiarity of the rotation of the magnetized Phobos around Mars leads to the magnetic field signatures, which, especially the direction, are phase locked with Phobos rotation rate. Such magnetic field signatures were observed on circular orbit of the Phobos-2 spacecraft (Mordovskaya et al., 2002).

The morphology of the magnetic field signatures caused by the interaction of the Phobos magnetic field with the solar wind plasma and observed during the time interval of March 22–26, 1989 are presented in Figs. 2–4. The plot of the distance Rx between Phobos and the spacecraft versus the time of the observation is represented in the bottom panels of Figs. 2–4 to illustrate that the magnetic field disturbances are really associated with Phobos. There is a clear correspondence between the disturbance of the magnetic field and the approaches of the spacecraft to Phobos. In Figs. 2–4, the magnitude of the observed magnetic field is marked by the solar wind parameters (Vs–the solar wind velocity in km/sec, Ns–the solar wind density in cm^{-3}) to illustrate that the manifestation of the phenomenon depends on the solar wind parameters. The arrows mark the time when the parameters were acquired.

Figures 2–4 give a lesson for the study of the solar wind interaction with a small, magnetized object. The magnetic field signatures observed near day-side of Phobos show the response of the solar wind to the Phobos obstacle. The draping magnetic field around Phobos appears at distances of 200–300 km from the Phobos day-side, the distance depends on the solar wind plasma parameters.

The events displayed in Fig. 2 result from the interaction of the Phobos obstacle with the solar wind plasma having high density (Ns) from 3 cm^{-3} up 12 cm^{-3}. Figures 3 and 4 give the examples of the interaction in the plasma with lower density, Ns is between 2 cm^{-3} and 0.4 cm^{-3}. The velocity of the solar wind changes slightly during these observations. Therefore, the density of the solar wind plasma plays a significant role in formation of the size and shape of the draping and compressional region near the dayside of Phobos and around Phobos.

The density and magnetic field of the solar wind plasma pile up in front of the obstacle that Phobos and its magnetic field represent to the solar wind. The pile up becomes significant when the proton skin depth is comparable with the actual size of the Phobos obstacle.



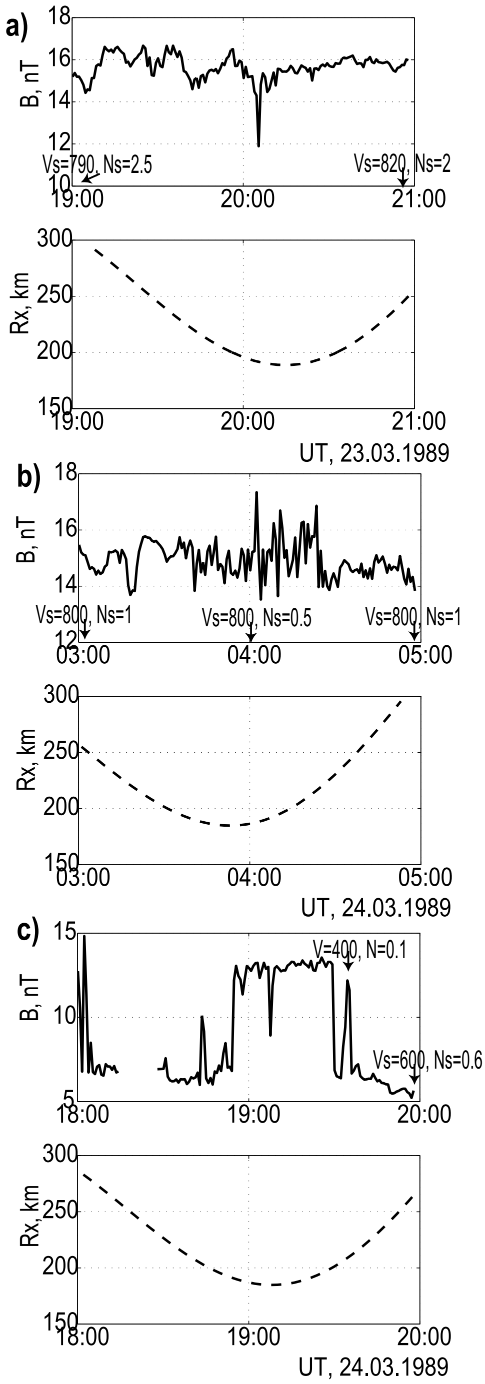


Fig. 2. **O**n the top the plot of the magnetic field signatures. **T**he lower graphs correspond to the time history of spacecraft approaches to the dayside of Phobos inside the unperturbed solar wind. **a**) The data from 20:15 to 22:15 on March 22, 1989. **b**) The data from 04:00 to 06:00 on March 23, 1989. **c**) The data from 11:00 to 13:45 on March 23, 1989.

Fig. 3. **S**imular to Figure 2, except **a**) The data from 19:00 to 21:00 on March 23, 1989. **b**) The data from 03:00 to 05:00 on March 24, 1989. **c**) The data from 18:00 to 20:00 on March 24, 1989. Fig. 3c shows the direct measurements of the planetary magnetic field of Phobos.

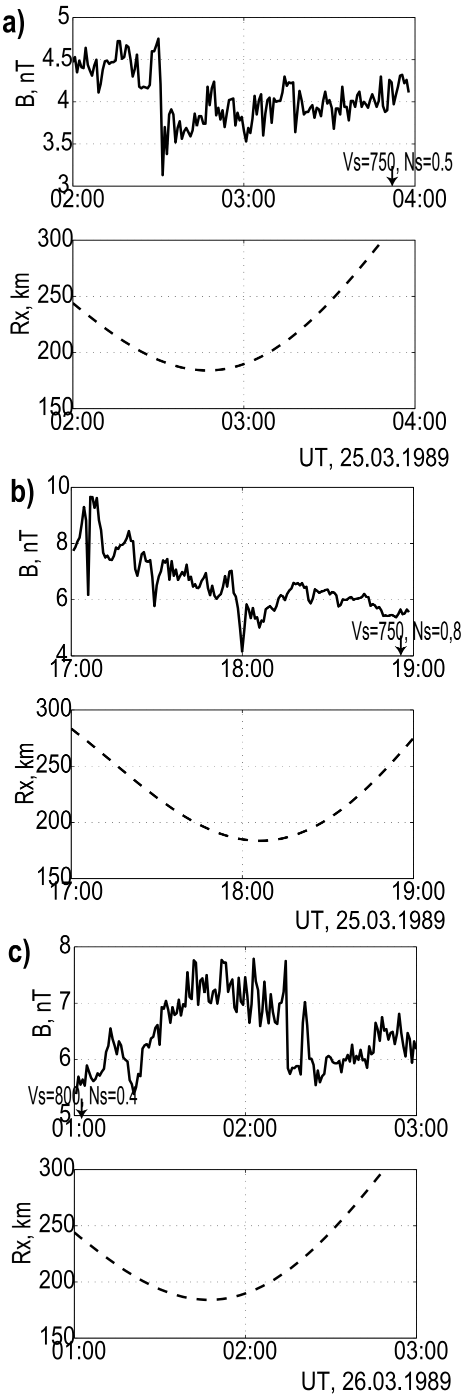


Fig. 4. **S**imular to Figure 2, except **a**) The data from 02:00 to 04:00 on March 25, 1989. **b**) The data from 17:00 to 19:00 on March 25, 1989. **c**) The data from 01:00 to 03:00 on March 26, 1989.

We can take the actual size of the Phobos obstacle from the paper by Mordovskaya et al. (2001) or estimate it from Figure 3 c) by calculating the size of region occupied by the planetary field of Phobos. This size is about 150–170 km and the relevant density is 1.8–2.3 cm^{-3}. Formation of a shock-like structure upstream of Phobos will take place for the solar wind plasma with density larger than 1.8–2.3 cm^{-3}. The magnetic field signatures in Fig. 2 demonstrate the shock-like structure upstream of Phobos and it is seen that in this case the draping of the field is stronger. Figures 3–4 show an absence of the shock-like structure ahead of Phobos magnetopause and the week draping of the field around the Phobos obstacle because the plasma density was low. For other plasma densities observed, the ion scale length l_s is l_s=93 km for Ns = 6 cm^{-3}; $l_s =$ 130 km for Ns = 3 cm^{-3}; $l_s = 160$ km for Ns = 2 cm^{-3}; $l_s =$ 294 km for Ns = 0.6 cm^{-3}. It easily seen that the nature of the interaction displayed by the magnetic field signatures in Figs. 2–4 is related to the ion scale lengths. The presence or absence of a shock-like structure ahead of the Phobos magnetopause are consistent with the ratio of the proton skin depth to the actual size of the Phobos obstacle. Depending on this ratio, some ions and magnetic field line will pile up in front of the Phobos magnetic barrier, forming fanciful patterns of the density and magnetic field signatures. The field signatures observed are various and depend on the density of the solar wind flow.

It is worth dwell upon an additional feature of behavior of the plasma density and the magnetic field (see Figs. 3b and 3c). The density value decreases by a factor of 2 in Fig. 3b and by an order of magnitude with a closest approach to Phobos, the decrease indicates to the absence and lack of plasma, at least that of the solar wind, near regions adjacent to the Phobos magnetopause.

On March 24, 1989, the dynamic pressure of the solar wind begins to decrease. The density of the solar wind decreased down to 0.5–1 cm^{-3} during this period. When the speed Vs of the solar wind falls down to 600 km/s, it was possible to observe a remarkable event shown in Fig. 3c. During 18:43–19:41 on March 24, 1989 the magnetic field signature has a sharp rise with a characteristic “magnetopause-like” behavior demonstrating clear encounter with an intrinsic magnetic field of Phobos. The field magnitude increased by 80% with respect to the background level, while the plasma density value was, apparently, close to the lower threshold of sensitivity of the plasma detector.

In Figs. 2-4, except for Fig. 3c, the magnetic field signatures are caused by the interaction of the solar wind with Phobos. On the other hand, Fig. 3c shows the direct measurements of the planetary magnetic field of Phobos. The study of the interaction of Phobos with the solar wind plasma indicated that the day-side obstacle of Phobos to the solar wind is over 150 km. The draping magnetic field around Phobos appears at distances of 200–300 km from the Phobos day-side due to the density and magnetic field pile up in front of the Phobos obstacle. The nature of the interaction and the magnetic field signatures observed are consistent with the ratio of the proton skin depth to the actual size of the Phobos obstacle to the solar wind.

In conclusion, the magnetization of Phobos substance is 0.15 CGS. The third part of volume of Phobos should consist of a magnetic substance similar to a magnetite Fe_3O_4 in order to obtain the given magnetization of Phobos. Since the density of Phobos is about 2 g/cm^3, we can suggest two explanations for the magnetization observed. First, Phobos is non-uniform and there exists an immense piece of a magnetic material within it. Second, Phobos consists of small pieces of a magnetic substance immersed into a non-magnetic low density material.

References

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