PHOBOS-II RESULTS AND THE MARTIAN MAGNETIC FIELD

(Letter to the Editor)

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Abstract. The results of the Phobos-2 mission concerning the Martian magnetic field are interpreted in the framework of a model for the planetary evolution taking into account certain effects of material properties.

The latest results obtained by the Phobos-2 mission require some additional remarks to the model of Martian evolution worked out previously (Franck and Orgzall, 1987; Orgzall and Franck, 1988), especially concerning the results for the magnetic field. The space probe found strong hints for the existence of an active planetary dipole field of the order of some 10 nT and tilted against the axis of rotation with an angle of approximately $(65 \pm 15)^\circ$ (results from the first data analysis given by Möhlmann, 1989, private communication; see also Riedler *et al.*, 1990).

The magnetic field strength is well in the limits given by Curtis and Ness (1988) that they interpreted as the 'off state' of the internal Martian dynamo. A comparison with the SNC investigations results in a strong field strength decrease in the last 1.3 billion years (or less, accepting a younger origin of the meteorites as for instance Vickery and Melosh (1987) propose with a single impact about 200 million years ago): from $1, \ldots, 10\ \mu T$ to the present day value, what corresponds roughly to two or three orders of magnitude.

Based on indications for vigorous outgassing processes of the Martian interior also found by the space probe we concluded a significant influence of these processes on the whole planetary evolution. Therefore the mantle melting temperature was raised by 50 (M6), 25 (M7) and 10% (M8), respectively, compared with the previous water-saturated model (cf. Table I and the model data in Franck and Orgzall, 1987; or Orgzall and Franck, 1988) because of an increase of the silicate melting temperature connected with that volatile loss. This was also suggested by Stacey and Loper (1988). The constant ratio should be taken as a time average over the whole evolution because the details and the transient behaviour of the outgassing are not known, so that this cannot be taken into account in an exact way and only a qualitative model may be proposed. The melting temperature is also a measure for the viscous activation energy via the homologous mantle

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TABLE I

Varied mantle melting temperatures as model parameters for Mars models M6, . . . , M8

Parameter	Unit	Model M6	Model M7	Model M8
$T_m^m(R_p)$	K	1390	1250	1175
$T_m^m(R_c)$	K	2305	2125	2030

temperature. The viscosity varies with water content too what can be considered in like manner by the variation of the melting temperature (see for instance Jackson and Pollack, 1987).

The results (cf. Table II and Figure 1 for the evolution of the nominal magnetic field strength $B_N(t) = \phi(t)/\phi$ (4.5 Ga, Earth), where $\phi(t)$ is the energy supply for the Martian dynamo at time t) are nearly similar to those given before (Orgzall and Franck, 1988), except that the time axis is shifted. Inner-core formation starts later, in the first time only a thermal dynamo is active. The eutectic core composition is reached later followed by the switch off of the gravitational energy contribution. The appropriate time scale depends on the model and therefore on the melting temperature rise. All models describe the SNC magnetization in reasonable error limits (3.8, . . . , 5.8 μT) and are characterized by an operating dynamo under present day conditions, but with a field strength that is too high referring to the experimental data. The discontinuities in the curves for the nominal field strength are explained in the same way as in the paper of Orgzall and Franck (1988).

Model M8 seems to be preferable to describe the Martian evolution. It starts with a thermal dynamo. After the onset of inner-core formation (at about 0.12 Ga) all energy sources available contribute to power the dynamo. Reaching the eutectic core composition (after approximately 2.75 billion years) results in the turn off of the gravitational contribution. After this only cooling and solidification sustain the dynamo action with nearly constant output. The SNC magnetization is explainable. Now the inner-core radius reaches those dimensions that the condition for R_m –

TABLE II

Selected model results for Mars models M6, . . . , M8

Parameter	Unit	Model M6	Model M7	Model M8
T_{cm}	K	1801	1674	1661
R_{ic}	km	948	1132	1436
t_{onset}	Ga	0.87	0.28	0.12
Q_g	10^{10} W	5.91	0	0
Q_1	10^{11} W	0.41	1.64	2.36
B_p (3.2 Ga, R_p)	μT	5.8	5.7	3.8
B_p (4.5 Ga, R_p)	μT	4.8	2.3	switching-off processes (theoretic value: 3.4 μT)

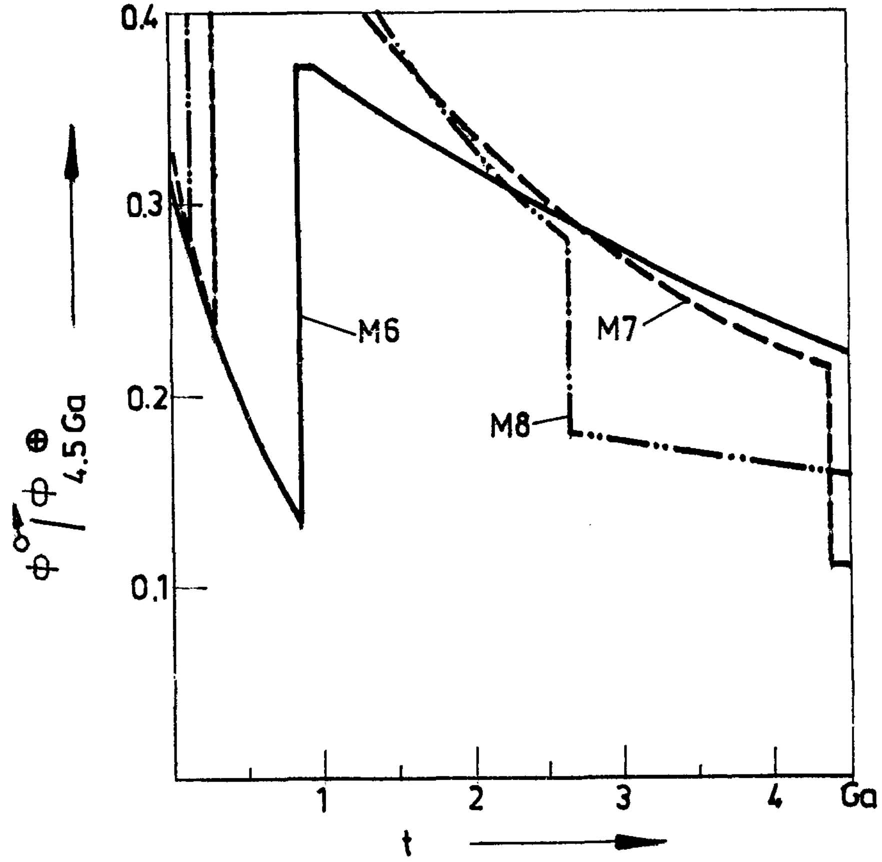

Fig. 1. Mars models M6, . . . , M8 – nominal magnetic field strength as function of time.

the magnetic Reynolds' number - becomes violated and switching-off processes could be observed. Because facts about this process are not known it could not be modeled appropriately but it seems reasonable that it won't proceed abruptly but slightly so that the nominal field strength approaches zero in a continuous manner. The ratio $B_{\text{obs}}/B_{\text{theor}}$ in the order of some 10^{-3} fits well the theoretical values of Curtis and Ness (1988), so that we interpret our basic energy balance Equation (1) of Orgzall and Franck (1988) to give the theoretically possible value. Due to the low ratio the dynamo action could cease at present what corresponds to conclusions drawn by Möhlmann (1989, private communication) that, for instance, the tilt angle between rotational axis and dipole axis gives some hints on anomalous states in the Martian core.

In that way the picture worked out in the previous papers should be modified a little so that the dynamo has not stopped in the past but we just observe this process.

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