

How Mars lost its magnetism

Mars has a complex and patchy magnetic field; neutron experiments may explain why

>> BACHIR OULADDIAF

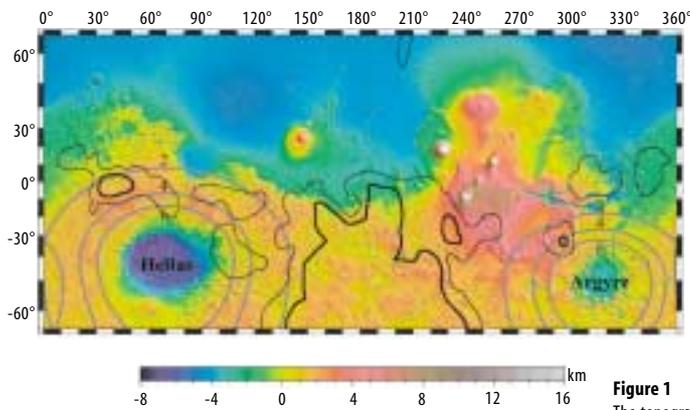


Figure 1
The topography of Mars showing the computed peak shock pressure in GPa around the Hellas and Argyre impacts (grey), and the 20 and 40 nanotesla contours of the magnetic field (black) measured by Mars Global Surveyor at an altitude of 380 to 420 kilometres

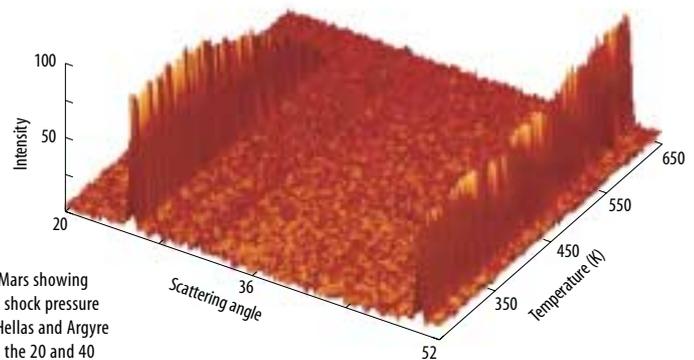


Figure 2
Part of the neutron scattering pattern collected on D1B from the pyrrhotite powder sample at room pressure and versus temperature

Our planetary neighbour Mars is currently exciting great interest as various space missions explore its surface and atmosphere. One of the key areas of interest is Mars' magnetic field and what happened to it in the distant past. Researchers believe that Mars once had a global magnetic field, like Earth's, but the iron-core dynamo that generated it shut down billions of years ago leaving behind only patches of magnetism due to magnetised minerals in the Martian crust.

NASA's Mars Global Surveyor spacecraft mapped these magnetic left-overs in 1999. The results were mysterious. While crustal magnetisation in the northern lowlands was negligible, it was much stronger in the older highlands of the southern hemisphere – with an especially strong magnetic field in a strip between longitudes 130°E and 240°E, but almost no magnetisation around the giant impact craters of Hellas and Argyre (figure 1).

The north-south divide probably arose because, when the Martian dynamo shut down, the younger, thinner northern crust had not yet solidified and thus became demagnetised – while the solid southern crust's magnetisation was already 'frozen' in. However, there is no apparent difference between the magnetised and non-magnetised areas in the southern terrain. One explanation is that the Hellas and Argyre impacts occurred after the dynamo shut down, and that the accompanying pressure shock-waves (rather than heat) demagnetised the crust around those areas.

Possible evidence for this scenario lies with one of the minerals identified in Martian meteorites as carrying the remanent Martian magnetisation – pyrrhotite, Fe_7S_8 . This mineral is ferromagnetic below a transition temperature of 325°C. This is due to alternate stacking of partially and fully-filled iron layers in the mineral which, although coupled antiferromagnetically, results in a residual magnetic moment. At moderately high pressures, however, pyrrhotite loses this magnetism, but the exact pressure at which this happens was not known.

Pyrrhotite under pressure

We decided to pin down the pressure-demagnetisation relationship more precisely using neutron diffraction. Samples of natural pyrrhotite were placed in pressure-clamp cells of up to 2 and 3 gigapascals (GPa), using deuterated ethanol as a medium to transmit even pressure, and placed on diffractometers D1B and D20 respectively. Two sets of peaks were isolated as being from the mineral; one set could be ascribed to magnetic scattering since it disappeared above the transition temperature (in an independent experiment, figure 2). The study then showed that this magnetic peak decreases with pressure and vanishes between 2.6 and 3.1 GPa, figure 3. An independent experiment based on a remanence measurement after pressure-release led to the same result.

Calculations indicate that the shock waves from impacts on the Martian surface would have indeed resulted in a maximum pressure contour of 3 GPa at the distance that coincides with the boundary between magnetised and non-magnetised crust. This strengthens the case of pyrrhotite as the mineral responsible for the Martian remanent magnetic field.

Besides nicely predicting the global magnetisation map, the results also have a major implication for the paleomagnetic signal of the Martian meteorites. All Martian meteorites have been shocked to pressures above 3 GPa, and since their remanence is also carried by pyrrhotite, they would have been demagnetised when they hit the Earth. Therefore, their paleomagnetic signal postdates shock. ■

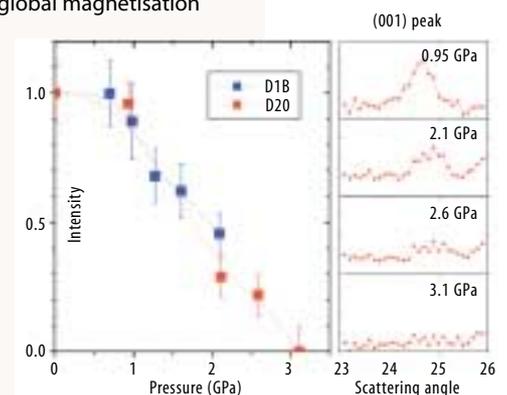


Figure 3
The neutron scattering pattern versus pressure: (a) showing how the intensity of the magnetic peak goes down with pressure; and (b) its evolution with increasing pressure, as measured on D20