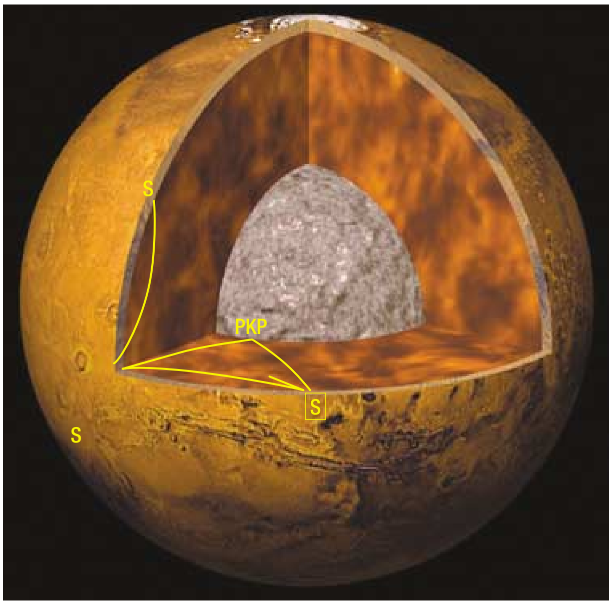
Mars in depth

P Lognonné, T Spohn and **D Giardini** describe the state of knowledge of Mars' interior and make the case for deep seismology to address the unanswered questions.

The crust and lithosphere of Mars have been extensively studied with high-resolution altimetry and gravity data from the Mars Global Surveyor mission. While confirming that crustal thickening plays a part in major geological features of Mars, no direct measurement of the crustal thickness could be made. Such a measurement is still missing and is not planned for ESA or NASA investigations.

Knowledge of the deep interior is even poorer. Models of the interior of Mars have been constructed from gravity and rotation data, with mineralogical constraints from SNC meteorites. The mean density and the J_2 coefficient were both obtained with good accuracy at the end of the 19th century, and are known today with a precision directly related to the uncertainty in the gravitational constant G. NASA's Pathfinder mission provided in 1997 the first measurement of the precession constant of the planet. NASA's Mars Global Surveyor spacecraft, with a detailed analysis of five years of orbits, provided a rough estimate of the amplitude of tidal deformation of the planet by the analysis of the gravity perturbation induced by the solar tide.

For the deep interior, both the real part or amplitude of the Love number (from MGS data) and its imaginary part or phase (from the secular acceleration of Phobos) rule out a completely solid core. At least an outer shell of the core must be liquid. The size of the core is between 1520 and 1840 km. With present estimates for the temperature, a light alloying element such as sulphur is necessary for a liquid core. But both the density and the volume of the core remain unknown. The isotope record of martian meteorites suggests that the core formed early and rapidly, within a few tens of million years. This probably required substantial melting of the silicate rock component and suggests a significant magma ocean on early Mars: such an ocean may have produced unknown layered structures in the seismic velocity profile, as for the Moon.



A seismic network could probe Mars' core. (Calvin J Hamilton)

The most accurate tool for investigating further is seismology. There have been two unsuccessful attempts to perform seismology on Mars: the Viking landers and the Optimism experiments on Mars96, lost just after launch. Mars' seismology – activity, noise and internal velocity models – remains to be discovered.

Marsquakes may be generated through the release of thermal stresses. This activity is about 100 times greater than the shallow moonquake activity detected by the Apollo seismometers with good signal-to-noise ratio. The amplitude of the Mars seismic signal, which can be estimated from surface-fault observations and from theoretical models of the thermo-elastic cooling of the lithosphere, is expected to be about four orders of magnitude lower than on Earth. There might be about 15 quakes of seismic moment 10^{15} Nm per year, with an increase/decrease of the frequency by 5 for a decrease/increase of the seismic moment by 10. Modelling suggests that about 50 events per year could be detected by a four-station network, with about 10 quakes per year having P waves detected by three stations and PKP waves (through the core) detected by the fourth station. In addition, the fundamental normal modes in the range 5–20 mHz could be excited by the largest marsquakes expected.

Abstract

Despite recent successful missions to Mars, much basic information about the planet's interior is missing. Progress will require deep seismology, using instruments on the martian surface, which are not part of any forthcoming mission. The Netlander mission, outlined here, could examine the seismic structure and enhance mineralogical models of Mars.

Analysis of these data will provide unique information on the martian interior, especially if coupled with other geophysical experiments. Compared to the Earth, the lower pressure in the martian mantle enhances the sensitivity of seismic velocities to mineralogy, making seismology a powerful tool for deep petrology. For example, with a low mantle iron content, sharp density and seismic velocity discontinuities (0.5 km s^{-1}) are expected to be present between 1100 km and 1500 km depth, associated with phase transitions of olivine. In contrast, an enrichment in iron with respect to the Earth's mantle induces the coexistence of α and γ phases of olivine over a 2 GPa wide domain of pressures, corresponding to depths between 1000 km and 1200 km. Consequently an increase of the iron content smooths out the discontinuities over a thickness of 100–200 km.

In the past five years Europe has played a major role in the preparation of a network mission, the Netlander project. This project was based on a CNES–US collaboration, originally associated with the late Mars sample return mission, and with a European collaboration for the landers. In parallel, an EC Training Network called MAGE is developing planetary geophysical research in Europe. Budgetary constraints have, however, forced NASA to cancel its contribution and CNES to stop system activities on the entry and landing system. After 15 years of work, both the Network precursor experiment and a Network mission are still missing from the international strategy for Mars exploration: this could be an original contribution of Europe and ESA. ●

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