Timing of the Martian dynamo

On Mars, the strong magnetization in the highland crust of the southern hemisphere and the absence of magnetic anomalies at the Hellas and Argyre impact basins have been taken as signs that the core dynamo that once drove the planet's magnetic field turned off more than 4 billion years (Gyr) ago. Here, we argue instead that the Martian dynamo turned on less than 4 Gyr ago and turned off at an unknown time since then. High spatial resolution magnetometry in both Martian hemispheres is needed to reveal the true history of the Martian dynamo.

The discovery by Mars Global Surveyor of remanent crustal magnetization was strong evidence that Mars — which now has no magnetic field — once had a core dynamo. The onset and duration of dynamo action place strong constraints on a planet's thermal evolution. The persistence of the Earth's dynamo for the past 3 Gyr is attributed to the solidifying of the
inner core, with the consequent release of latent heat and with gravitational energy powering the magnetic field.

Terrestrial planets with a liquid core and no solidification of the inner core may lack a dynamo — as proposed for Venus. Although vigorous thermal convection in a liquid core could theoretically generate a magnetic field, no examples of this have been found in the terrestrial planets so far. Therefore, although an early dynamo driven by the cooling of a hot liquid core is possible, the most likely scenario for a terrestrial-type dynamo is onset after the beginning of inner-core solidification and shut-off when the core is substantially frozen.

The Moon provides support for this hypothesis. Correlation of Apollo subsatellite magnetometer data with lunar geology shows that magnetic fields were stronger over Imbrian age units than pre-Imbrian, consistent with a late dynamo turn-on. Lunar palaeointensity data show that a dynamo turned on relatively abruptly about 4 Gyr ago and that the magnetic field became weaker over 1 billion years. This late onset of the lunar dynamo may mark the beginning of inner-core solidification.

The belief that the Martian dynamo stopped after only several hundred million years has led to theories such as the cessation of a plate-tectonic style of mantle convection more than 4 Gyr ago. But we are not convinced that the early dynamo interpretation is correct, and believe the onset time of the Martian dynamo is uncertain.

Rather than requiring a dynamo that turned on and off over 4 Gyr ago, the evidence suggests that the dynamo did not begin until well after this. Only the weakness of the present Martian magnetic field limits its duration. The absence of magnetic anomalies at the Hellas and Argyre basins implies that the Martian dynamo did not exist until after the bulk of the southern hemisphere’s crust had formed. If it was operative then, the crust should have been magnetised. Large impacts that subsequently punched holes in the crust would have produced distinctive magnetic anomalies. As no anomalies associated with impact basins have been observed, the bulk of the crust in the south is not magnetised and there was no Martian dynamo at crustal formation or when the basins formed at about 4 Gyr or earlier. Impacts into the previously unmagnetised crust of a Mars with a magnetic field should have created magnetic anomalies.

Although we cannot rule out the possibility that the dynamo turned on after the southern crust formed and stopped before the major impact basins were formed, it is easier to explain its turn-on after 500 Myr of core evolution than its turn-off before this time. Models of core cooling suggest that a dynamo lasts longer than a few hundred million years, especially as core cooling leads to inner-core solidification that powers the dynamo as long as the inner core continues to grow. This dynamo action might await the onset of inner-core growth, which could take 500 Myr or more. So although dynamo action could be shortened by a change in Martian mantle convection from a plate-tectonic regime (efficient core cooling) to a rigid-lid regime (inefficient core cooling), we still believe that the onset did not occur until after 500 Myr of core evolution and the formation of the major impact basins.

If the dynamo turned on after the giant impact basins formed, then the magnetised southern regions must either be later magmatic additions to the crust (after 500 Myr of evolution) or thermal reworking of older crust. Although, on average, the crust has cooled over time, local regions have been heated by upwelling plumes. The non-uniformity of the magnetization in the south suggests that it arose mainly from localized heating and cooling events that postdate the global cooling to below the Curie point of the southern highland crust. As there does not seem to be magmatic activity in most of the magnetized regions, these heating events must have been due to upwellings smaller than those responsible for Tharsis and the Elysium volcanoes.

There is no unambiguous constraint on the dynamo turn-off time other than its absence at present. The remanence of the SNC (Shergotty, Nakhla and Chassigny) meteorites with formation ages of 1.3 Gyr to 180 Myr is consistent with ancient surface fields of 500 to 5,000 nanotesla (ref. 10), but there could be such fields at the surface of Mars even today. Nevertheless, the presence of localized magnetic anomalies in the younger crust of the northern hemisphere indicates that the dynamo could not have turned off too quickly. Strongly magnetized terrain also extends from the southern hemisphere highlands into the Tharsis region, one of the youngest surfaces on Mars, placed well after the heavy bombardment.

We believe that high spatial resolution magnetometry with balloons or airplanes in both northern and southern hemispheres would resolve the nature and timing of the magnetization, much as shipborne magnetometers improved our understanding of the Earth’s dynamo and plate tectonics.

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