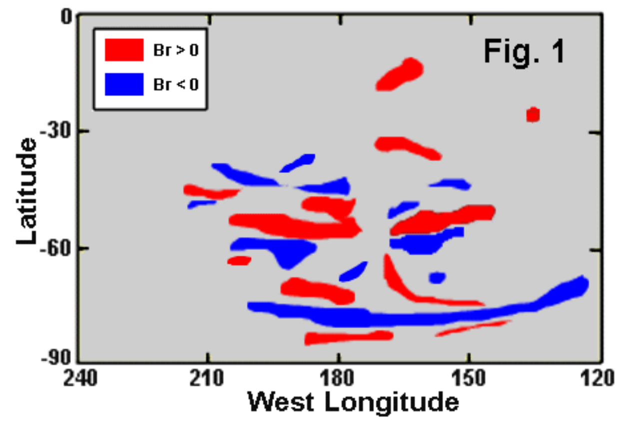
MAGNETIC LINEATIONS ON MARS: EVIDENCE FOR PLATE TECTONICS, OR FOR MAGNETIC EOLIAN DEPOSITS? A. Ruzicka, Dept. Geology, Portland State University, Portland, OR 97207-0751, U.S.A. (e-mail: aruzicka@uswest.net)

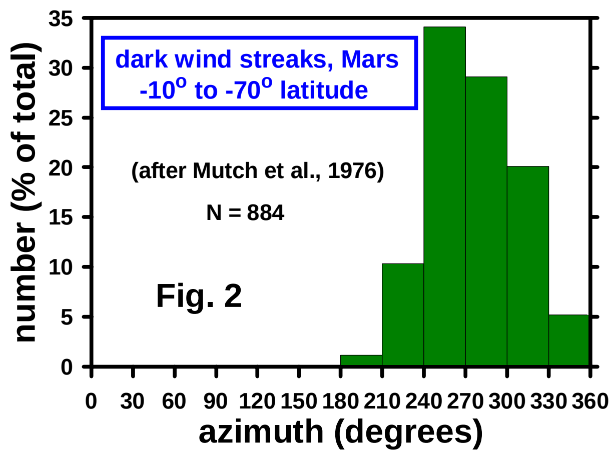
Introduction: One of the most striking results of the Mars Global Surveyor mission to date has been the discovery of intense and spatially extensive magnetic anomalies on Mars [1-3]. These anomalies are concentrated in the cratered uplands of Mars, often form lineations, and have been interpreted as evidence of ancient plate-tectonic processes on the planet [3]. Subsequent researchers [4-7] have tried to come to terms with the surprising conclusions of Connerney et al. [3]. Here, I explore the possibility that the magnetic anomalies on Mars are caused not by spreading processes, but rather by magnetized surficial deposits of initially eolian origin. This hypothesis has implications for the crustal structure and evolution of Mars that are obviously quite different from the prevailing plate-tectonic hypothesis.

Magnetic Anomalies on Mars: The spatial distribution of magnetic anomalies provide constraints on their origin. Fig. 1shows a map of magnetic anomalies in the Terra Cimmeria and Terra Sirenum region of Mars, using the same map area and projection scheme of Connerney et al. [3]. This area has the most numerous and intense magnetic anomalies on Mars [2,3]. Positive (red) and negative (blue) magnetic anomalies of the radial component of the magnetic field are indicated, as interpreted based on the data of Connerney et al. [3]. To create this map, interpolation was used between areas with missing or poor data coverage. A few other anomalies occur in this region, but their spatial extent are difficult to interpret, owing to incomplete data, and they are omitted from Fig. 1. Thus, Fig. 1 portrays the better-defined anomalies in this area. Most, but not all, of the magnetic anomalies on Mars are elongate and have an E-W trend (Fig. 1) [2,3]. Trends estimated for elongate anomalies range between ~75-115° W of N, but are concentrated around ~80-100°W of N. The apparent widths of the anomalies are comparable to the spatial resolution of the magnetic data (~100-200 km) [2,3]; their lengths range from ~200 to ~1100 km in the map area (Fig. 1). The longest large (positive) magnetic anomaly on Mars appears to occur [2] outside of the map area shown in Fig. 1, and stretches for ~2800 km from Terra Tyrhhena to Terra Arabia (~285-330°W, ~5-10°S).

The Eolian Hypothesis: The hypothesis that the martian magnetic anomalies were produced in part by eolian processes is motivated by the recognition that on Mars, eolian features are widespread, and magnetic grains are known to be ubiquitous on the surface [e.g., 8-10]. If a sufficient number of magnetized grains could be accumulated in localized areas, and if they could become oriented relative to one another, intense magnetic anomalies could potentially result.

Eolian features on Mars are manifested in part by streaks and elongate splotches that indicate wind directions, and in part by planetary-scale markings of high- and low-albedo surficial material [e.g., 8-10]. Inspection of albedo and wind-streak maps [e.g., 8-11] show that dark wind streaks and oriented dark splotches in craters occur near or in the areas of magnetic anomalies, although such features are not especially concentrated in these areas. Fig. 2 shows that dark wind streaks in the southern latitudes of Mars have consistent orientations, and suggests that the winds responsible for their formation blew mainly from east to west [e.g., 8-10]. This type of wind system could have been responsible for producing magnetic eolian deposits that trend primarily east-west, similar in orientation to the magnetic lineaments (Fig. 1). In contrast, the orientations of bright wind streaks do not agree with the orientations of the magnetic lineaments. Planetary-scale albedo features are often elongate and of similar length-scale to the anomalies. Indeed, the longest magnetic anomaly detected on Mars occurs adjacent to, and roughly parallels, the large, low-albedo telescopic feature, Sinus Sabaeus, and has a similar length-scale. Thus, the orientations of the magnetic lineaments and their spatial extent are consistent with an initial eolian origin for the magnetic lineaments.



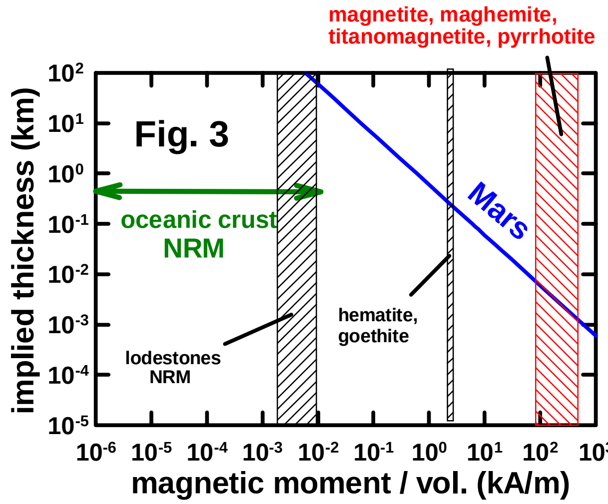


The intensities of the anomalies provide another important constraint. Fig. 3 shows the magnetization of various materials [12,13] compared to the thickness of deposits that would be needed on Mars to account for the data of Connerney et al. [3]. The latter authors suggested that if the martian anomalies are analogous to those produced by seafloor spreading, a substantial thickness of the martian crust would have to be magnetized. Assuming a remanent magnetization of 20 A/m, which is somewhat higher than the values observed for oceanic crust (Fig. 3), a 30-km-thick magnetized crust is needed [3]. If lower values of magnetization are assumed, even thicker sources are required (Fig. 3). However, there is no obvious reason why the magnetized slabs should extend so deep in the martian crust. The magnetic "stripes" in the Earth's oceanic crust extend only a few km deep [e.g., 12], an order of magnitude less deep than the models for Mars [3].

Instead, the martian anomalies may be produced by thinner, albeit more concentrated, deposits of more highly magnetized materials. The saturation magnetization of some minerals that may be present on Mars, such as magnetitite, maghemite, titanomagnetite, and pyrrhotite, are so high that "ore" deposits of these minerals could be only ~1-10 m thick and still account for the intensity of the magnetic anomalies (Fig. 3). Considerably greater thicknesses would be needed for deposits made of hematite or goethite (Fig. 3). Although relatively thin ore deposits can potentially account for the data, they are probably thicker than these calculations suggest, as the remanent magnetization of ore deposits of these minerals could be less than their saturation magnetization. In any case, it is clear that ore bodies on Mars would have to have considerably more remanent magnetization than shown [13] even by lodestone ores on Earth (Fig. 3).

As the martian magnetic anomalies are found mainly in the cratered highlands [2-3], deposits of magnetized grains would probably have had to form in the early history of Mars, when the planet's dynamo was still operating. In this case, initially airborne magnetic grains could have become oriented during settling to the surface, or by gentle wind action once the grains were on the surface. Presumably, different wind deposits would have been laid down during periods of alternate dynamo polarity, which could account for eolian streaks of alternate magnetic polarity. The postulated eolian deposits would probably have had to become lithified long ago, to prevent them from becoming remobilized by wind. They could have experienced additional magnetization by reactions leading to lithification. Thus, both depositional and crystallization remanent magnetization could have been involved in the formation of the hypothesized ores.

Assessment: The eolian model circumvents many potential problems with the spreading hypothesis. These include (1) a lack of overall bilateral symmetry for the anomalies (Fig. 1) [4]; (2) the larger magnitude and spatial widths of the anomalies on Mars compared to that of terrestrial ocean crust [e.g., 4,6,7]; and (3) the lack of any appreciable correlation between the magnetic anomalies and topography or geologic map units [e.g., 3,5,7] or gravity anomalies [e.g., 7]. For features initially produced by eolian activity, no bilateral symmetry would be expected, and no correlation with geologic structures, geologic units, gravity, or topography would necessarily occur, if the deposits were relatively thin. However, it remains to demonstrated whether highly magnetized ores could be produced on Mars by the processes envisioned here. Clearly, further study is needed.



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