A Possible Cause of Magnetic Anomalies on the Southern Martian Hemisphere *

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From the topology of a synthetic aurora map, we propose a mechanism for the magnetic anomalies on the southern martian hemisphere, i.e., impacts by asteroids when the dynamo is active. The quasi concentric circles of aurora suggest that there are two-to-three convectional cells for each impact. The whole synthetic aurora is induced by three major impacts of asteroids. The east–west lineation features of crust magnetizations are due to the east–west trending locations of three impacts. The alternatively changed sign of crust magnetization originates from the alternatively changed flow direction on the tops of adjacent convectional cells.

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The measurements by the Mars global surveyor (MGS) spacecraft established that Mars does not currently possess a significant global magnetic field. At the same time, strong and localized crust magnetic sources were detected, which are correlated with ancient, heavily cratered southern martian hemispherical highland.[1] These crust magnetizations are recognized as the evidence of a past dynamo that turned off 4 billion years ago. The crust magnetizations are often found to organize in east–west directional linear features and are thought of as the reminiscence of plate tectonics as on Earth by some researchers.[2] However, other researchers argue that the dynamo turned on after the formations of the Hellas and Argyre impact basins, the crust magnetizations were caused by later localized heating and cooling events like upwelling plumes.[3] The cause of magnetic anomalies remains an unsolved problem.

Several years later, the ultraviolet spectrometer spectroscopy for the investigation of the characteristics of the atmosphere of Mars (SPICAM) on board Mars Express spacecraft detected an aurora on Mars.[4,5] Soon after, a synthetic aurora map composed of several aurora observations was made.[6] It is this aurora map which gives us a clue for the possible cause of magnetic anomalies since the positions of aurora are where the strength of the radial component of magnetic field reaches a maximum.

In this Letter, we propose a mechanism for the crust magnetization, i.e., the impacts of several asteroids on young Mars when the dynamo was on action. After impact the stopped and deformed asteroid becomes a source of heat, leading to the formation of a flow domain with symmetry of an axis pointing vertically upward through the center of the heat source. Figures 1 and 2 show the flow, current and magnetic field induced by the impact of a single asteroid on two mutually perpendicular planes, respectively. Due to the limited size of the heat source, there would be only two or three convectional cells above it.

The number of convectional cells above a heat source depends on the ratio of the horizontal size to the underground depth of the heat source. The vertical gradient of temperature and the frictional force play an important role here. Each convectional cell has its horizontal scale (from its inner edge to its outer edge) comparable with its vertical scale. Therefore, for a horizontal large size heat source which is shallowly located underground, the number of convectional cells above it would be large (maybe more than three). In contrast, for a horizontal small size heat source which is deeply located underground, the number of convectional cells would be small (maybe less than two).

The cell size increases from the innermost cell (cell 1) to the second innermost cell (cell 2) due to the limited scale of a heat source. The outermost cell (cell 3) should be the largest due to the fact that there is relatively weak vertical temperature gradient. Accordingly the flow speed, current intensity and magnetic field strength should descend away from the axis. The horizontal scale of cell 1 (from the symmetry axis to its outer edge) should be comparable with the underground depth of the heat source as the temperature-induced buoyancy force needs to be balanced by the frictional force.

Suppose the magnetic field of the dynamo points vertically downward (the same argument and conclusion hold for an upward magnetic field), then on the top of cell 1, the outward flow of the electric conducting medium would induce an azimuthally circling current with its vortex pointing upward. On the top

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of cell 2, the inward flow would induce an azimuthally circling current with its vortex pointing downward. Finally on the top of cell 3, the outward flow would induce an azimuthally circling current with its vortex pointing upward again. Therefore, at the boundary between adjacent convectional cells there would be maximum upward or downward magnetic field due to the oppositely directed current on two sides of it. The magnetic field points upward at the center of cell 1, downward at the boundary between cells 1 and 2, upward again at the boundary between cells 2 and 3 and finally downward again on the outer edge of cell 3.

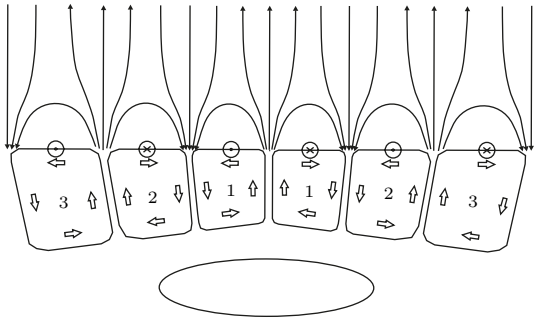

Fig. 1. A diagram shows the cross section of impact induced flow domain with the symmetry axis on it. The ellipse represents heat source. Numbers 1, 2, and 3 indicate the convectional cells. The arrows indicate the flow direction. The circles with dot or cross at their centers indicate the induced current direction. The lines with arrows at their ends indicate the induced magnetic field lines.

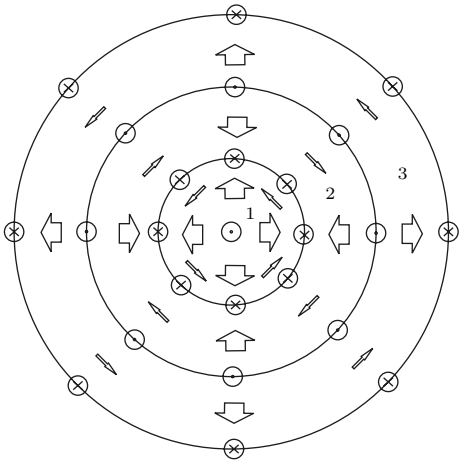

Fig. 2. A diagram shows the cross section of impact induced flow domain on the surface of Mars. Numbers 1, 2, and 3 indicate the convectional cells. The thick arrows indicate the flow direction. The thin arrows indicate induced current direction. The small circles with dot or cross at their centers indicate the induced magnetic field direction. The large concentric circles indicate the boundaries of convectional cells.

The magnetic field lines are closed at low altitude above each cell. Some magnetic field lines emitting from the boundary between cells 2 and 3 may enter the boundary between cells 1 and 2. Some may enter the outer edge of cell 3. Other field lines originated from the same place should enter space becoming open field lines. The same situation applies to the magnetic field lines emitting from the center of cell 1, some of them enter the boundary between cells 1 and 2, and others enter space becoming open field lines. The boundaries of cells and the center of cell 1 are potential places for aurora where magnetic field lines converge.[7] We think whether there is an observable aurora at the moment in the above-mentioned place or not depends on the condition of the solar wind and the orientation of the magnetic field lines at these places relative to the interplanetary magnetic field (IMF) in the solar wind, since an individual field line may switch from open to closed or vice versa by its interaction (magnetic reconnection) with IMF. Aurora will only appear at the feet of open field lines through the precipitation of high energy particles from the solar wind.

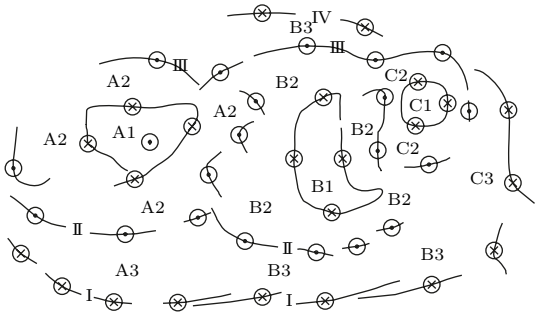

Fig. 3. Redrawn aurora map. Characters A, B and C represent heat sources. Numbers 1, 2 and 3 indicate convectional cells. Each line segment indicates the aurora arc. These line segments are also the boundaries of convectional cells. The circles with dot or cross at their centers indicate the induced magnetic field direction.

When two heat sources are nearby, each single impact induced flow domain is squeezed and deformed. The cells with the same upward or downward flow direction near the boundary between two impact domains would become neighbors (resulting in minimum friction), while cells with oppositely upward or downward flow direction would disappear. The aurora map tells us that the magnetic anomalies would probably be induced by three major impacts. Consequently, there would be three heat sources as shown in Fig. 3. Source B is located on the east of source A, and source C is located on the northeast of source B. On the two sides of the boundary between sources A and B, only cell 2 is left. The same situation applies to the boundary between sources B and C.

From the sizes of cell 1 of three heat sources, we can easily infer that source B is the deepest (with the largest initial impact energy), source A is the next deepest, and source C is the most shallow. Source C is younger than source B for two reasons. The first is that source B should last longer than source C due to its depth. The second is that in the north-east

of source B, cells of source B are deformed by cells of younger source C. We can marginally identify that the outer edge of cell 2 of source C has crossed the outer edge of cell 3 of source B (the place where medium has already frozen before the impact of asteroid C while the inner cells of source B are still active), which is strong evidence of a later impact of asteroid C. Sources A and B are nearly of the same age.

Due to the east–west trending locations of sources A, B, and C, the boundaries between cells 2 and 3 of three sources connect on the north side (line Ⅲ). There is a maximum upward magnetic field at the boundary. The same situation also applies to the south side (line Ⅱ). The outer edges of cell 3 of sources A and B connect smoothly on the south (line I), accompanied with a maximum downward magnetic field. Between lines Ⅱ and Ⅲ, there is a domain dominantly occupied by cells 1 and 2 of three sources, an area with downward magnetic field at the boundaries between cells 1 and 2, and upward magnetic field at the boundaries between adjacent cells 2. On the north of Line Ⅲ stands the outer edge of cell 3 of source B (line Ⅳ), accompanied by a maximum downward magnetic field. Special attention needs to be paid to a tiny spot inside cell 1 of source A, a place with upward magnetic field. The east–west orientated lines I, Ⅱ, Ⅲ and Ⅳ are consistent with the observed east–west trending linear features of the crust magnetizations. The alternatively changed sign of the magnetic field at lines I, Ⅱ, Ⅲ and Ⅳ also agrees with the observations of MGS. In our model, this alternation of magnetic field sign originates from the alternation of the flow direction on the top of adjacent convectional cells.

It is important to point out that the embedment of source C inside cell 3 of source B is evidence that heat sources do not originate from inside of Mars but from outside (impact of asteroid), since the former would have a smooth flow pattern, i.e., source C would be a neighbor of source B instead of being surrounded by the outer cell of source B. The point of the external origin of heat source is also supported by the shallow and localized distribution of heat sources over the martian surface. The fact that there are two to three convectional cells above each source indicates that impacts occurred before the formation of crust or in its very early onset.

From the pattern of the aurora, we infer that it was induced by ancient impacts of asteroids. However, impacts of asteroids should be random over the martian surface, so why does aurora caused by three major impacts concentrate at that part of the southern hemisphere? Though this problem is beyond the scope of our study, we can guess that this area is somehow special by its composition (higher electric conductor) or by the downward magnetic field of dynamo that is much stronger (southern magnetic pole perhaps) than at other areas. Outside the magnetic pole regions, magnetic field has dominant horizontal component which has much weaker electric induction effect. Therefore nothing of significant magnetization is left.

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