MAGNETIC ANOMALIES OF IMPACT CRATERS AT LOW MAGNETIC LATITUDES

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Abstract

Hypervelocity meteor impacts create circular or oval craters and fracture the subsurface. This fracturing has been associated with geothermal resources, metallic ore deposits, and even oil and gas fields. These practical targets give the study of meteor impacts importance aside from the several more basic scientific reasons for impact crater research. An examination of the worldwide distribution of known impact crater locations shows that very few craters appear on or near the magnetic equator. Although this could be mere chance, it is possible that some low latitude impact craters are buried or hidden by heavy vegetation and are overlooked because their magnetic anomalies do not appear particularly ring-like. Magnetic anomalies from impacts are variable, but three main categories capture the majority: (1) simple ring anomalies created by the uplifted rim of the crater, (2) complex crater anomalies consisting of an outer ring and a center anomaly, and (3) a simple crater filled with non-magnetic debris in modestly magnetic bedrock. At low magnetic latitudes, each of these types can produce induced magnetic anomalies with sufficient magnitudes for detection by aeromagnetic surveys, but which are not decidedly ring-like in appearance. Low latitude rings usually show sizeable anomalies only at their north, south, east, and west extremities. The east and west anomalies may not be large enough spatially to detect with wide line spacing, but the north and south anomalies are usually spatially broad. Most of the remainder of the ring is of such low magnitude as to be almost undetectable. Complex craters produce sizeable magnetic lows in the center. Craters filled with non-magnetic debris may produce detectable magnetic highs. The ability to predict what types of anomalies may be formed by low magnetic latitude impact craters may be useful in identifying these structures in areas such as West Africa or Brazil, where dense vegetation and poor access make detailed initial inspection problematic.

Introduction

Although there is no good reason to believe that planet Earth has received markedly fewer meteor impacts than other inner Solar System planets or moons, we know of only about 175 meteor impact craters on the Earth's surface. The distribution of these craters is shown in Figure 1. The distribution of known impact craters follows a curious pattern. Rather than the distribution being even over the Earth's land surface, most of the known craters are found in either Europe or North America, with several more found in the Sahara Desert and Australia. From this distribution, it appears that the density of craters is greatest in populated Western countries where the density of scientists is also high, or in arid areas where craters are somewhat easier to find.

Of the areas without many known impact craters, Siberia stands out, as does Amazonia, and sub-Saharan Africa. The identification of impact craters in these areas is hindered by problems with access, and by dense vegetation. However, there is another zone with few or no known impact craters which is not so readily identifiable, but can be seen in Figure 2. The region around the Earth's magnetic equator is effectively devoid of known impact craters. This is no doubt in part because of the previously mentioned issues of access and vegetation. However, I suggest another factor may come into play; that is, the magnetic anomalies of craters in the vicinity of the magnetic equator do not appear to be especially ring-like, as so many appear in northern latitudes. Could it be that we are overlooking impact craters at low magnetic latitudes because their low latitude magnetic signatures are so different from what we expect at high latitudes?

In this expanded abstract, I examine some of the different ways impact craters cause magnetic anomalies, and model what these anomalies might look like at magnetic equatorial latitudes.

Figure 1. Locations of known impact craters.

Figure 2. Magnetic equator overlain on locations of known impact craters shown in Figure 1.

How Meteors Cause Magnetic Anomalies

When large bolides travelling through space intersect the Earth, their speed is hardly affected, and they crash into the Earth at speeds of tens of kilometers per second. These impacts are termed "hypervelocity" impacts, and they often leave oval or circular features that are manifested by changes in topography, by circular lakes, and by subsurface changes that can be detected by geophysical methods. Changes in seismic velocity and rock density make seismic reflection and gravimetry useful methods for studying impact craters, but these methods are most often used when there is already a strong suspicion of the existence of a crater. In contrast, aeromagnetic data has been collected over large swaths of almost every continent for various reasons, and these data can be accessed and examined for the magnetic anomalies that could indicate impact craters.

The magnetic anomaly of impact structures may be complex. There are four basic processes that produce magnetic anomalies in and around impact structures:

- the formation and deposition of magnetized impact rocks;
- the displacement of magnetized rocks in the impact cratering process;
- the decomposition of existent rock magnetization by shock; or
- the formation of new magnetic phases in rocks.

Hypervelocity impact craters come in a wide variety of sizes, but most of them have a somewhat circular shape. Craters can be classed as either simple or complex, as illustrated in Figure 3. Simple craters are circular features having the central portion gouged out. The edge of the crater may be upturned, and debris may be scattered some distance beyond the crater. Rarely does a significant amount of the impacting bolide survive intact. At middle to high magnetic latitudes, simple craters may form ring-like magnetic anomalies simply because the upturned rim is closer to the magnetometer in an aeromagnetic survey. In other instances, simple craters appear because they disturb the magnetic pattern in the surrounding bedrock by their absence of magnetic material. Figure 4 shows this type of simple crater in magnetic data from northeast South Carolina (Talwani et al, 2003).

Complex craters are formed when the impact is so strong that it produces wave-like undulations in the bedrock. Complex craters usually have an uplifted zone in the center and may have one or more rings. The Yallalie structure in the Perth Basin of Western Australia, shown in Figure 5, is an example of a buried complex crater with an easily discernible magnetic signature showing the central uplift and multiple rings.

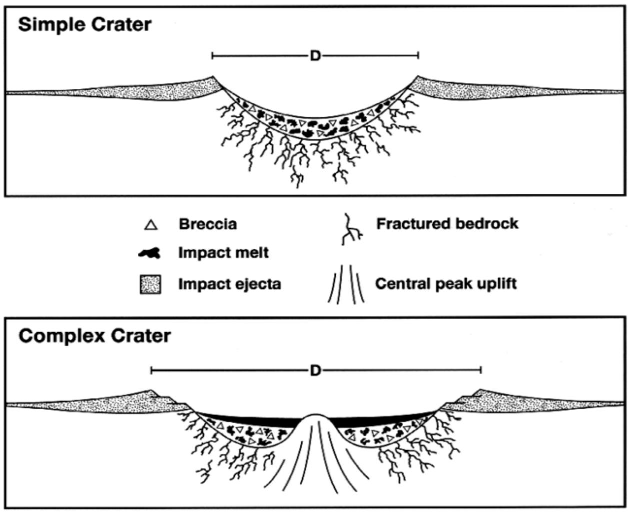

Figure 3. Cross-sections of simple and complex impact craters. (Image extracted from web site http://craters.gsfc.nasa.gov/assests/image/craterstructure.gif)

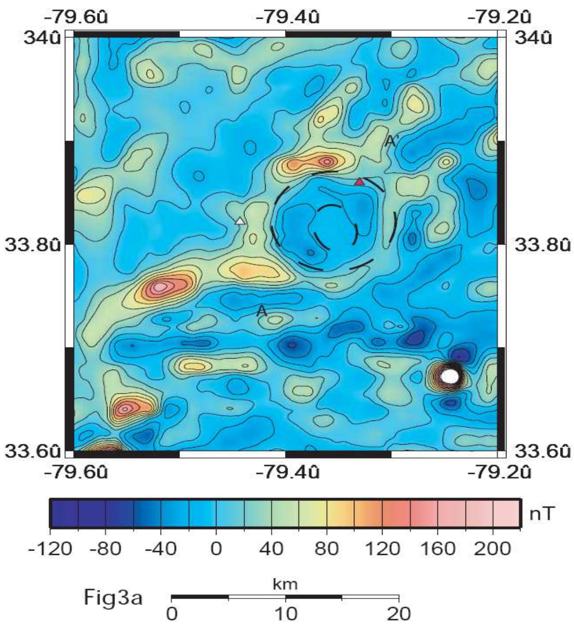

Figure 4. Magnetic anomaly formed by the absence of magnetic material in a buried crater in a marshy area in northeast South Carolina (extracted from Talwani et al, 2003).

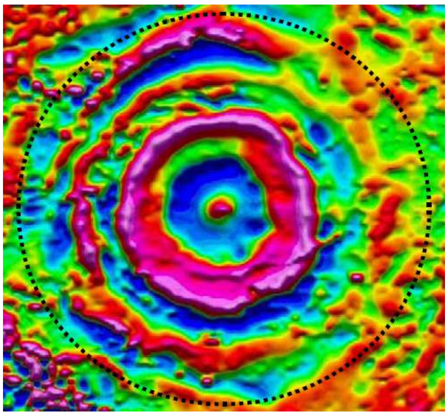

Figure 5. The aeromagnetic anomaly of the Yallalie structure in West Australia clearly shows the main elements of a complex crater. The dotted circle has a diameter of 15 km. (Extracted from Hawke, 2003)

Magnetic Anomalies of Impact Craters at Low Latitudes

To get an idea of the magnitudes and types of anomalies produced by low magnetic latitude impacts, I computed the induced magnetic anomalies that might be produced by simple and complex craters in a gneissic bedrock having a magnetic susceptibility of 0.004 SI units. For the high latitude case, I used a magnetic field intensity of 46820 nT, a magnetic inclination of 60 degrees, and a declination of 0 degrees. For low magnetic latitudes, I used a magnetic field intensity of 33000 nT, a magnetic inclination of 5 degrees, and a declination of 0 degrees. I modeled an aeromagnetic survey in which the magnetometer altitude was 30 m above ground level, the line spacing was 100m, and the lines were surveyed north-south. To get an order of magnitude estimate of what anomaly might be expected from a volcanic or sedimentary setting, one can multiply or divide the gneissic response by 10, accordingly.

The induced magnetic anomalies produced by a simple crater are shown in Figure 6. For the model, the ring is 200m high and 1000m wide (outer radius-inner radius), and 10 km in diameter. It has the same susceptibility as the gneissic bedrock (0.004 SI). For the high latitude model, the ring structure is clearly delineated as a circular magnetic high. A magnetic S-N profile through the center of the anomaly produces two 95 nT peak-to-peak magnetic anomalies over the edge of the rings (Figure 7, left panel). The low latitude anomaly is very different in character. It has broad negative anomalies over the north and south portions of the ring, and the east and west extremes produce locally small but high magnitude dipolar E-W anomalies. However, because of their small size, these latter could be easily missed in a survey with a wider line spacing. The remainder of the ring produces such small magnitude anomalies as to be undetectable in a reasonably varying background. The north and south magnetic lows are the most reliable feature to indicate the presence of the ring, and as shown in Figure 7 (right panel), the anomaly magnitudes, though only about half the peak-to-peak magnitude of the high latitude model, are still easily detectable.

For a complex crater, I modeled a single ring with the same parameters as I used for the simple ring, but also included a central magnetic zone. The central block is 600m thick and has lateral dimensions 3km x 3km. Figure 8 shows the high and low latitude magnetic responses for the same survey parameters as were used in the simple crater model. The anomaly produced by the high latitude model appears very familiar to most of us, but the low latitude model is trickier to interpret, and might go unrecognized as a complex ring-structure. The central dome in both models produces the maximum peak-to-peak anomaly. For the high latitude model it is 160 nT and for the low latitude model it is about 60 nT. The south-to-north profile of the low latitude anomaly is shown in Figure 9. Note that the central dome anomaly is largely negative over the dome, with positive anomalies at the north and south outside edges of the dome.

The final example I show is the low latitude anomaly produced by a crater hole in gneissic bedrock with magnetic susceptibility of 0.004 SI. In this instance there is no uplifted rim, simply a 3km x 3km hole filled with non-magnetic debris. Figure 10 shows the anomaly produced by the hole in plan view (left panel) and in south-to-north profile (right panel). The anomaly produced is positive, with a magnitude of more than 50 nT. Although this might appear normal to, say, a Brazilian or an Ethopian geophysicist, it may seem counterintuitive to someone with little experience in low latitude magnetics that a non-magnetic hole can produce a strong positive anomaly.

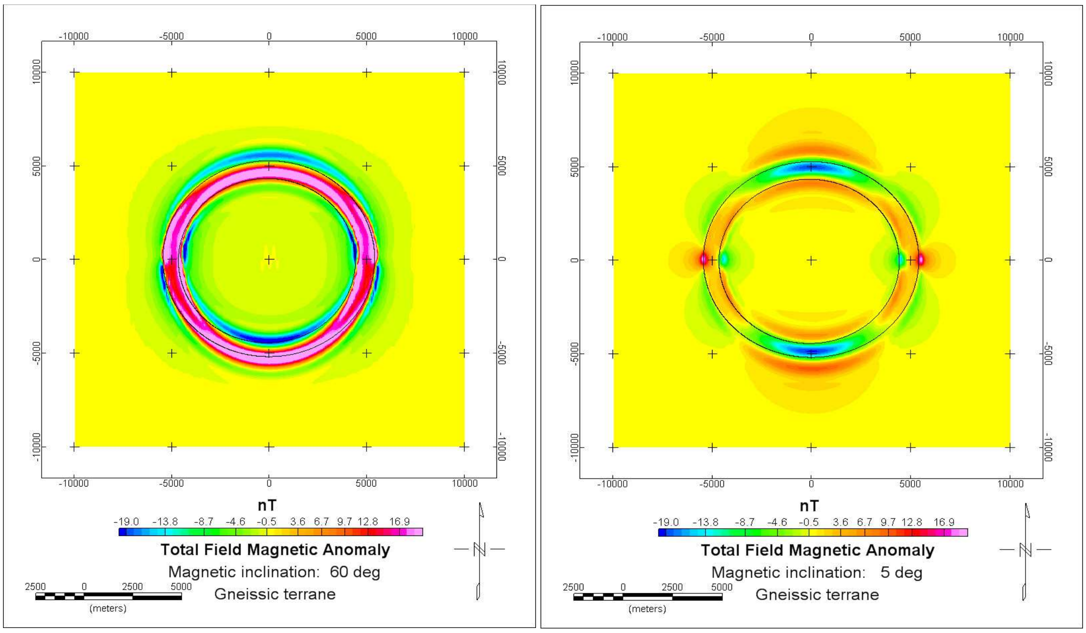

Figure 6. Magnetic anomalies produced by the magnetized ring of a simple impact crater at high magnetic latitudes (left) and low magnetic latitudes (right).

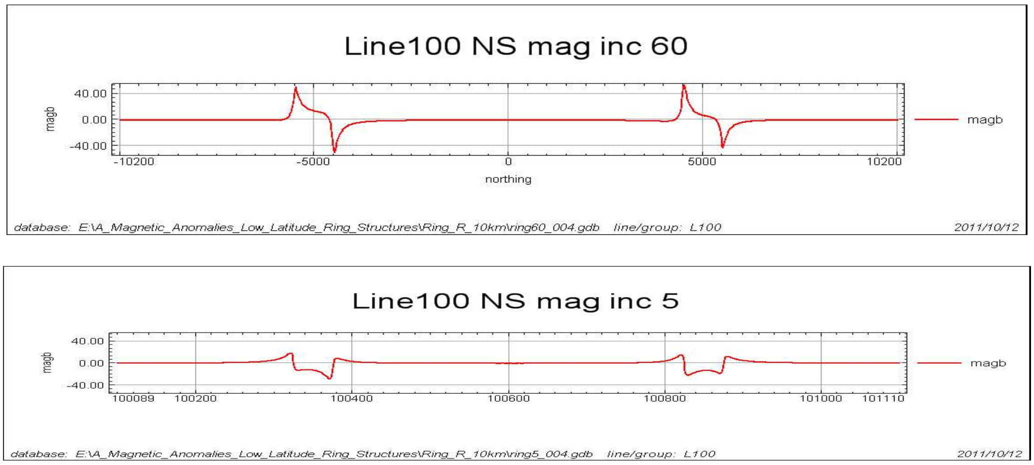

Figure 7. South-to-north profiles through the centers of the magnetic anomalies shown in Figure 6.

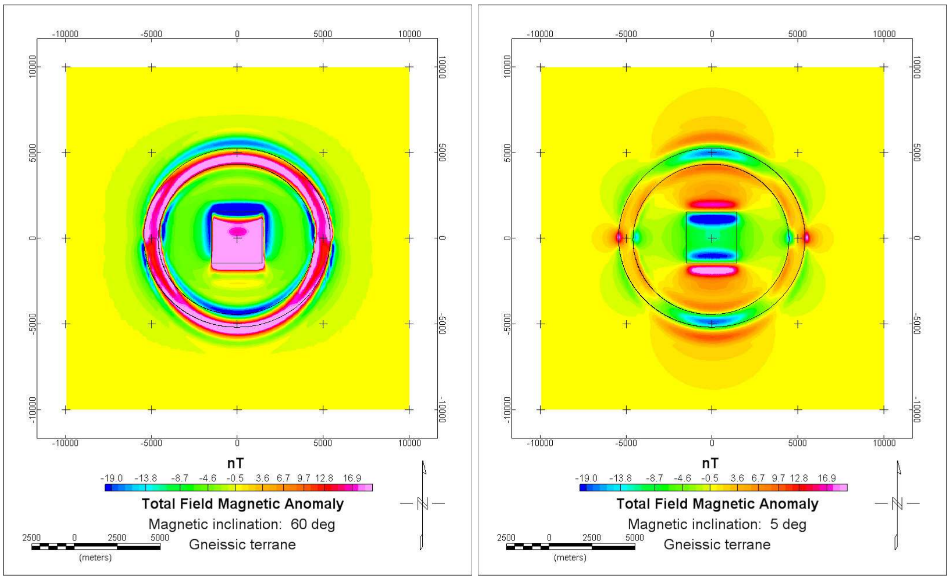

Figure 8. Magnetic anomalies produced by the magnetized ring and central uplift of a complex impact crater at high magnetic latitudes (left) and low magnetic latitudes (right).

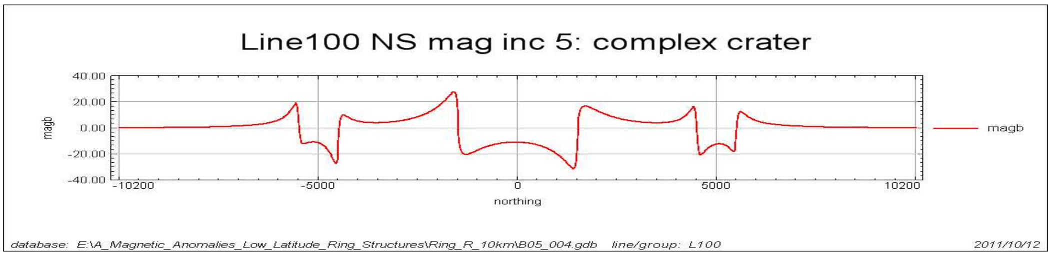

Figure 9. South-to-north profile of the magnetic anomaly produced by the complex impact crater at low magnetic latitudes.

DISCUSSION AND CONCLUSIONS

The dearth of impact craters in the vicinity of the Earth's magnetic equator might simply be a matter of chance. However, many of the countries through which the magnetic equator passes are heavily vegetated (e.g. Brazil) and/or has poor infrastructure development (e.g., Somalia). Both these factors make discovery of impact craters more difficult. Geophysics can help in the effort to discover buried or obscured craters, and airborne magnetic data in particular can be useful, so long as one knows what kind of anomalies to look for. At low magnetic latitudes, north-south trending structures may produce only very small induced magnetic anomalies; the largest anomalies come from east-west boundaries. In searching magnetic databases for low latitude simple ring-line impact craters, one should look for modest negatives coincident with the ring on the north and south sides. Complex craters may also have a strong negative anomaly associated with the central uplift. Simple craters formed in modestly magnetic bedrock may be filled with non-magnetic debris, and at low magnetic latitudes, these may produce a positive magnetic anomaly.

As some commonly used reduce-to-pole transforms tend to be unstable in the presence of noise at very low magnetic latitudes, I believe the interpreter needs to develop an intuition as to what equatorial anomalies look like "in the raw."

I have intentionally not considered the effects of remanent magnetization in this study, even though it may be fairly common. Remanence adds a degree of complexity that I feel is unwarranted until a clear understanding of the induced anomalies has been achieved.

REFERENCES

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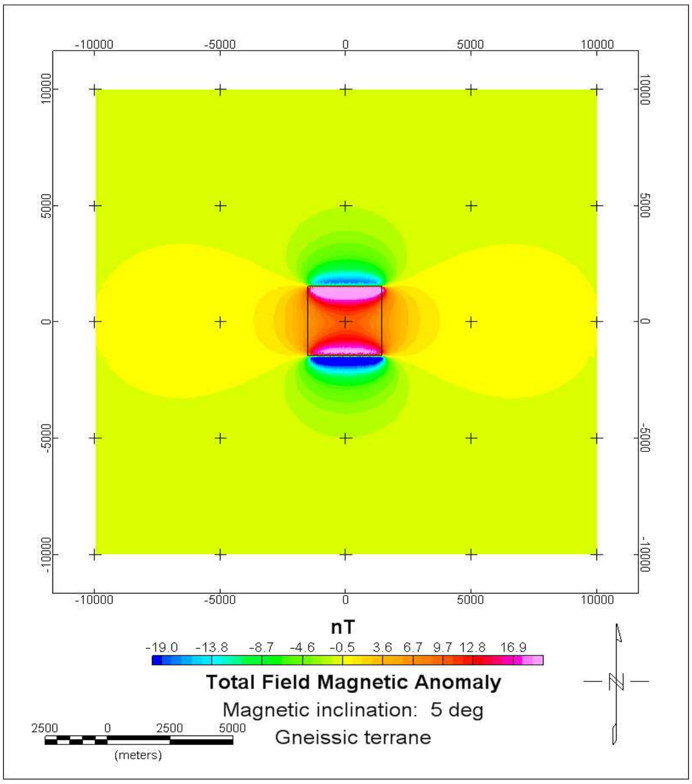

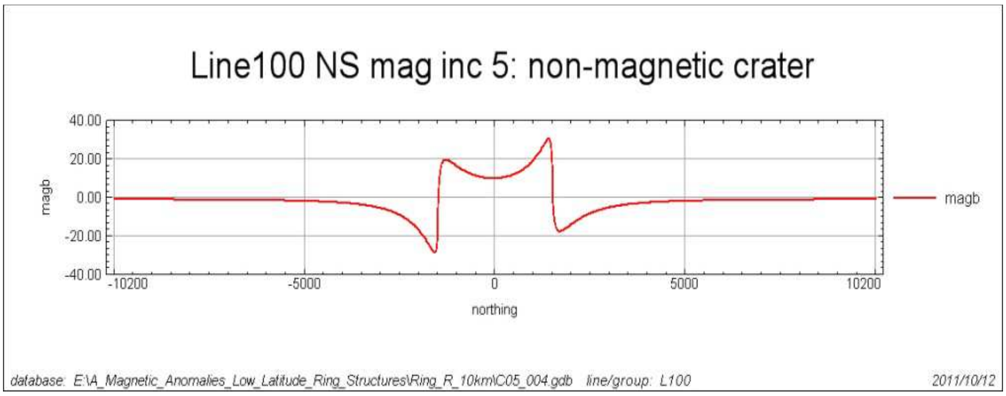

Figure 10. Anomaly produced by a low latitude crater hole filled with non-magnetic material in a slightly magnetic host rock. Top panel: Plan view of the anomaly. Bottom panel: South-to-north profile of the low latitude magnetic anomaly produced by the non-magnetic crater.