MAGNETIC ANOMALIES OF CRATER FIELDS DETECTED BY DRONE

M. Takac[1], R. Kavkova[1,2], G. Kletetschka[1,2,3], V. Petrucha[4] [1]Faculty of Science, Charles University, Czech Republic, [2]Institute of Geology, Academy of Sciences of the Czech Republic, Czech Republic, [3]Department of Geology and Geophysics, University of Alaska Fairbanks, USA, [4]Technical University, Faculty of measurements, Prague, Czechia, (takacma@natur.cuni.cz).

Introduction: Airless planetary surfaces are covered by multiple impact craters. Such impact cratering processes allow understanding not only deformation that takes place but also the nature of the impactor if the composition of the crater field can be accessed. In this work we focus on impact craters that were created by an iron impactor. One example of such crater is the Berringer/Arizona crater in Arizona. Another is recently discovered crater in Greenland [1] that is believed to be also created by an iron impactor. Once the iron hits the planetary surface there is evaporation and melting while the initial crater shape is formed. Apart from the ejection and evaporation of both target and impactor material, portion of the impactor material mixes with the target rock and is left in the crater fill. The distribution of the impactor material would relate to the direction and angle of the impact process [2]. In case of iron, we hypothesize that the crater fill would contain inhomogeneous iron distribution, more iron would be contained in the direction of the impact. We also hypothesize that in case of the vertical impact the maximum iron concentration of the impactor material would be in the crater center. However, in the case of e.g. 45 degree angle, the maximum concentration would be off centered approximately half way between the crater center and the crater rim. If the impact angle would be steeper (e.g. 60 degrees) the maximum iron concentration would be closer than half way from the center toward the rim in the impactor direction. Here we describe how this distribution can be detected magnetically.

Iron material has significant induced magnetization. For this property any iron mixing with planetary substrate exposed to inducing magnetic field (e.g geomagnetic) can be characterized by well-planned magnetic survey. In case of 90 degree angle, the iron distribution near the crater center would generate induced magnetic field. If the cross dimension of the volume of the enhanced iron distribution would be comparable or larger than the distance of the altitude of the magnetic survey one would identify magnetic dipolar field whose axis would be parallel with the direction of the ambient geomagnetic field. Identification of the dipole magnetic signature in respect to the crater center should be give its position near the center in respect to the crater diameter. If , however, the impactor angle would any other than 90 degrees, the off-centered iron distribution would generate induced magnetic dipole whose center would be also off-centered along the direction of the impact. In case, however, when the altitude of the magnetic survey is smaller than the dimension of the volume of iron mixing, the resulting survey would identify the approximate position of the boundaries of the enhanced iron mixing.

Arizona crater serves as a good example. Magnetic mapping was done prior 1975 [3]. Magnetic anomalies can reveal distribution of the magnetic sources at depth under the crater [4, 5, 6]. Because the impactor's composition is iron, it provides induced magnetization that can be revealed by magnetic survey [4,6]. Iron-generated magnetic anomalies may provide an indicator of the direction of the impact and its angle. This is because part of the material from the impactor mixed with the underlying material and stayd inside the crater on the opposing side from the incoming direction [2] [7]. Detailed analysis of magnetic anomalies [3] reveals the off centered SE location which gives the hints of the incoming direction of the impact. The distance of the overall magnetic anomaly signature from the center of the impact may provide a constrain for the angle of this impact.

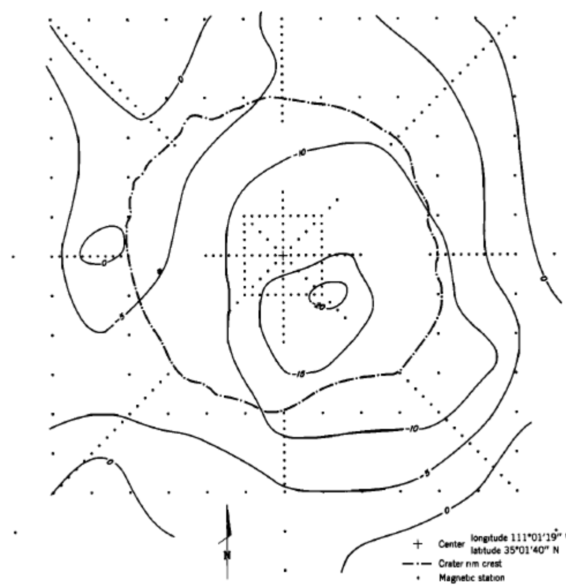

Fig. 1, Magnetic anomalies over the Arizona crater modified from [Regan and Hinze, 1975][3].

Another example is Hiawatha crater in Greenland where the 4 km survey over 31 km diameter crater indicates magnetic anomaly off centered towards south.

We performed a field testing over the former military testing ground that experienced intense mixing with the iron material. Testing area was measured autonomously, magnetometer data were collected simultaneously with photogrammetric data. Final magnetometer map of the impact structures can be correlated with actual 3D model of the surface which was captured at the moment of acquiring magnetometer data. Our data Fig 2 shows how mixing of iron from the impacts increases away from the roads and forest that was avoided during the testing. While the altitude of the survey was 75 m, we detected the magnetic enhancement constituting about 10 nT from the iron mixing of the soil from the impacts.

Fig. 2: Magnetic survey over the former army impact field focused on the area away from the road and forest. The data are the difference between two identical magnetometers (ground station and drone).

Magnetometry is well known and proven method used for mapping of impact structures. In planetary scales, satellite magnetometry is common. Small (meters in diameter) impact structures could be tricky to determine. An unmanned autonomous vehicle equipped with magnetometer can be used for detailed magnetometer survey on or above a ground surface.

Material and Instruments: For the first time we used pair of magnetometers that have total mass of less than 500 g, including the battery where one serves as a base station and the other is part of UAV (unmanned aerial vehicle) – drone. Both magnetometers are three-axis vector fluxgate magnetometers with flat-ring cores. A similar device would be used on Mars. For testing field on Earth we have chosen an old military rocket testing field. It is a fall area where many rockets hit the ground in the area between the roads and forest. Magnetometer data were collected with two parallel magnetometers where one served as a ground station and one was part of the autonomous drone.

Acknowledgments: This work was supported by GACR 17-05935S, and grant RVO 67985831.

References: [1] Kjær, K.H., et al. (2018). *Science Advances* 4, 11: eaar8173. [2] Pierazzo, E., and H. J. Melosh (2000). *Meteorit. Planet. Sci.,* 35(1), 117-130. [3] Regan, R. D. & Hinze, W. J. (1975) *JGR* 80(5), 776-788). [4] Kletetschka, G., and J. H. Stout (1998). *Geophysical Research Letters*, *25*(2), 199-202. [5] Kletetschka, G., et al. (2000). *PEPI* 119(3-4), 259-267. [6] Kletetschka, G., et al. (2015). , *Ieee Sensors Journal*, *15*(9), 4875-4881, [7] Shoemaker, E. M., et al. (2005), *Aust. J. Earth Sci.*, *52*(4-5), 529-544,