EGU22-8906
https://doi.org/10.5194/egusphere-egu22-8906
EGU General Assembly 2022

Studying Terrestrial Impact Structures With Cosmic-Ray Induced Atmospheric Muons

Teemu Öhman[1], **Marko Holma**[1,2], and Pasi Kuusiniemi[1,2,4]
[1]Arctic Planetary Science Institute, Finland (teemusp.ohman@gmail.com)
[2]Muon Solutions Oy (marko.holma@muon-solutions.com), Finland
[4]International Virtual Muography Institute, Tokyo, Japan

Muography is used in, e.g., volcanology, archaeology, engineering and mineral exploration to characterise material densities [1–2]. To our knowledge, muography has not been applied for impact crater studies.

Muons are produced in the atmosphere as a by-product of particle reaction cascades commenced when high-energy cosmic-ray particles collide with air nuclei. Muons lose energy at a rate dependent on the density of the material. Muon counts are translated to density information and radiographic (2D), tomographic (3D), or time-lapse images. Joint inversion of muographic and gravity or seismic data is also possible [1,3].

Muon detectors are muon telescopes (MT) or downhole detectors (DD). The larger MTs "see" one direction at a time. DDs fit standard drill holes and "see" 360° but typically with a lower spatial resolution. They collect muon data from a conal volume of rocks.

Muography is energy-efficient and does not require radiation sources. In addition, muographic data are not affected by parameters other than density and, to a minor extent, chemistry. Also, the user has a lot of control for obtaining the required data quality and image resolution (e.g., more and/or larger detectors or longer surveys improve both parameters). This is a notable advantage over most other types of geophysical instruments.

The muon flux diminishes quickly with increasing depth. Hence, the deeper the detectors, the longer the surveys. In caves and mines below ~0.5 km, the measuring times have typically been months to years. However, this is not a severe challenge for impact structures, as most of them are shallow features and, consequently, the flux of muons has not yet been seriously diminished.

Every 1% difference in density provides an easily detectable ~3% difference in the muon flux. Granitoids have densities around 2600–2800 kgm^{-3}, while mafic rocks can reach ~3000 kgm^{-3}. In contrast, the densities of suevitic breccias vary substantially depending on the melt and clast contents, hydrothermal overprint, and weathering. They often have densities of ~2200–2300 kgm^{-3}, while the densities of impact melt rocks tend to lie between those of target rocks and suevitic breccias. Fault breccias in crater rims and central uplifts can have densities ~100 kgm^{-3}

lower than the surroundings.

A combination of MTs and DDs may provide the best results for impact structures. Topographic central peaks can be studied by both techniques. Crater fill materials and subdued central uplifts can be imaged via DDs. For preserved rims, it is best to use MTs on the crater floor or the terrace zone. The rims of shallow impact structures may be difficult for MTs, because only a few approximately horizontal muons bear information on the rim. In such a case, DDs can be applied much deeper, but the measurement may take longer. Overall, muography provides a cost-effective and more comprehensive 3D view of the crater than drill cores alone.

References: [1] Cosburn K. et al. (2019) *Geophys. J. Int., 217,* 1988–2002. [2] Zhang Z.-X. et al. (2020) *Rock Mech. Rock Eng.,* 4893–4907. [3] Le Gonidec Y. et al. (2019) *Sci. Rep.,* 3079.