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Muography as a Novel Field Observation Tool of Geomorphic Research

Marko Holma[1,2], Adrian M. Hall[5], Pertti Sarala[6], Niko Putkinen[7], Hiroyuki K.M. Tanaka[8,9,4], László Oláh[8,9,4], and Pasi Kuusiniemi[2,3,4]

[1]University of Oulu, Kerttu Saalasti Institute, Nivala, Finland (marko.holma@oulu.fi)
[2]Muon Solutions Oy, Finland
[3]Arctic Planetary Science Institute, Finland
[4]International Virtual Muography Institute, Tokyo, Japan
[5]Department of Physical Geography, Stockholm University, S-10691 Stockholm, Sweden
[6]University of Oulu, Oulu Mining School, Oulu, Finland
[7]Geological Survey of Finland, Espoo , Finland
[8]Earthquake Research Institute, The University of Tokyo, 1-1-1 Yayoi, Bunkyo, Tokyo 113-0032, Japan
[9]International Muography Research Organization (MUOGRAPHIX), The University of Tokyo, 1-1-1 Yayoi, Bunkyo, Tokyo 113-0032, Japan

Cosmic-ray muography is a novel methodology for monitoring and spatial imaging density variations in solid and liquid materials. It is based on the translation of the “raw” muon flux attenuation data to meaningful images that visualise the target’s bulk density radiographically (2D) or tomographically (3D). Both can also be applied as time-sequential mode allowing long-term monitoring of density-affecting processes. The core strength of muography is that it permits the observation of processes that change density and occur in timescales from hours to years. In geosciences, this may allow, for example, monitoring of glaciers, ground frost, movements of waters and fluids, propagation of fractures, and detection of faults. In the latter case, periodic drying may render a fault muographically visible during monitoring. Large faults can be imaged also directly. The already classic application of applying muography for long-term monitoring of active volcanoes allows detection of magma ascent and, therefore, early warnings of possible eruptions. In addition, muography can also be used for practical and industrial applications such as tunnelling, mining and geo- and civil engineering. In these cases, muography provides unique opportunities for long-term monitoring of activities and work safety.

The capabilities of muography are particularly fitting for studying bedrock fractures, weathering and the inner structure of different landforms that (a) comprise at least a few percentage differences between bulk densities of two or more rock or soil types (or their mixtures), (b) are located within the uppermost few hundreds of metres of crust, and (c) allow the installation of the muon detector(s) below or side of the volume of interest. Regarding the latter, detectors must be positioned between the open sky (the source of muons) and the volume of interest (object). In geomorphic research, appropriate settings for muography include the sides of mountains, hills,

valleys, cliffs, gorges, glacigenic deposits, river terraces, caves, tunnels or boreholes. Many of the current muon detectors are mobile and robust, and due to self-sustainability, automation and remote access to data, they allow field measurements even in distant, rugged or harsh environments.

Our earlier research has demonstrated that the actual muography data can, for example, detect concealed faults and fractures, visualise and monitor groundwater table, reveal permeability barriers or zones of high porosity in soil and rock masses, image density anomalies in crystalline rocks, detect ascent of magma within an active volcano, and map out natural caves. Other researchers have demonstrated and proposed many other exciting applications in geoscience, archaeology, civil engineering, and many other fields of human activity. We suggest that muography provides extraordinarily fresh prospects for studies of the structure of many different types of landscape elements and monitoring and, perhaps, predicting their evolution [1]. The possibilities include research on soil erosion, subsurface fracturing and weathering, hillslope evolution, groundwater reservoirs, river channel erosion, drainage divides, glaciers, landslides, karst terranes and their aquifers, sinkholes, collapses, regoliths, saprolites, bauxites, soil geoengineering, and short- and long-term climate change.

[1] B. Ferdowsi et al., Earthcasting: Geomorphic Forecasts for Society, Earth’s Future 9, e2021EF002088. doi:10.1029/2021EF002088.