

Location of water deposits in the polar regions of the Moon. Gunther Kletetschka ^{1, 2*}, Jaroslav Klokočník ³, Nicholas Hasson ^{1, 4} Jan Kostelecký ^{5, 6}, and Aleš Bezděk ^{3, 7}, ¹Geophysical Institute, University of Alaska, Fairbanks, 903 N Koyukuk Drive, Fairbanks, AK, USA, gkletetschka@alaska.edu, ²Institute of Hydrogeology, Engineering Geology and Applied Geophysics, Faculty of Science, Charles University, Albertov 6, 12000 Prague 2, Czech Republic, ³Astronomical Institute, Czech Academy of Sciences, CZ 251 65 Ondřejov, Fričova 298, Czech Republic, ⁴ Water and Environmental Research Center, Institute of Northern Engineering, University of Alaska Fairbanks - Fairbanks, AK 99775 1764 Tanana Loop AK, USA, ⁵ Research Institute of Geodesy, Topography and Cartography, CZ 250 66 Zdiby 98, Czech Republic, ⁶ Faculty of Mining and Geology, VSB-TU Ostrava, CZ 708 33 Ostrava, Czech Republic, ⁷ Faculty of Civil Engineering, Czech Technical University in Prague, CZ 166 29 Praha 6, Czech Republic

Summary: Our Moon periodically moves through the magnetic tail of the Earth that contains terrestrial ions of hydrogen and oxygen. Reconnection inside this magnetosphere's tail reverts the ions flow back to the Earth and allows for oxygen and hydrogen transfer into the lunar surface regolith when the Moon is inside the Earth's terrestrial magnetosphere. We discovered, using gravity aspects, this inference reveals polar deposits of potential frozen water signatures forming volumes of permafrost in the lunar subsurface. Our analysis predicts that impact cratering processes were responsible for specific pore space network that were subsequently filled with the water-ice in the polar regions of the Moon. Identified hydrogravity strike anomalies by the novel gravity aspect approach serve as potential resource utilization sites for future landing exploration sites (e.g., Artemis objectives). The unique locations may become necessary structures for future human settlement. In this work, we conjecture plasma-magnetotail reconnections has allow the accumulation of up to ~3000 km³ of terrestrial water-ice, filling the pore spaced regolith, for which novel gravity strike signals appear.

Introduction: Artemis mission's planning requires cogent analyses of potential resource utilization sites [1]. Lunar surface operations are both novel, and expensive, and require geophysical explorations. The best knowledge for these later known resource extraction sites, currently must be decided from remote inference. The lunar environment is unlike contemporary earth analogues geophysics (gravity, ionosphere, that is to say, almost entirely). Indeed, our lunar satellite experiences ion-magnetohydrodynamics often overlooked when discussing resource formation. For example, the lunar environment is shielding for five days of each Earth orbit period from a magnetic field tail extending all the way from the Earth's geomagnetic field [2].

Gravity aspects: We use a novel method for detection of underground density anomalies via anomalous gravity signal. This method was developed for the study of various geological structures on the

Earth (the impact craters, subglacial volcanoes, lakes, lake basins, paleolakes or oil&gas deposit sites around the world) and extended for the impact craters, maria and catenae on the Moon [3,4].

Gravity studies applied to geoscience commonly employ just the traditional gravity anomalies, or second radial derivatives of the disturbing gravitational potential. This work uses a wider set of functions of the disturbing gravitational potential, we call them “*gravity aspects*”. These are derivation operators acting on the *gravity anomalies* Δg , the *Marussi tensor* (\mathbf{T}), the second derivatives of the disturbing potential (T_{ij}), with the second radial component T_{zz} , two of the three *gravity invariants* (I_j), their *specific ratio* (I), the *strike angles* (θ) and the *virtual deformations* (vd). Our prior use revealed their diverse sensitivity to the underground density contrasts due to causative bodies. Here we compute them to a high degree and order with sufficient numerical stability. It appears that such application provides a finer and more complete information that is possible to get out from the satellite gravity measurements. Theory of this approach was outlined in the book of Klokočník et al [4] with further references and examples and specific application of this method to the Moon is in the Supplementary material.

Gravity data: The input data here uses harmonic geopotential coefficients of the spherical harmonic expansion to degree and order d/o of the perturbational gravitational potential (Stokes parameters). A set of these coefficients defines a global static gravitational field. We use the best models available based on satellite records [5,6]. This defines the limits of d/o = 1200 and 1500 for the models GRGM1200A [5] and GL1500E [6] respectively, with practically useful limit d/o = 600 (recommended by the authors of these models themselves). Application of these models allows for the theoretical ground resolution ~10 km. The precision is about 10 mGal. For this paper we chose the GRGM1200A model (after tests concerning degradation of gravity aspects for different harmonic degree and order and/or appearance of artifacts).

Results: We computed and plotted the gravity aspects, namely the strike angles θ and the second radial derivatives T_{zz} near the lunar poles - see Fig. 1. We used two color modes to express the degree of alignment of strike angles: blue as misaligned and red with high degree of alignment. The choice of contrasting alignments (i.e., aligned vs non-alignment), was chosen to be the most conservative, so that only areas with high Comb values (0.99-1.00) were outlined in Fig. 1. The calculations resulted in agreement areas of high degree alignment and for Comb > 0.99. Hence, we outlined these areas by black lines. We then identified 27 areas of significant alignment areas of the θ near the north pole and 33 such areas near the south pole on the Moon (Fig. 1).

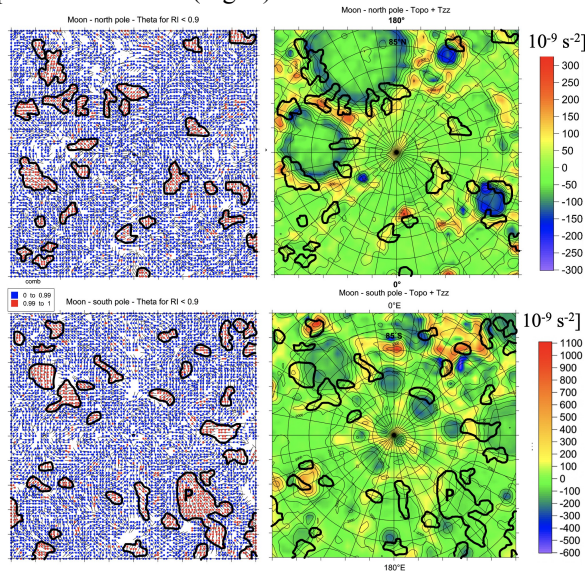


Fig. 1: Geophysics, topography and geological subunits of the Moon's polar regions. Left two panels: Gravity strike angles θ [degrees, with respect to the local meridian] plotted for ratio I (RI) < 0.9 (see equation (2)). The black lines outline the significant clusters of highly aligned strike angles; B. Gravity second derivative T_{zz} [10^{-9}s^{-2}] along with topography [m]. The black lines are outlines of highly aligned, strike angles.

Note that Fig 1. shows how the T_{zz} , second derivative of the disturbing gravitational potential distributes near the polar regions of the Moon. The values are spread between -300 E to 300 E near north pole and from -600 E to 1100 E near south pole. In the north pole region, the low values are indicative of

compressional regime; thus, near surface rocks are denser and spread near the inner ring of the two large impact structures in upper left corner of the Fig. 1 (upper north pole panel on the right). Note, the minimum values of T_{zz} reside inside smaller impact craters are expressed in topographic mapping. Similarly, we obtained values for T_{zz} near the south pole (Fig. 1, lower panel). Note a larger span of T_{zz} values and association of T_{zz} minima with the interior of impact structures and topographic heights with the positive T_{zz} values (Fig. 1).

Conclusions: We applied a new method of presenting gravity measurements on the Moon. This new method is sensitive to the anisotropy of the Moon's regolith. Our method detected specific regions near the north and south poles that point to the presence of significant volume of pore space. This pore space was likely created by impact cratering process. Since the polar regions accumulate water/ice deposits, it is very likely that these identified regions hold significant amounts of water ice, suitable for resource utilization plans of future planned missions (Artemis [1]).

Acknowledgments: GK was partially supported from the Czech Science Foundation 20-08294S, Ministry of Education, Youth and Sports LTAUSA 19141. This work was partly supported from the projects RVO #67985815 and #67985831 (Czech Academy of Sciences, Czech Republic), and the project LO 1506 (PUNTIS) and #LTT18011 from the Ministry of Education of the CR. We thank Dr. F. L. Lemoine (GSFC NASA) for his consultations. The input data – the harmonic geopotential coefficients (Stokes parameters), magnetic field parameters and surface topography of the Moon are generic. The data to our figures (in surfer program, png files) and our figures with high resolution can be received from J. Kostecký on request.

References: [1] Angelopoulos, V. (2011) *Space Sci. Rev.* **165**, 3-25. [2] Terada, K. *et al.* (2017) *Nat. Astron.* **1**, 5. [3] Klokočník, J., *et al.* (2020), *Planetary and Space Science*, 105113. [4] Klokočník, J., *et al.* (2020) *Subglacial and underground structures detected from recent gravito-topography data.* (Cambridge Scholars Publishing). [5] Lemoine, F. G. *et al.* (2014) *Geophys. Res. Lett.* **41**, 3382-3389. [6] Konopliv, A. S. *et al.* (2014) *Geophys. Res. Lett.* **41**, 1452-1458.