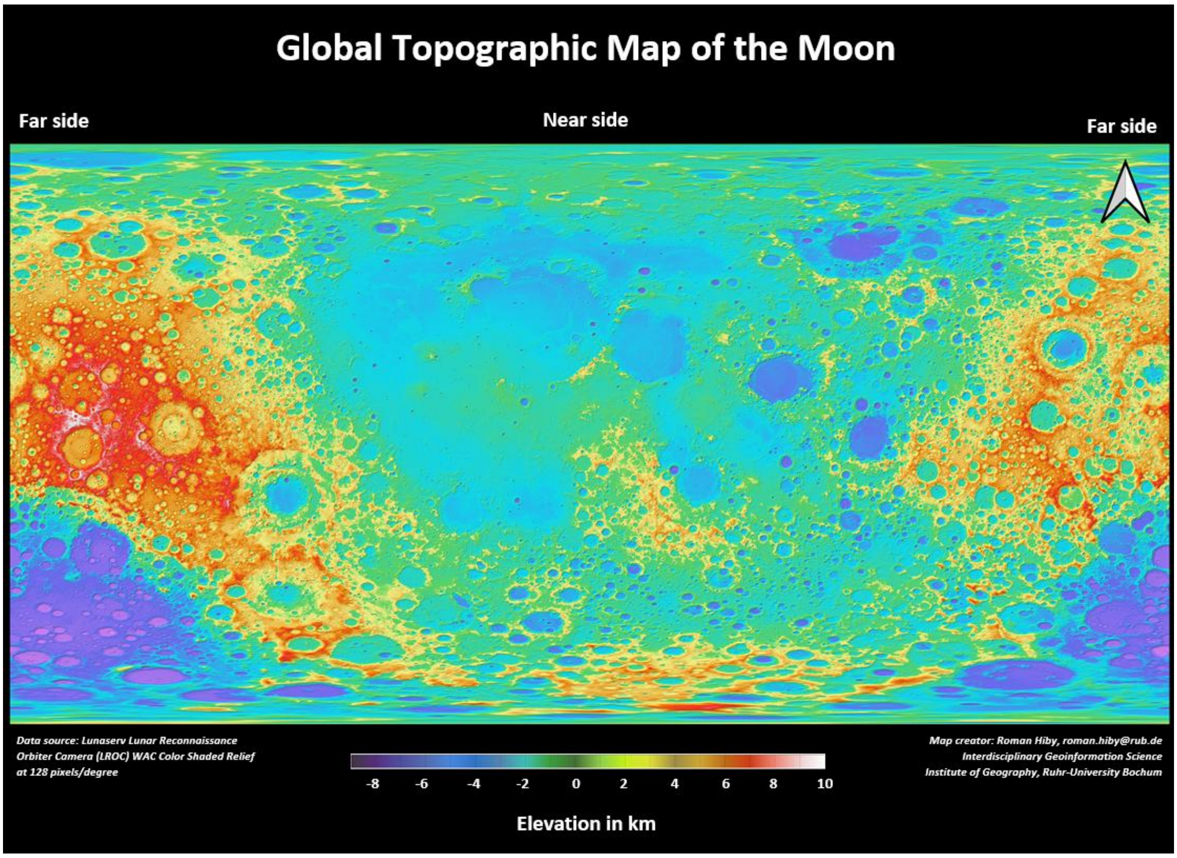
Explanation of the Lunaserv maps

The purpose of this document is to provide information about the products of Lunaserv maps, how they are to be interpreted and to what extent they have the potential to be integrated into one or more of the available teaching materials. It is important to note that these maps and the information obtained from them could not be produced without the satellite data obtained from the lunar orbit. A global analysis of lunar parameters is not possible from ground-based data on the Moon, simply because the sample size is too small. Therefore, the given data sources in the form of satellites on the Moon are highly relevant. The use of lunar observation satellites also offers much better possibilities than satellite observation of the Earth due to the absence of an atmosphere and thus the absence of weather phenomena, as well as the lower gravitational force of the Moon. The map content listed can also be viewed and used interactively via the augmented reality app "Columbus Eye".

Global topographic map of the Moon:



In the app:

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The Global Relief Map of the Moon is based on data from the Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC). The Global Lunar Digital Terrain Model with a resolution of 100m/pixel and the Lunar Orbiter Laser Altimeter (LOLA) 30m Digital Terrain Model (downscaled to 100m/pixel) were used as the basis for creating the relief map.

This map shows the relief and thus the elevation data of the global lunar surface. The average radius of the Moon is defined as the zero point. 34 colors were selected for the color scale in order to differentiate the classification of depressions and elevations globally as clearly as possible. The deep depressions of the Moon are color-coded blue to purple and reach a depth of -9 km (e.g. Antoniadi crater near the south pole on the side facing away from the Earth). The terrain around the zero point is colored green. The plateaus are visualized in red to white and can reach a height of up to 10.75 km (e.g. edge of the Engelhardt crater near the equator on the side facing away from the Earth).

When looking at the global relief of the Moon, it is noticeable that the side facing the Earth is mostly below 0 km altitude due to the formed mare valleys. The highlands on the side facing away from the Earth can also be seen on the relief map, as the areas are usually well above 0 km in altitude. In addition, the lowest areas of the Moon are located south of the highlands on the side facing away from the Earth.

This global relief map of the Moon can potentially be used for teaching materials 1, 2 and 3. With regard to the formation of the Moon and its geology, the map can be used to support the explanation of the geological disparity between the Earth-facing and Earth-facing sides and to better explain the formation of the Moon. With regard to location factors, the existing relief structures can be used to identify suitable and less suitable areas for human settlement. This map can also be used for teaching material 3 on gravity, as the mare on the side facing the Earth and the highlands on the side facing away from the Earth serve to explain the strong gravitational influence of the Earth in the early formation of the Moon. Due to the centrifugal force, the relief on the side facing away from the Earth was much more pronounced.

Further information can be found in the underlying source: https://pds.lroc.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/DATA/SDP/WAC_CSHADE/WAC_CSHADE_README.TXT [15:26, 05.01.2023]

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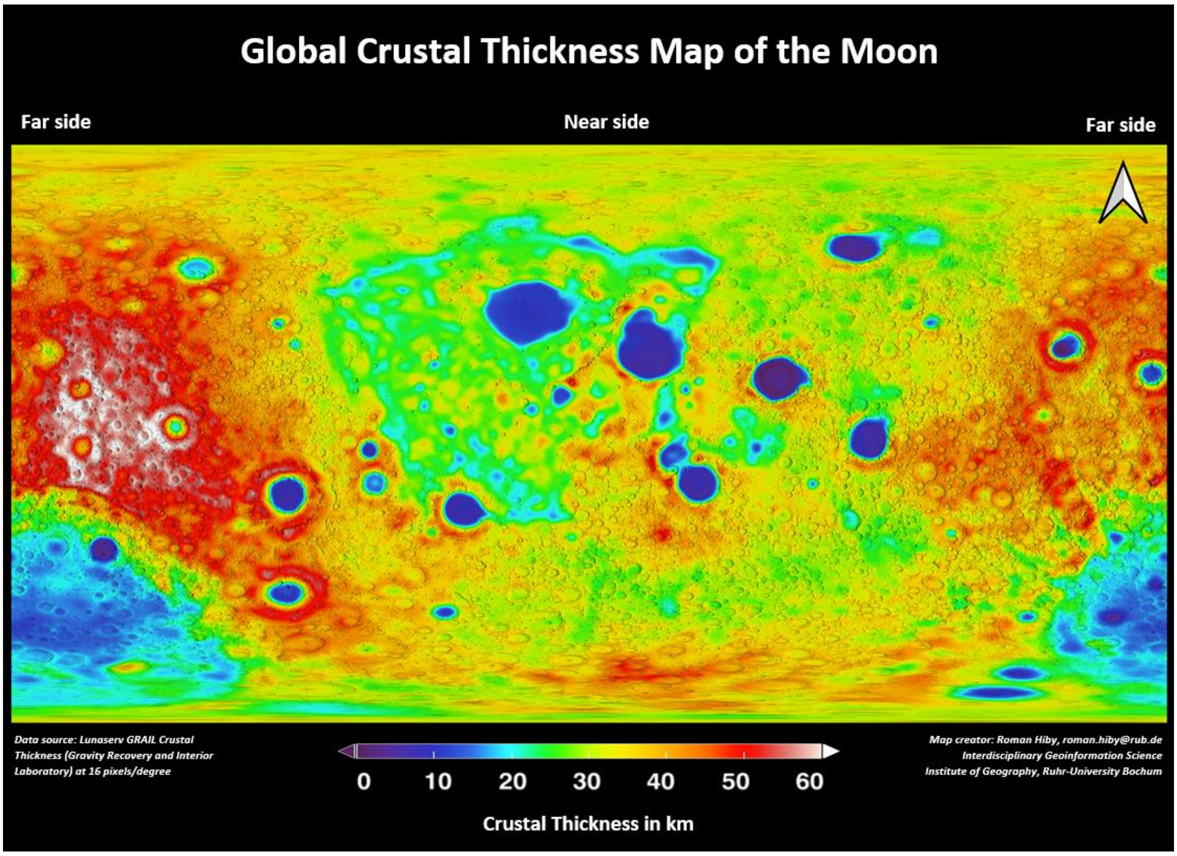
Global crustal thickness map of the Moon:



In the app:

The map of the global crustal thickness on the Moon is based on data from the Gravity Recovery and Interior Laboratory (GRAIL) and has a resolution of 16 ppd ("pixels per degree"). The map shows which crustal thickness is present in which areas on the lunar surface. A low crustal thickness of 0-10 km is shown in purple to blue and a high crustal thickness of 50-60 km is shown in red to white.

A closer look at the global crustal thickness on the Moon shows that the mare on the side facing the Earth and the southern areas on the side facing away from Earth have the lowest crustal thickness. The highlands on the side facing away from the Earth show the highest crustal thickness on the Moon.

On the Moon, crustal thickness and local gravitational differences go hand in hand. This means that the gravitational force is stronger in the regions with a lower crustal thickness than, for example, in the highlands, where the highest crustal thickness is present on the Moon. Among other things, this is due to the associated topography and the distance to the center of mass, but also to the density of the lunar rock.

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The low crustal thickness is the result of numerous violent impacts that have formed the mare on the Earth-facing side of the Moon. In some cases, the lunar surface lies directly on the mantle rock, which means that there is hardly any crust in these mares. The mare "Moscoviense" and

"Crisium" have the thinnest crustal thickness on the Moon at almost 0 km. As a result, the lunar rock in these regions has a high density and increases gravity.

It can therefore be stated that the gravitational anomalies on the Moon behave in exactly the opposite way to the crustal thickness. The highest gravitational force prevails in regions with the lowest crustal thickness and vice versa.

This map of the global crustal thickness of the Moon can potentially be used for teaching materials 1 and 3. With regard to the formation of the Moon and its geology, the map can be used to support the explanation of the geological disparity between the Earth-facing and Earth-facing sides and to better explain the formation of the Moon. This map can also be used for teaching material 3 on gravity, as the mare on the side facing the Earth and the highlands on the side facing away from the Earth serve to explain the strong gravitational influence of the Earth in the early formation of the Moon and also to explain the Moon's own gravitational anomalies.

The map can also be used in combination with the relief map for teaching material 2 in order to work out topographical location factors for the individual regions on the Moon.

Further information can be found in the underlying source: Wieczorek, M., Neumann, G., Nimmo, F., Kiefer, W., Taylor, G., Melosh, H., Phillips, R., Solomon, S., Andrews-Hanna, J, Asmar, S., Konopliv, A., Lemoine, F., Smith, D, Watkins, M., Williams, J, Zuber, M. (2013). The Crust of the Moon as Seen by GRAIL. Science, 339 (6120), 671-675.

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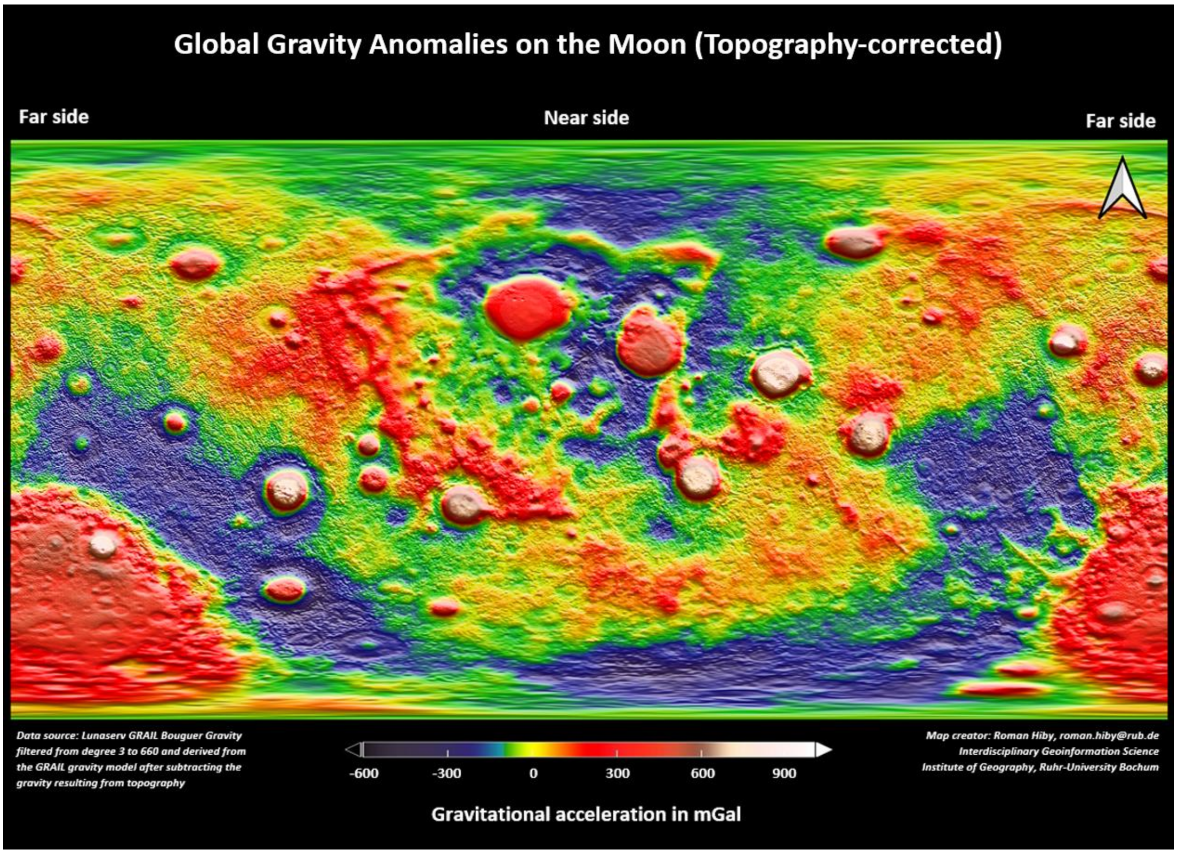
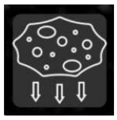
Global gravity anomalies on the Moon (topography-corrected):



In the app:



The map of the global gravitational anomalies on the Moon is based on data from the "GRAIL GRGM900C gravity model". The special feature here is that the gravitational anomalies were calculated minus the effects of topography. As already explained in the global crustal thickness map, the topography and the crustal thickness and density have an effect on the Moon's own gravity, as the lower-lying and denser surface of the Moon has a higher gravity than the highlands. In turn, this map shows where the gravitational anomalies can be localized when adjusted for topography. This allows conclusions to be drawn about the exact density of the lunar surface, for example. The gravitational acceleration anomalies (gravity) are given in mGal (milligal, named after Galileo Galilei) in the available data and visualized in color depending on the value range. 1,000 mgal corresponds to 1 cm/s². Negative gravitational anomalies are visualized on the map from dark green to blue, while positive gravitational anomalies are shown in red to white. The range extends from approx. - 600 mGal to approx. +1,000 mGal. The highest values can be found at the large compacted impact craters, on the one hand in the mares on the side facing the Earth, and on the other hand partly on the side facing away from the Earth.

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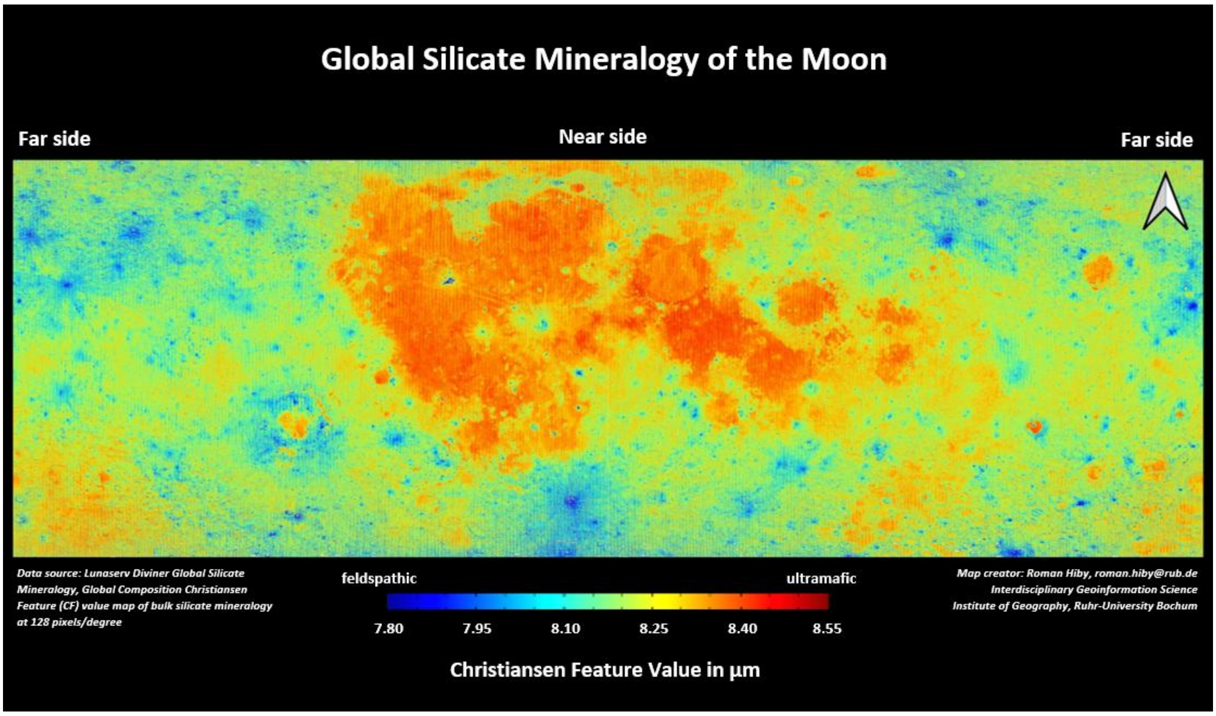
This map of the topography-adjusted gravitational anomalies on the Moon can potentially be used for teaching material 3. It serves to explain the Moon's own gravitational force and the associated anomalies after the topography adjustment. The influence of topography on lunar gravity can also be worked out by adding the maps of global crustal thickness and relief.

Further information can be found in the underlying source: Zuber, M., Smith, D., Watkins, M., Asmar, S., Konopliv, A., Lemoine, F., Melosh, H., Neumann, G., Phillips, R., Solomon, S., Wieczorek, M., Williams, J., Goossens, S., Kruizinga, G., Mazarico, E., Park, R., Yuan, D. (2013). Gravity Field of the Moon from the Gravity Recovery and Interior Laboratory (GRAIL) Mission. Science, 339 (6120), 668-671.

Global silicate mineralogy of the Moon:



The Global Silicate Mineralogy Map of the Moon is derived from Lunar Reconnaissance Orbiter (LRO) Diviner Lunar Radiometer data using multispectral thermal emission mapping and highlights the compositional variability of common lunar terrain with unusual compositions in the blue (minimum at 7.80 µm) and red (maximum 8.55 µm) colors. The available multispectral thermal emission data have a high spatial resolution, a nearly global coverage and show a high sensitivity for the relevant low-iron mineralogy on the Moon.

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The range of values is characterized using the Christiansen Feature (CF). This is an indicator that has already been used in numerous silicate mineralogical analyses. In the CF value range used, feldspathic minerals can be seen at shorter wavelengths of less than 8 μm (marked light to dark blue). These tend to be lighter-colored minerals from lunar rocks. Mafic and ultramafic rocks are dark minerals from magmatic rocks, such as olivine, which occur at wavelengths above

8.4 μm (marked orange to dark red). In order to confirm the range of CF values, rocks on Earth had to be examined in a lunar-like environment, as otherwise deviating values were found.

Over 90% of the lunar surface rock is between 8.04 and 8.36 μm. Pyroxenes in particular settle in this value range. The Earth-facing side, which consists of numerous maria valleys, is dominated by dark and basaltic minerals and shows predominantly mafic characteristics. The side facing away from the Earth, with its highlands, is clearly assigned to the lighter feldspar. These findings were also confirmed by the rock samples from the Apollo missions.

This map of the global silicate mineralogy on the Moon can potentially be used for teaching materials 1 and 2. With regard to the formation of the Moon and its geology, the map can be used to support the explanation of the geological disparity between the Earth-facing and Earth-facing sides and to better explain the formation of the Moon. With regard to the location factors, geological findings on the surface rock can be used to identify suitable and less suitable locations for lunar colonization.

For more information, see the underlying source: Greenhagen, B. T., Lucey, P. G., Wyatt, M. B., Glotch, T. D., Allen, C. C., Arnold, J. A., Bandfield, J. L., Bowles, N. E., Hanna, K. L. D. Hayne, P. O., & Song, E. (2010). Global silicate mineralogy of the Moon with the Diviner Lunar Radiometer. Science, 329(5998), 1507-1509.

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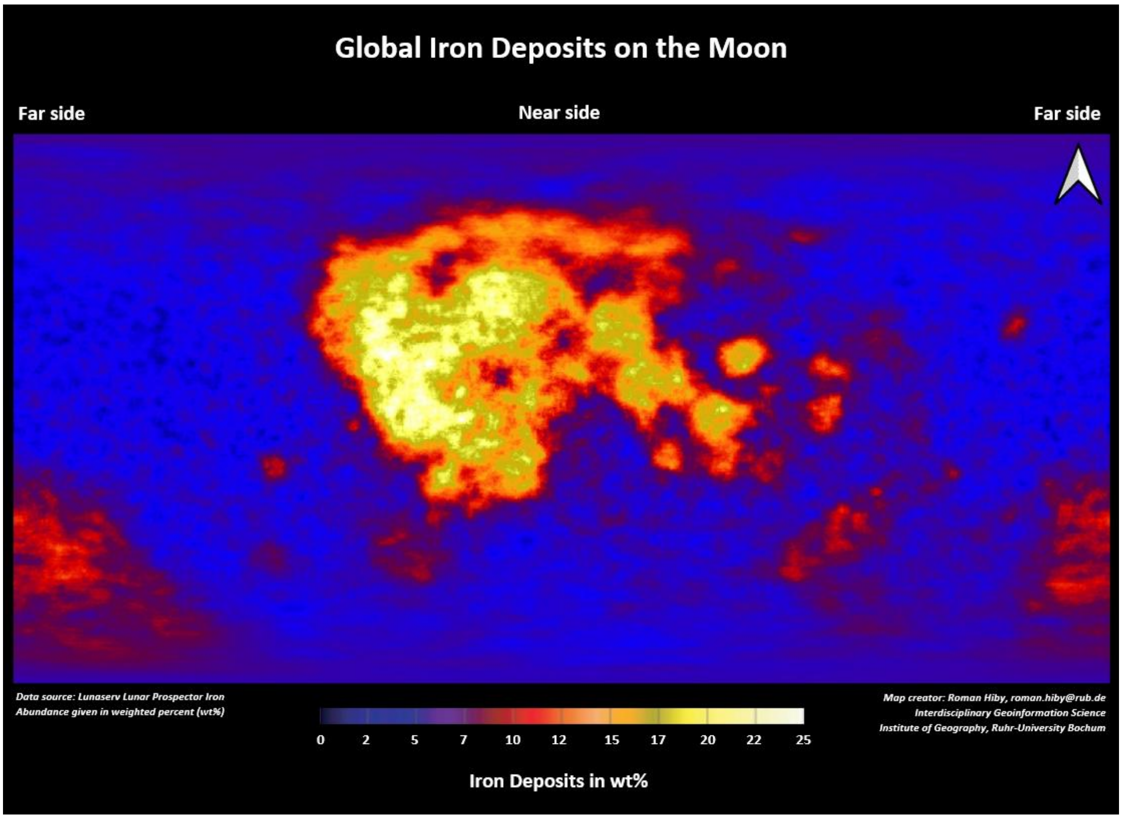
Global Iron Deposits on the Moon:



The map of global iron deposits on the Moon is based on data from the Lunar Prospector (LP) gamma-ray spectrometer (GRS) and neutron spectrometer (NS). The absolute iron occurrence is given in "weighted percentage" (wt%). The value range extends from 0 wt% iron occurrence in dark blue to 10-15 wt% in red/orange and up to 25 wt% in white. The map shows a strong occurrence of iron in the surface rocks on the Earth-facing side of the Moon, particularly in the mare valleys. The iron occurrence is most pronounced in the western mare valleys (>22 wt%). In the highlands on the side facing away from the Earth, on the other hand, there is only a very low occurrence of iron in the lunar surface (<5 wt%).

This map of global iron deposits on the Moon can potentially be used for teaching materials 1 and 2. With regard to the formation of the Moon and its geology, the map can be used to support the explanation of the geological disparity between the Earth-facing and Earth-facing sides and to better explain the formation of the Moon. In terms of site factors, geological knowledge of surface rocks, such as iron deposits in this case, can be used to identify suitable and less suitable sites for lunar colonization.

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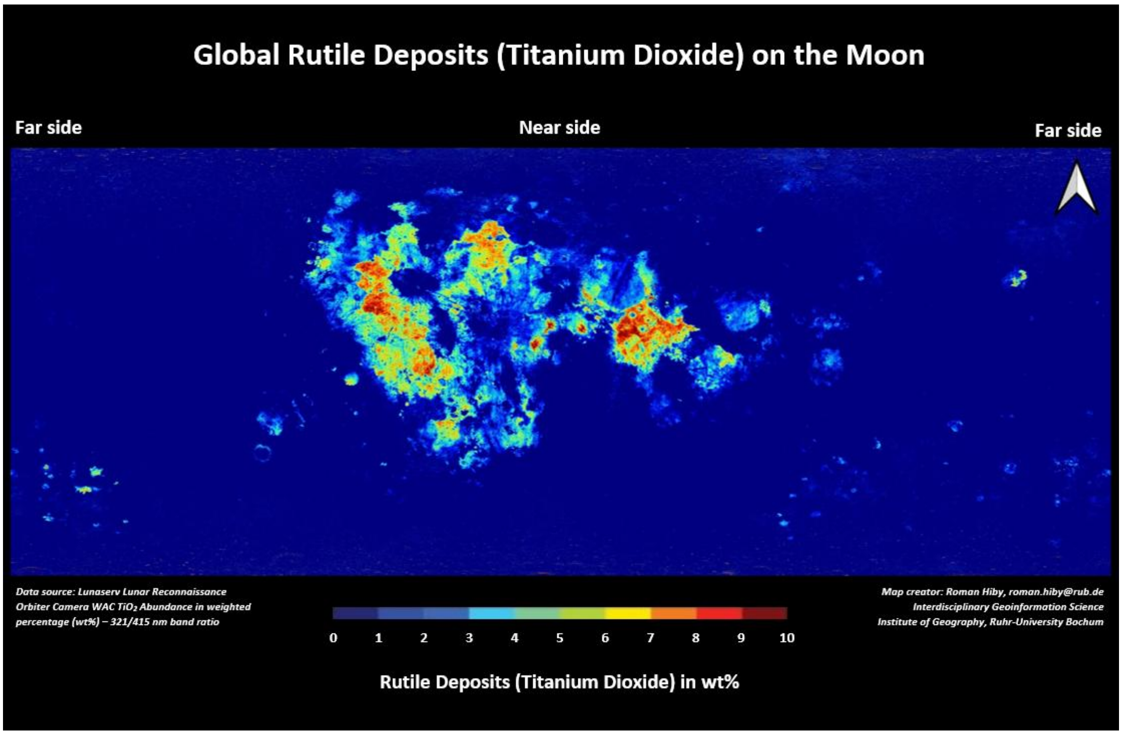
For more information, see the underlying source: D. J., W. C. Feldman, R. C. Elphic, R. C. Little, T. H. Prettyman, S. Maurice, P. G. Lucey, and A. B. Binder (2002). Iron abundances on the lunar surface as measured by the Lunar Prospector gamma ray and neutron spectrometers. Journal of Geophysical Research: Planets, 107(E12). https://doi.org/10.1029/2001JE001530

Global Rutile Deposits in the Moon:



The map of global rutile deposits (also titanium dioxid/TiO_2) on the Moon is derived from the multispectral 321/415 nm bands of the Wide-Angle Camera (WAC) of the Lunar Reconnaissance Orbiter (LRO) and is given in "weighted percentage" (wt%). For validation, real lunar soil samples were compared with the respective values of the 321/415 nm bands at the respective locations.

The range of values extends from 0 wt% rutile occurrence, visualized in dark blue, to 10 wt% rutile occurrence, visualized in dark red. In general, the occurrence of TiO_2 is almost exclusively limited to the mare of the side of the Moon facing the Earth. With a few exceptions, the side facing away from the Earth is permanently below 2 wt% TiO_2.

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This map of global rutile deposits (also titanium dioxide/TiO_2) on the Moon can potentially be used for teaching materials 1 and 2. With regard to the formation of the Moon and its geology, the map can be used to support the explanation of the geological disparity between the Earth-facing and Earth-facing sides and to better explain the formation of the Moon. With regard to the location factors, geological findings on the surface rock, such as rutile in this case, can be used to identify suitable and less suitable locations for lunar colonization.

For more information, see the underlying source: Sato, H., Robinson, M.S., Lawrence, S.J., Denevi, B.W., Hapke, H., Jolliff, B.L., Hiesinger, H. (2017) Lunar Mare TiO2 Abundances Estimated from UV/Vis Reflectance, Icarus, doi:10.1016/j.icarus.2017.06.013.

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