Some lunar regolith are better for living off the land on the moon

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Multi-dome lunar base being constructed, based on the 3D printing concept. Credit: ESA/Foster + Partners

Between now and the mid-2030s, multiple space agencies hope to send crewed missions to the moon. of These plans all involve establishing bases around the moon's southern polar region, including the Artemis Base Camp and the International Lunar Research Station (ILRS).

These facilities will enable a "sustained program of lunar exploration and development," according to the NASA Artemis Program mission statement. In all cases, plans for building facilities on the surface call for a process known as In-Situ Resource Utilization (ISRU), where local resources are used as building materials.

This presents a bit of a problem since not all lunar soil (regolith) is well-suited for construction. Much like engineering and construction projects here on Earth, builders need to know what type of soil they are building on and if it can be used to make concrete.

In a study, geologist Kevin M. Cannon proposed a lunar soil classification scheme for space resource utilization. This could have significant implications for future missions to the moon, where it would help inform the construction of bases, habitats, and other facilities based on soil type and location.

Dr. Cannon is an assistant professor at the Department of Geology and Geological Engineering and Space Resources Program at the Colorado School of Mines, an engineering university in Golden, Colorado. His research is focused on the role geologic processes play in the formation and evolution of planetary materials on the surfaces of different bodies in the solar system. The paper that describes his proposed scheme, "A lunar soil classification system for space resource utilization," appeared in the journal *Planetary and Space Science*.

For space agencies, ISRU comes down to harvesting local resources to create building materials and provide for the crews' basic needs (water, air, fuel, etc.). This reduces the amount of prefabricated components or materials that need to be launched into space, dramatically reducing costs in the process.

For years, NASA, the ESA, and other space agencies have investigated how lunar regolith could be used as feedstock for 3D printers. Combined with a bonding agent or sintered to produce a molten ceramic, this regolith could then be "printed" onto inflatable modules to create various facilities.

Thanks to soil analysis and sample return missions conducted by robotic missions and the Apollo astronauts, scientists have learned a great deal about the composition of soil on the moon. In particular, they learned that (like soils here on Earth) the composition varies from one location to another.

"In any construction project on Earth, you'd want to know what kind of ground you're building on," explained Cannon via email. "The same will almost certainly be true on the moon, and it helps to have a consistent scheme for one person to describe a soil to another."

Here on Earth, soil classification schemes are used for everything from construction and civil engineering projects to environmental science. Soil types can also influence keep considerations, like how deep a foundation is needed depending on what is being built or what the slope should be on a highway embankment. However, these schemes do not apply to the lunar environment:

"Soil classifications on Earth are largely based on how 'plastic' the soil is due to clays and water, and often you get sorting that happens where for example a soil is mostly coarse gravel or mostly fine silt. On the moon there are no clays, the soils are completely dry, and almost everywhere you have an even blend of different particle sizes. So the systems we use terrestrially really just don't transfer."

In addition, there are also the formation mechanisms, which are significantly different on the moon. Whereas soil on Earth results from "weathering" (erosion) by water and wind, lunar regolith was created by a combination of volcanic activity and a long history of impacts by asteroids, meteoroids, and micrometeoroids.

The result of this is a lunar surface covered in a thick layer of rock fragments, glass beads (impact and volcanic), aluminum-bearing minerals (plagioclase), and agglutinate—a type of pyroclastic igneous rock formed from partly fused volcanic bombs found only on the moon.

To develop his classification scheme, Cannon used sample data from the Apollo soil samples and developed proof of concept maps for the entire moon. To determine which soil types were well-suited for construction purposes, his scheme considered two key characteristics of lunar regolith: bulk iron content and grain size.

In terms of composition, lunar regolith consists of (in order of its mass fraction) elemental oxygen, silicon, iron, calcium, aluminum, magnesium, and other trace elements. Additionally, grain sizes typically range from 40–800 micrometers—0.04 to 0.8 mm—with most falling between 45–100 micrometers.

The resulting classification scheme is simple, elegant, and can be applied anywhere on the moon. "The lunar system is meant to be straightforward and involves measuring the chemistry of the soil and the average particle size.

These two metrics give you nine different soil classes to start," said Cannon. "Then the system can be extended with "tags" that add extra info. Lunar soils can be classified with measurements on the ground by rovers or astronauts, or with satellite data from orbit, for example."

Luckily, this classification scheme has application that go beyond base construction. Identifying soils based on their composition is an excellent way to scout resources that needed for specific tasks. This includes soils rich in water ice, which could be used for everything from drinking water and irrigation to oxygen gas and propellant—liquid hydrogen and oxygen (LH2 and LOX). It also includes other mineral elements that are needed to manufacture infrastructure, vehicles, and assorted components. As Cannon summarized:

"There's implications for all sorts of things we'd do with soils, like extracting metals and oxygen from them, but specifically for construction, we actually think a lot of structures will end up being made of the soil itself using 3D printing. Some soil types are going to melt at lower temperatures and have more even distributions of grain sizes, which would make for better feedstock in that case. Or, for any type of construction, how compressible the soil is will change from one soil class to another."

More information: Kevin M. Cannon, A lunar soil classification system for space resource utilization, *Planetary and Space Science* (2023). DOI: 10.1016/j.pss.2023.105780

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