GEOPOLYMER CAMP 2024

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Geopolymer solutions for Lunar / Martian habitats and Space works.

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Questions to Artificial Intelligence

Claude-Instant / Anthropic AI

(March 28, 2024)

GEOPOLYMER CAMP 2024

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Questions to Claude-Instant / Anthropic AI

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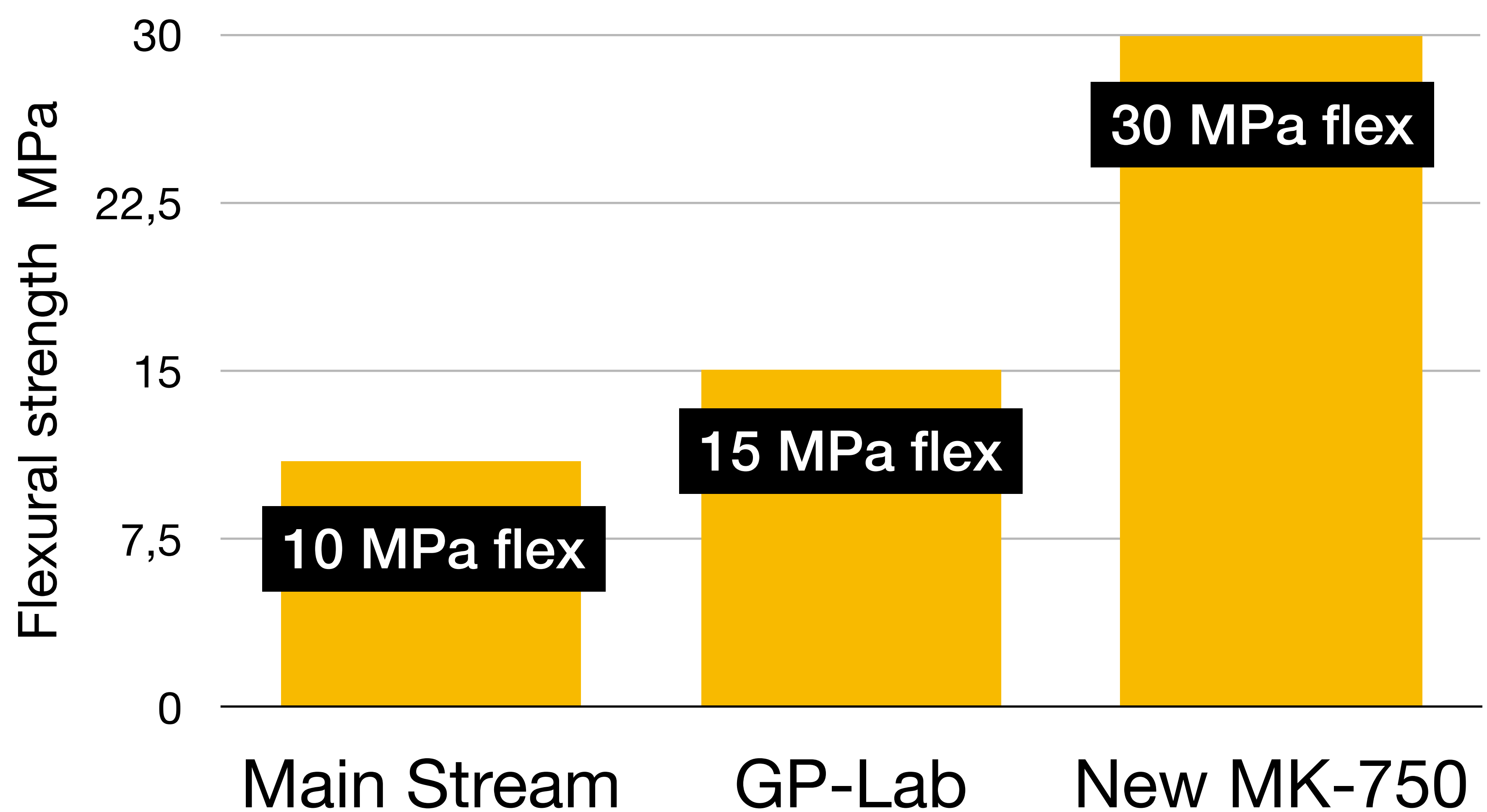
Why geopolymers are excellent candidates for lunar habitats and for work to be carried out in space ?

Why geopolymers are excellent candidates for lunar habitats ?

- *Resource efficiency:* Geopolymers can be produced using lunar regolith as the raw material source of aluminum and silicon. This allows habitats to be constructed directly on the moon without transporting heavy traditional building materials from Earth.
- *Resistance to radiation:* The amorphous structure of geopolymers makes them more radiation-resistant than crystalline materials like concrete. This is important for shielding habitats from solar and cosmic radiation.
- *Thermal properties:* Geopolymers have good thermal insulation ability, which helps maintain a stable interior temperature within habitats subject to temperature swings of over 100°C between day and night.

Why geopolymers are excellent candidates for lunar habitats ?

- ***Strength and durability:*** When mineral fillers are added to the Geopolymer pastes, for example with the addition of feldspar powder, they cure into very strong and durable ceramic-like materials that can withstand the temperature extremes and lack of atmosphere on the lunar surface. Their strength allow their use for structural applications.



Flexural strength 25-30 MPa Compressive strength 180 MPa with mineral filler: feldspar.

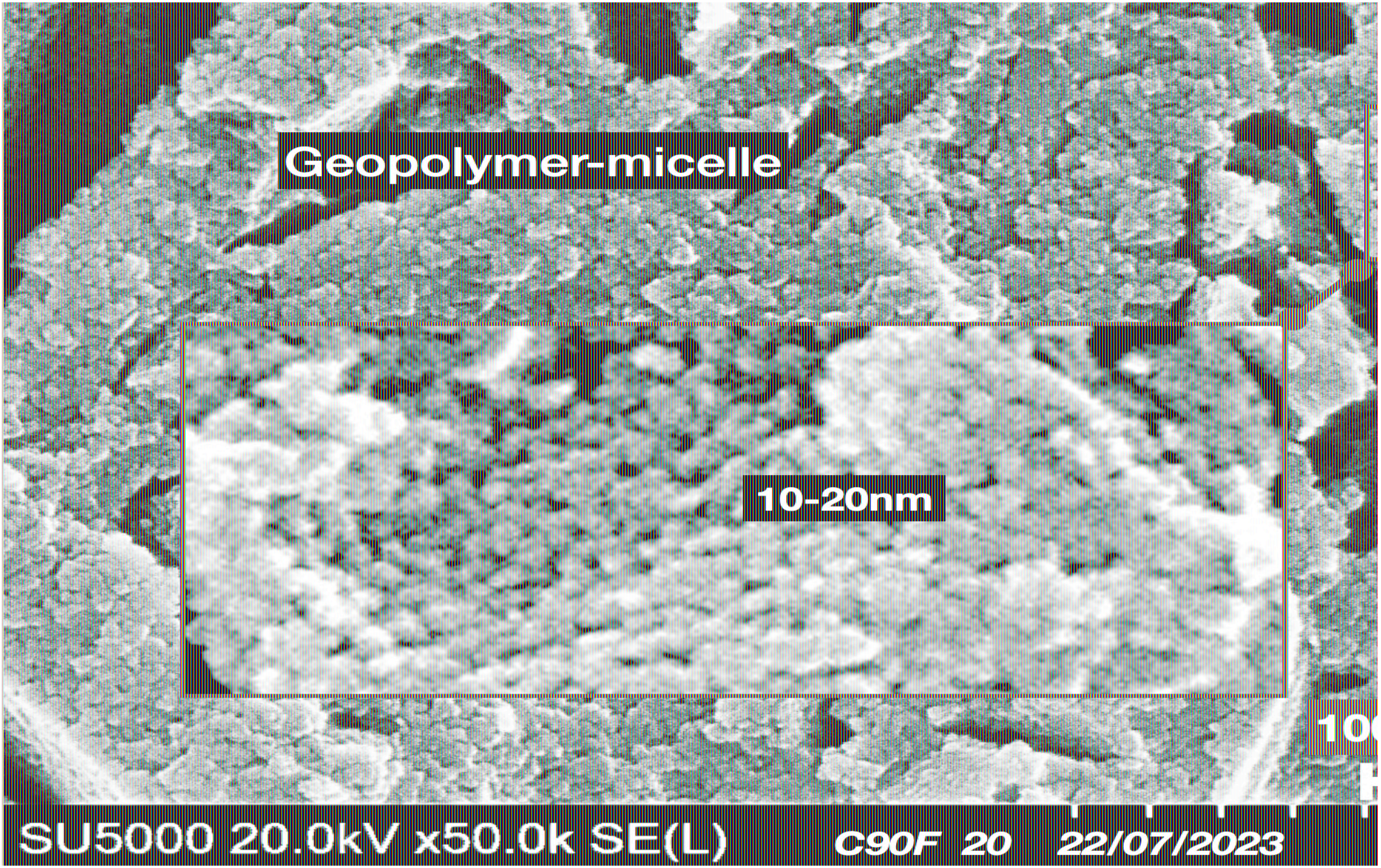
Why geopolymers are excellent candidates for lunar habitats ?

- Lightweight: Geopolymer compositions can be formulated to be lighter than traditional concrete, reducing the mass that needs transport from Earth.

- 3D printable materials: Certain geopolymer pastes can be used in extrusion-based printing approaches, allowing versatile on-site construction techniques.

- **Stability in vacuum:** Unlike ordinary PC concrete and AAM alkaline-activated-materials, geopolymers retain their integrity and strength when exposed to hard vacuum conditions on the lunar surface.

Stability of geopolymers in a high vacuum



- *X-ray diffraction and NMR* analyses confirmed that the 3D-network of the poly(sialate) geopolymer micelle remains intact in vacuum.

Stability of geopolymers in a high vacuum

- ***Amorphous structure:*** Unlike PC concrete and AAM alkaline-activated-materials, the amorphous structure of geopolymers does not allow direct sublimation of water or other constituents under vacuum.
- ***Low permeability:*** The 3D geopolymer micelle network gives geopolymers very fine nano-porosity (in the range of 5 to 10 nm) and low permeability. This greatly limits water loss in a vacuum.
- ***Strong chemical bonding:*** Si-O-Al/Si bonds are stronger than ionic bonds in cement (Ca-O-Si) or (NASH) alkaline-activated-materials. The geopolymeric network is therefore more chemically stable in the face of aggression.

Stability of geopolymers in a high vacuum

- ***Limited water absorption:*** unlike PC and AAM hydrates, water is not a structural component of geopolymers, but only a reaction carrier. Residual water content is lower.
- ***No liquid water:*** Residual water in geopolymers is either chemically bound (Si-OH) or in vapor form. It cannot evaporate suddenly in vacuum.
- ***No spall*** : Thanks to these characteristics, geopolymers do not spall or burst in a lunar vacuum, unlike some ordinary PC or AAM. Their polymeric network remains intact. Studies have shown that geopolymer samples exposed for several months to high vacuum ($<10^{-5}$ Pa) show no signs of deterioration.
- ***Residual water*** in the pores sublimates very gradually by various mechanisms (diffusion, etc.) without damaging the structure.

Stability of geopolymers in a high vacuum

- *The gas permeability* of the geopolymers, already very low at atmospheric pressure, becomes virtually zero in a vacuum due to the clogging of pores by the progressive sublimation of water.
- *Repeated vacuum/pressure cycles* produce no deterioration, demonstrating the absence of bursting caused by the expansion of water during pressure variations.
- *Their high thermal stability* also protects them from significant temperature variations in space.

Geopolymers therefore appear to be particularly resistant to the extreme environmental conditions encountered in the vacuum of space, unlike many ordinary cements.

What are the limitations and technical challenges ?

- ***Feedstock variability:*** The chemical and mineralogical composition of local lunar regolith may vary significantly depending on location. This could impact geopolymer properties and recipes would need optimization.
- ***Water requirement:*** Geopolymerization requires water, which is scarce on the moon. Water would need to be carefully imported/ recycled.

<u>This last statement is wrong!!</u>

Estimation made in 2023: 2.7×10^{14} kg water or 2.7×10^{11} m^3

2,700 billions m^3

which are continuously renewed by solar wind impact on the moon, in addition to the frozen ice already detected in the polar regions.

nature geoscience Volume 16 | April 2023 | 294–300

A solar wind-derived water reser
Moon hosted by impact glass be:

Huicun He and al. (6 Chinese + 3 UK scientific teams)

(…) The past two decades of lunar exploration have seen the detection of substantial quantities of water on the Moon's surface .

……

Today, there is little doubt that most of the Moon's surface harbours water in one form or another. However, the origin(s) of this lunar surface water and its spatial distribution and evolution during regolith gardening remain largely unknown.

There are several potential sources and processes that could have contributed to the water inventory at the surface of the Moon, such as solar wind implantation.

It is generally thought that solar wind hydrogen-ion implantation could react with surface minerals to produce hydroxyl or water in lunar soils.

The surface water produced and/or delivered on the Moon's equatorial regions may migrate to polar regions, driven by temperature oscillations.

Here we report the abundance, hydrogen isotope composition and core-to-rim variations of water measured in impact glass beads extracted from lunar soils returned by the automatic Chinese Chang'e-5 mission (in December 2020).

The impact glass beads preserve hydration signatures and display water abundance profiles consistent with the inward diffusion of solar wind-derived water. …

We estimate that the amount of solar wind-derived water hosted by impact glass beads in lunar soils may reach up to 2.7×10^{14} kg (…)

However, it is not molecular water H_2O, but hydroxyl group -OH in Si-OH

Solar-wind derived water on Moon

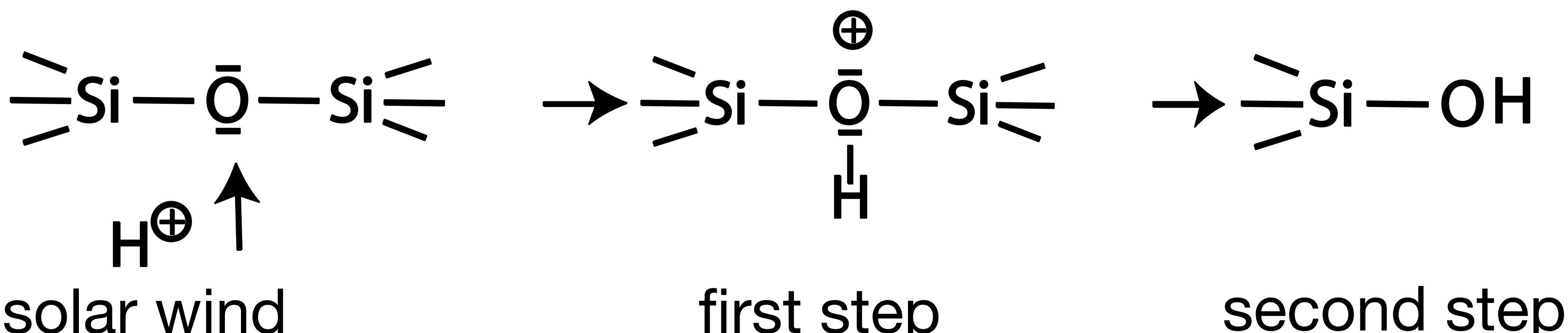
Proton-Induced Hydroxyl Formation on the Lunar Surface

E.J. Zeller and *al.* Brookhaven National Laboratory, USA

Journal of Geophysical Research Vol. 71, No. 20 October 15, 1966

… The interaction of both the particle and photon component of the solar-wind with the lunar surface material is expected to produce diverse chemical reactions.

Experimental evidence for proton-induced Si-OH formation was obtained by bombarding a glass, chemically similar in composition to common silicate minerals, with high-energy protons H+.



Solar-wind derived water on Moon

Once formed, the OH is permanently bound to the lattice.

This specific property is also found in our man-made geopolymers, where the chemically bound water is actually in the form of hydroxyl -Si-OH or -Al-OH structural units.

High-Strength 3D-Printed
Geopolymer Ceramic
0.7 mm to 1mm thread

Solar-wind derived water on Moon

Once formed, the OH is permanently bound to the lattice.

Our experience in the synthesis of high-tech geopolymer ceramic materials shows that these hydroxyl units -Si-OH / -Al-OH release molecular water H_2O only at medium temperatures in the range of 200°-250°C.

$$2(\text{-Si-OH}) \longrightarrow H_2O + \text{-Si-O-Si-}$$

This exploitation of the solar-wind derived water is therefore possible under these conditions.

CONCLUSION: geopolymers are excellent candidates for lunar habitats and for work to be carried out in space.

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