Lunar water from the solar wind

The surface of the Moon is not totally devoid of water. Analyses of lunar soils reveal that impact glasses contain significant amounts of water, with an isotopic composition that is indicative of an origin from the solar wind.

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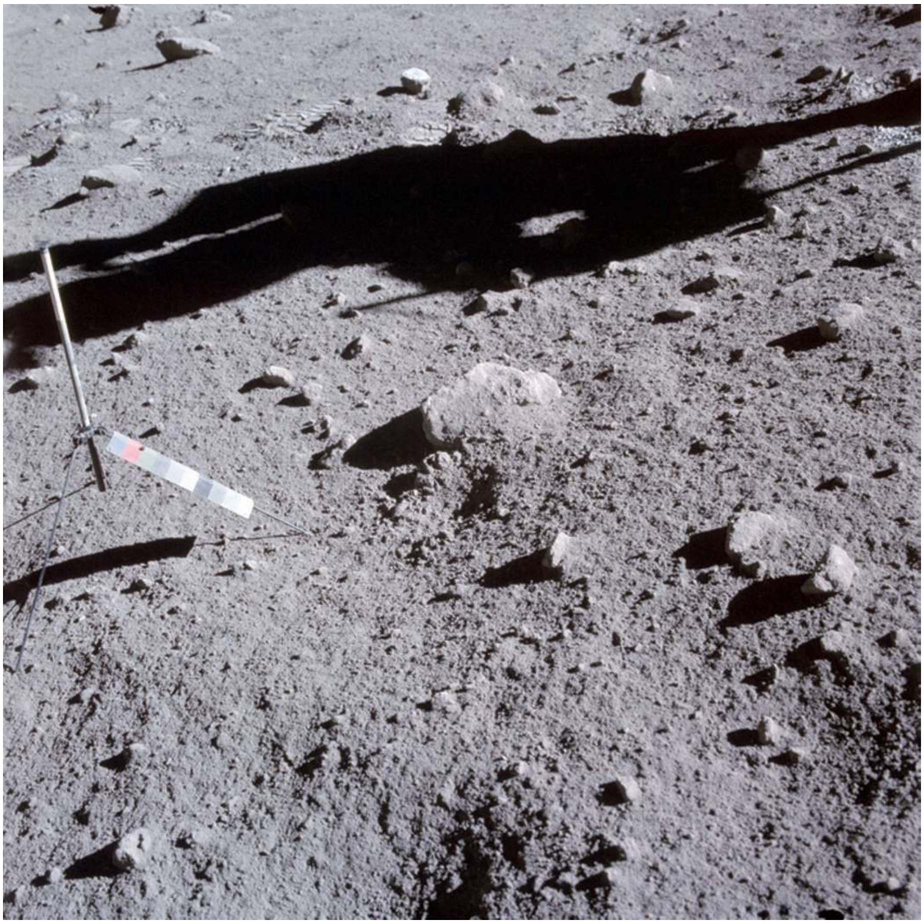

Figure 1 | Lunar sampling site for sample 64501. Liu and colleagues[2] analysed glassy particles from the Apollo samples, including lunar sample 64501 from the Apollo 16 mission, and found water and hydroxyl with isotopic compositions that point to an origin from the solar wind.

During the early evolution of the Solar System, water sufficiently far from the forming Sun condensed to ice. Specifically, at a distance of between one and five times the Sun–Earth distance, the temperature and pressure of the solar nebula allowed water to turn to ice and eventually react with other solid material. Thus, any planetesimals that accreted outside this snowline from the ambient mixture of gas and grains grew into water-rich bodies. So far, the only generally accepted way of delivering water to the inner Solar System is collision with water-rich asteroids or comets that originate from the outer Solar System. For example, water on Earth comes from several bodies formed outside the snowline, that were accreted before and after the impact of a Mars-sized body that formed the Moon[1]. Writing in *Nature Geoscience*, Liu *et al.*[2] report significant amounts of water contained in lunar soils that can be demonstrated to originate primarily from implanted solar wind hydrogen, opening the door to another source of water for inner Solar System bodies.

The Sun loses a small fraction of its mass at a rate of approximately 10^9 kg s^{-1} through a continuous flow of particles called the solar wind. The solar wind has been sampled and returned to Earth by NASA's Genesis mission[3]. It is highly ionized and primarily contains protons in line with the composition of the Sun. These particles are prevented from hitting the surface of the Earth by the protective terrestrial atmosphere and magnetic field. But the Moon, which lacks such protection, is continuously struck by solar wind ions.

The surface of the Moon is covered by a soil layer that is several metres thick. This layer is generated by the physical erosion of lunar surface rocks by impacting meteoroids, as well as by interactions with solar wind and particles from outside the Solar System. Solar wind ions hit the Moon's surface at 450 km s^{-1} and implant in lunar surface material to depths of 50–100 nm (ref. 3). Because the Moon lacks Earth-like tectonic processes, the solar-wind-derived material cannot be transferred into the lunar interior.

The detection of rare gases in the very top layer of lunar soil minerals, at abundance ratios that match those of the Sun and quickly declining in concentration with depth, has demonstrated that solar-wind-implanted ions are found in the lunar regolith[4]. However, whether hydrogen implanted by the solar wind can be converted into hydroxyl or molecular water — the forms that can readily be incorporated into minerals — is not clear. Glassy fragments in the lunar soils — quenched from impact melts and termed agglutinates — might capture and retain a large fraction of the solar wind component.

Liu and colleagues[2] analysed agglutinates from Apollo samples to look for the presence of water derived from solar-wind-implanted hydrogen. They used Fourier transform infrared (FTIR) spectroscopy to determine the form of hydrogen in the glasses, and ion microprobe mass spectrometry to measure the ratio of deuterium to hydrogen, to probe a possible solar origin. During the formation of the Sun, all the deuterium in the accreting nebula gas reacted with hydrogen to form ^{3}He such that the Sun is devoid of deuterium — unlike all other objects in the Solar System.

Liu and colleagues demonstrate that a large fraction of the analysed glass samples contain between 200 and 300 ppm of dissolved hydroxyl and water, and both are poor in deuterium. These observations are consistent with an origin by impact melting of lunar soils that were enriched in hydrogen implanted by the solar wind. The range of measured deuterium to hydrogen ratios also indicates at least two other sources of hydrogen: a minor component produced during nuclear reactions with the incoming high energy particles, and another component that is enriched in deuterium, similar to water in most comets.

The Moon was once considered to have been left ith little water following the putative Moon-forming giant impact[5]. However, it has been shown that the lunar environment is not totally dry[6–9]. The origin and distribution of this water, and the timing of its delivery to the Moon, remain an open debate.

Liu and colleagues[2] present evidence that the lunar surface contains water that originates from the solar wind — as well as the water delivered by comets, as previously proposed[9,10]. To understand and predict the surface water budget of inner Solar System bodies that have generally been considered dry, the next step is to constrain the delivery fluxes from these two very different sources.

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