Feature

The Apollo missions and Moon rocks, 1969–1972

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On 16 July 1969, three men set off for the Moon; just four days later, two of them planted their feet on its surface. Their objectives: to explore the lunar surface, carry out experiments, and gather geological samples for study. Geology was at the very centre of the moon missions, and recovery of Moon rocks one of the measures of success. The samples obtained are amongst the most treasured natural artefacts of science.

The Moon. A bright disc in a dark sky scarred and mottled by craters. Moon is our closest neighbour, a planetoid stared at by generations through any lenses they had to hand. So examined, its cratered surface has never failed to ask questions of us (Fig. 1).

Having been inspired to examine the geology of the Apollo missions by a visit to the Smithsonian Institution, Washington DC, I was pleased to discover the

Apollo Lunar Surface Journal (www.hq.nasa.gov/alsj/frame.html). Its rich archive material is full of astronaut transcripts, satellite catalogues and other materials – an amazingly full archive resource. This material documents the authentic feelings of the twelve men who eventually set foot on the Moon (Fig. 2); their emotions and excitement of their discoveries, and their palpable excitement. This contribution draws on these resources in wonder at the achievements of the Apollo astronauts and the scientists that followed them.

Geology of the Moon

The Apollo missions (together with the un-manned, Soviet Luna missions) contributed to an already growing body of knowledge on lunar geology. But, significantly, they provided *tangible* evidence of the rocks themselves that enhanced our understanding of Moon's geology previously only observed from Earth, and mapped out by photogeology. Some 382 kg of moon rocks were recovered, and these form a unique resource, carefully curated by NASA to this day (https://curator.jsc.nasa.gov/lunar/).

For details of the geology of the moon, derived from the lunar landings, together with the unmanned Soviet Luna missions, the classic *US Geological Survey Professional Paper* by Don E. Wilhelms, *The Geologic History of the Moon*, v.1348, 1987 is worthy of study, as are the various sample catalogues in the *Apollo Lunar Surface Journal*.

My connection with the geological study of the moon is slight, admittedly, and as such, this article relies on the work of others, with some of the most accessible summaries given in the suggested reading. What I can claim, is that I was one of the many small children who watched the flickering TV screens of the time, a transmission of incredible images of men on the Moon, and of the first steps in the exploration of a new world. Perhaps, at the very moment when Neil Armstrong first set foot on the Moon, my resolve to be a geologist was born.

Moon geology is best examined through the lens of stratigraphy, which places both the surface features and their underlying solid geology in the context of Moon formation. There are many concepts of how the Moon was actually formed, but the idea here is simply to take a peak at the Apollo missions and their role in documenting the surface geology of the planetoid, and is impact stratigraphy.

In essence, the geology of the moon is linked to the phases of its development (Table 1). The earliest phase, the pre-Nectarian, represents the oldest part of Moon geology, and sees the formation and differentiation of a feldspathic crust seen in the impact-scarred upland Terrae. The Nectarian saw the formation of basins with feldspathic crust, and terminated with huge impacts that promoted the flood basalt-dominated Maria, during the Imbrian (Fig. 3). The Eratosthenian saw the end of the Imbrian type basaltic eruptions, and it was followed by the Copernican, associated with the cessation of volcanism, and the creation of more impact crater fields. Ultimately, it included the formation of the blanketing regolith, comprising extensive impact breccias, and finely comminuted impact 'soil' into which the astronauts stepped in wonder.

Apollo astronaut–geologists

When the original Apollo astronauts returned to Earth, they did so as heroes. Though the ill-fated Apollo 13 never reached its target (but returned its crew to

Earth unharmed), after the initial Apollo 11 mission there would be five other successful landings. Apollo 17 was the last mission to place astronauts on the moon, at the close of 1972. In all, twelve men have stood on Moon's surface.

The words of all these Moon landers are preserved in transcript by NASA, and specifically those that apply to geological sampling and exploration, and reading them one can get a sense of the breathless enthusiasm of the first Moon explorers for the rocks that surrounded them (Fig. 4) – especially those of Apollo 11, of the extensive Moon roving of Apollo 15, and of the specialist knowledge of Apollo 17, the last of the Moon crews.

Though the astronauts who eventually made it to the Moon were mostly military men, they were also trained in geology. Only one, Harrison 'Jack' Schmitt, was a geologist, and he would be one of the last astronauts to set foot on the moon with Apollo 17.

Starting in 1964, geological training for the astronauts involved fieldwork in some of the most important geological sites on Earth (Fig. 5). Meteor Crater, near Flagstaff in Arizona was first to be visited. Not surprisingly, the nearby Grand Canyon would also be on the geological agenda – though there could be little expectation of sedimentary units to be found on Moon's cratered surface. To supplement this there would be trips to volcanic landscapes in Iceland and Mexico, as well as the man-made cratered landscape of the Nevada nuclear test site.

The Astronauts used the geological experience gathered on these trips to describe what they saw, and did so with aplomb.

‘Houston…we are landed in a relatively smooth crater field…The groundmass throughout the area is a very fine sand to a silt…I’ve seen what looked to be plain basalt and vesicular basalt.’

Neil Armstrong, Mission Commander, Apollo 11, July 1969.

The Apollo 11 men, Neil Armstrong and ‘Buzz’ Aldrin, were the first to identify the basalts that would become the subject of much study in the early part of the 1970s. Basalt it was, but with a unique mineralogy. Such basalts were characteristic of the Maria – the dark, smooth areas of the Moon that indicated flood basalts associated with impacts. Specimens are on display in a number of US museums (Fig. 6) – with ‘touchstones’ providing a tangible link with the distant body, and the astronauts’ lunar endeavours.

The rocks were collected with a variety of tools, and many of these are on display in the Smithsonian Institution’s Air and Space Museum, one of the most visited in Washington DC. Here, in a darkened gallery, much revered space suits sit alongside functional tools designed to do their job on the atmosphere-less lunar surface, handled by men clad in their cumbersome, life-preserving suits (Fig. 7). The tools were designed to allow the astronauts to collect samples and to place them into bags safely – avoiding the possibility of damaging their suits. There needed to be quick release catches, relatively inert metals to avoid contamination, and bags robust enough to survive the challenges of the lunar surface. Using the correct tool was an important consideration, to be actively discussed amongst the men on the Moon’s surface.

‘Do you want the medium-size scoop of the big scoop?’ ‘No, actually, the medium size scoop is the best. All you've got to do is cut the surface to the depth of about a centimetre in an undisturbed area here – where we haven’t picked up the rocks, Okay?’

Stuart Roosa, Command Module Pilot to Alan Shepard, Commander, Apollo 14, February 1971.

Scoops, rakes, entrenching tools – there was a great variety of implements available to the lunar geologists (Fig. 8).

‘We’re about 15 meters from a 20 meter blocky-rimmed crater…All the blocks on the rim look like the pyroxene, plagioclase gabbro…If we can, we might get just a block instead of breaking into it, and then we’ll go with the rake’

Harrison Schmitt, Lunar Module Pilot, Apollo 17, December 1972

Not surprisingly, a geological hammer was also carried to the Moon with each crew – but more often than not this geologist’s icon was left behind on its surface, too heavy to come back to Earth when the more precious cargo – the rocks themselves – were to be carried back home in specially designed sample bags (Fig. 9). And it would be these moon rocks that were pored over avidly by teams of geologists and mineralogists, enough to set the scientific community alive with excitement. This excitement would be felt by the astronauts themselves – especially when there was something different to be found.

With Apollo 11 identifying the basaltic rocks of the Maria, the lighter coloured, cratered surface of the Terrae was much more distinct for the astronauts of later missions. These rocks were often startlingly white, sometimes with a pinkish hue – and were always discussed by the astronauts.

> 'There are some really interesting rocks out there. I see some that are pure snow white, and we've got a whole run of them.'
>
> John W. Young, Mission Commander, Apollo 16, April 1972

Investigation of these samples and others like them determined they belonged to an aluminium and calcium rich feldspathic suite of rocks that have been described as anorthosite, though with some caveats (Fig. 10). In turn, these rocks are identified as relicts of the original lunar crust, formed as a result of the bombardment of the plutonic surface in its early stages. The oldest known lunar sample, the so-called 'Genesis Rock', dating back to the very origin of the Moon, was collected by Apollo 15 astronauts in August 1971, and is anorthosite belonging to the pre-Nectarian (Fig. 11a, b).

Other materials that seemed out of the ordinary attracted the attentions of the moon-landers, too. Pyroclastic glass, splashed out on the surface during the eruption of basalt, was distinctive enough to excite the astronauts, and was often targeted for collection.

> 'Say, Houston, one of the first things that I see, by golly, is little glass beads. I got a piece about a quarter of an inch in sight, and I'm going to put it into the Contingency Sample Bag…'

Pete Conrad, Mission Commander, Apollo 12, November 1969

But, arguably, it was the first interaction of the Apollo astronauts with the lunar surface that would leave the most lasting impression. There were extensive deposits of impact breccias, together with footprints deeply made into the soft regolith that coated much of the surface, a pulverized 'soil' created by the impacts that pockmark the Moon (Fig. 12).

The men of Apollo 11 were first to examine this 'soil', to experience the feeling of standing 'on the moon' (Fig 13), their boots deep in lunar regolith.

'I notice in the soft spots where we had footprints nearly an inch deep that the soil is very cohesive and it will retain a slope of probably 70 degrees on the side of the footprints…'

Neil Armstrong, Mission Commander, Apollo 11, July 1969

With their successful return on 24 July, the crew of Apollo 11 – Neil Armstrong, Edwin 'Buzz' Aldrin, and command module pilot Michael Collins – had made history. The others that followed gathered information and samples that are amongst the treasures of science. The images that were beamed back to Earth and transmitted on TV screens around the globe showed the first men on the moon moving about the planetoid, gathering specimens, taking images and deploying equipment. The world had not seen anything like it – but the geological training had stood them in good stead. And they would inspire others to pursue the science of geology – it certainly had that effect on me.

Suggestions for further reading

Lindsay, J.F. (1976) *Lunar Stratigraphy and Sedimentology*. Elsevier, Amsterdam

Mutch, T.A. 1973. *Geology of the Moon–A Stratigraphic View*. Revised Edition, Princeton University Press, Princeton.

Wilhems, D.E. (1987) The Geologic History of the Moon. *US Geological Survey Professional Paper*, v. 1348, 302 pp.

Apollo Lunar Surface Journal, www.hq.nasa.gov/alsj/main.html

Apollo Sample Catalogues, www.hq.nasa.gov/alsj/frame.html

Apollo Geology Training and Field Exercises www.hq.nasa.gov/alsj/ap-geotrips.html

Apollo Voice Transcripts Pertaining to Geology www.hq/nasa/gov/alsj/alsj-GeologyVoiceTranscripts.html

Lunar Sample Curations https://curator.jsc.nasa.gov/lunar/

Smithsonian Institution https://airandspace.si.edu/events/apollo11/

Figure Captions

Fig. 1. Moon. The geology of the surface of our nearest neighbour is readily seen from Earth, with the lighter, cratered Terrae distinguished from the darker, basaltic Maria. (Image: NASA).

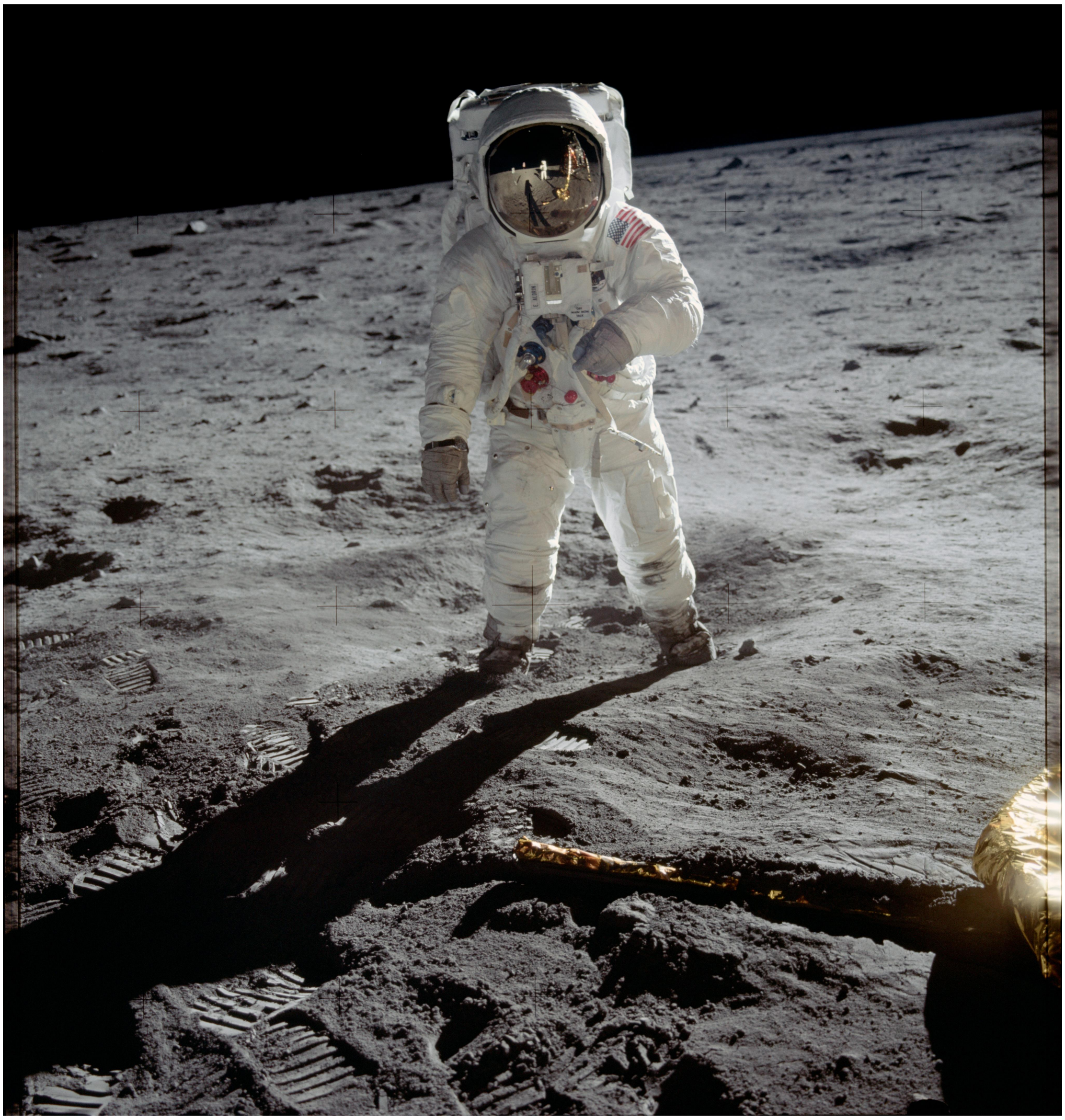

Fig. 2. Neil Armstrong, Apollo 11 Mission Commander, on the surface of the Moon, 1969. (Image: NASA)

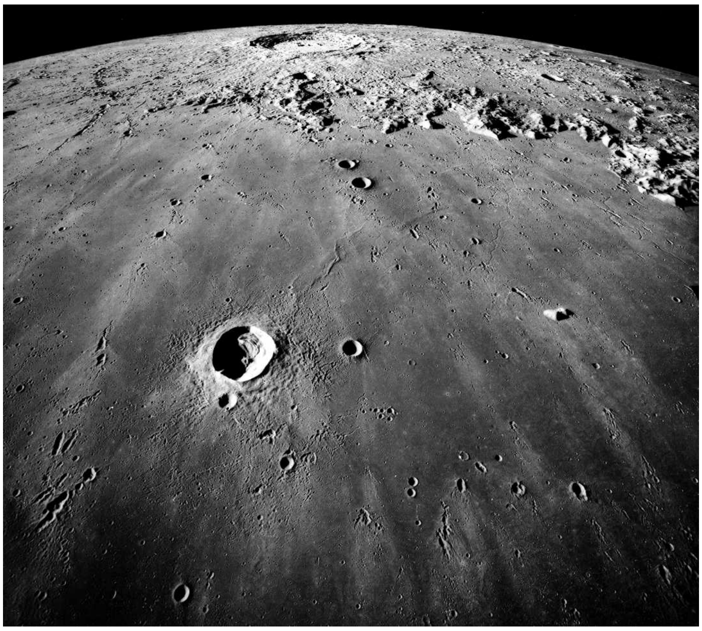

Fig. 3. Mare Imbrium, with Copernicus crater near the horizon. The crater at the centre of the image is Pytheas. An image from the Apollo 17 mission. This shows the extent of the basaltic Mare. (Image: NASA)

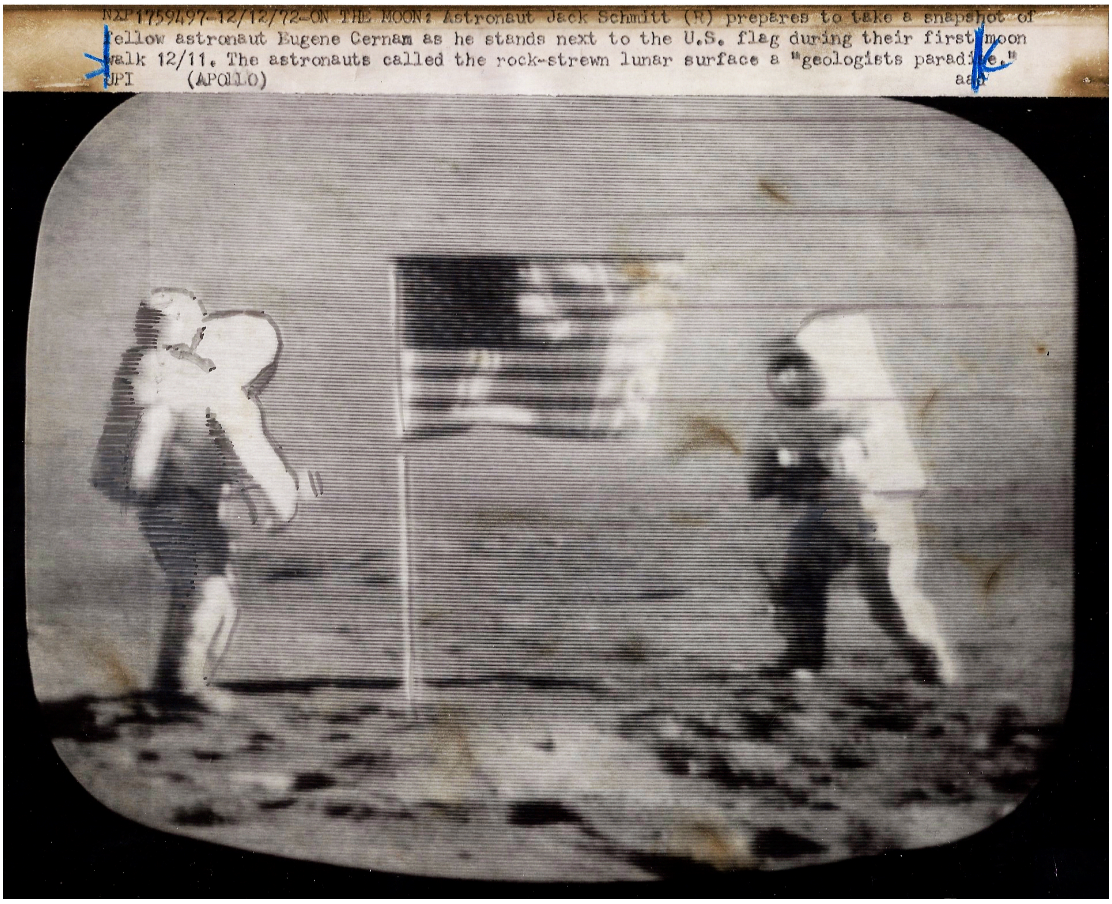

Fig. 4. Original, grainy press photograph of Apollo 17 astronauts on the Moon's surface. With Schmitt the only geologist amongst the Moon men, his words, that the lunar surface was a 'geologist's paradise', carry some weight. (Image: P. Doyle)

Fig. 5. Apollo 15 astronauts James Irwin (left) And David Scott (right) engaged in geological field training in New Mexico. (Image: NASA)

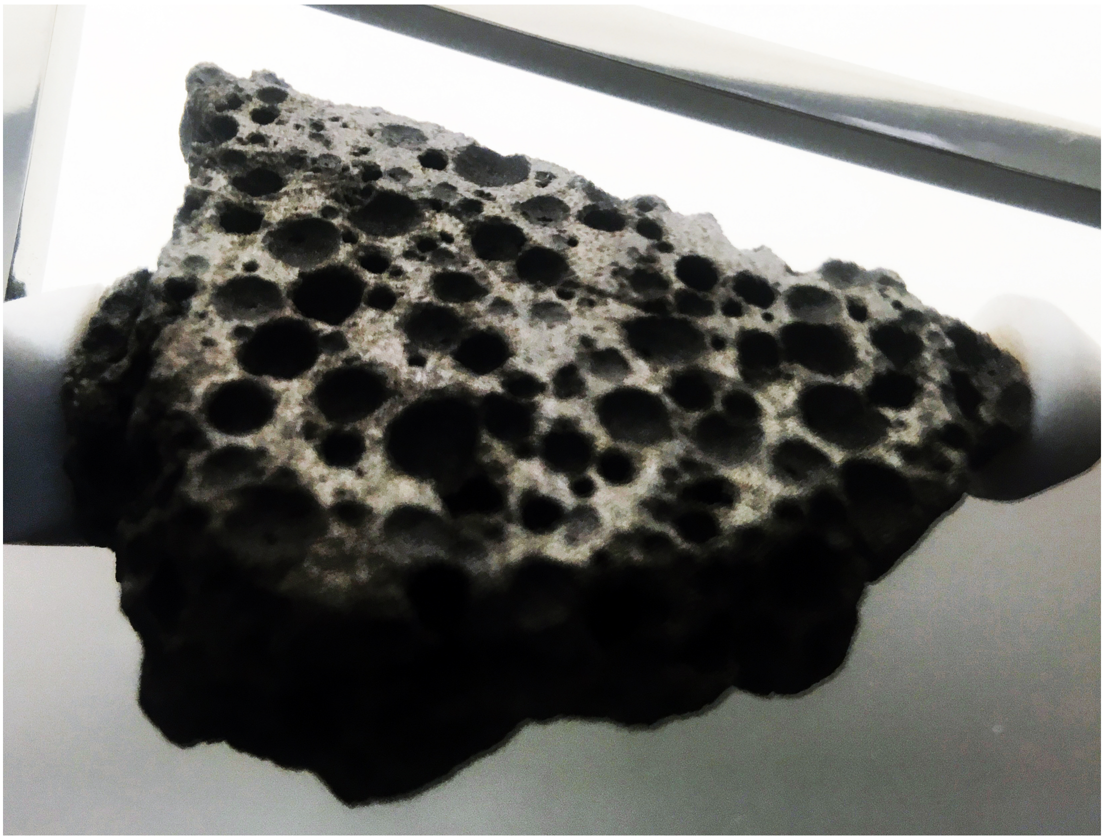

Fig. 6. Basalt collected by Apollo 15 astronauts, on display in the Smithsonian's Air and Space Museum, in Washington DC. Length approx. 60 mm. (Image: P. Doyle)

Fig. 7. Space suit worn by Apollo 15 Mission Commander, David Scott. The suit is preserved in the Smithsonian Institution, and is stained by particles of lunar regolith. (Image P. Doyle)

Fig. 8. Tools of the Apollo geologist, on display in Washington DC's Smithsonian Institution. **A**, bulk sampler, used to gather the so-called Contingency Sample – this was one of the first samples taken in case a quick get-a-way was required. **B**, medium sampler, for more detailed sample collection. **C**, sample grab, used to pick up individual rocks (allowing the fines to drop away). **D**, trenching tool, used to dig into the lunar regolith. (Images: P. Doyle)

Fig. 9. Apollo Sample bag. (Image: P. Doyle)

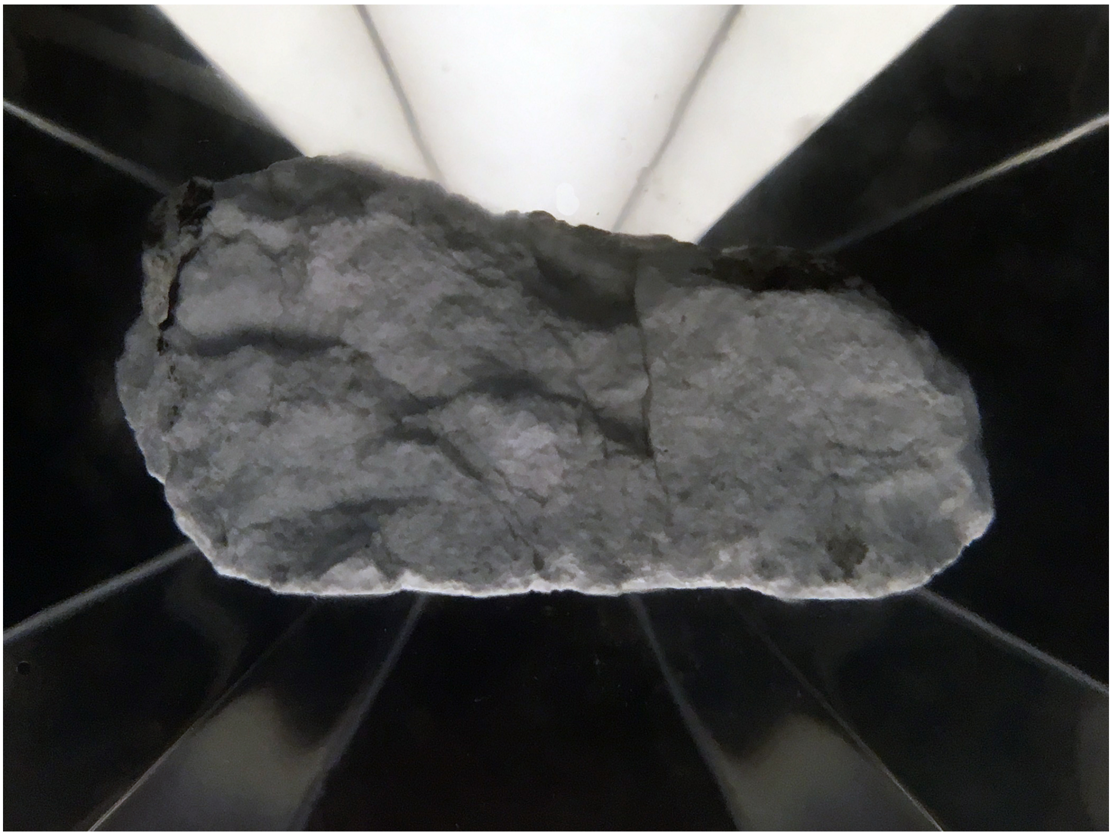

Fig. 10. Feldspathic-rich moon rock typical of the ancient crust of Moon, identified as anorthosite, on display in the Smithsonian Institution. Length approx.. 50 mm. This anorthite-dominated rock is thought to have formed due to segregation during bombardment of the crust. (Image P. Doyle)

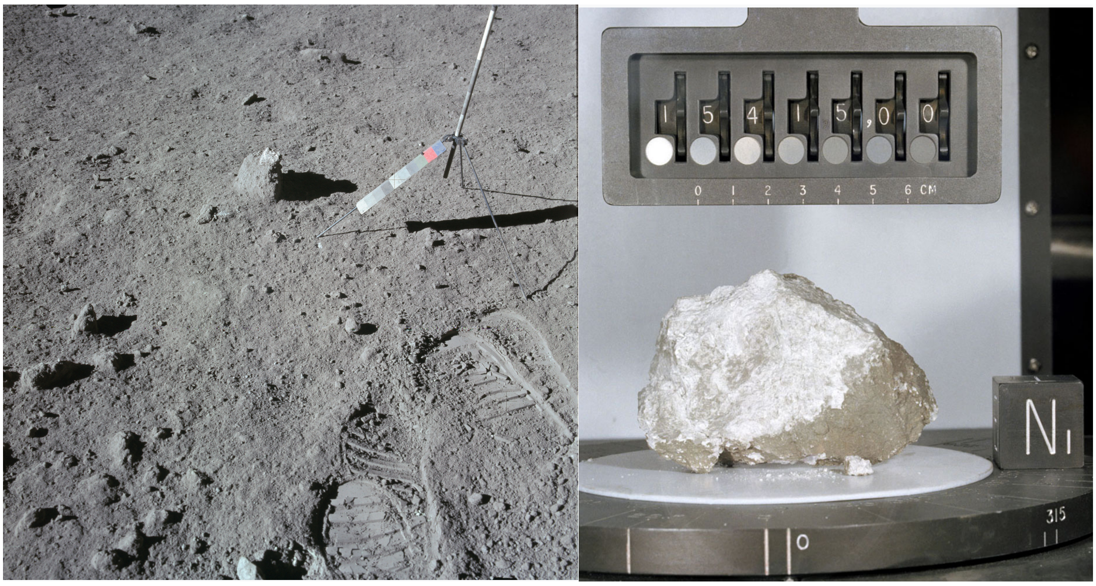

Fig. 11. The so-called 'Genesis Rock'. **A**, on the Lunar surface. **B**, as sample 15415 in the NASA sample repository (Images: NASA)

Fig. 12. Sample of Lunar 'soil' on display in the Smithsonian Institution. Field of view approximately 10 mm. (Image: P. Doyle)

Fig. 13. ‘One small step for man, one giant leap for mankind’. Apollo 11 boot print deeply impressed into the pulverized Lunar regolith. (Image: NASA)

Mya (to base)	System	Events	Apollo Mission
~1,100	Copernican	Impact cratering with ray systems, typified by the crater Copernicus	Apollo 12, 14, 16, 17
~3,200	Eratosthenian	The end of the basaltic volcanism typical of the Imbrian, and identified with the Crater Eratosthenes	Apollo 12
~3,850	Imbrian	Formation of the Maria, the outpouring of basalt due to impact, typified by Mare Imbrium	All missions
~3,920	Nectarian	Formation of the heavily cratered Nectaris Basin due to heavy impacts	Apollo 14, 16, 17
~4,533	Pre-Nectarian	Origin of the lunar crust	Apollo 15, 16, 17

Table 1: Moon Systems, typical events and Apollo sites. The Soviet un-manned Luna spacecraft also returned moon rocks