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The Surface of the Moon

Editor's Note

This year has marked the 20th anniversary of one of the most noteworthy events in the history of our species: our first steps on another world. *The Universe in the Classroom* has celebrated the July 20, 1969, walk on the Moon by Neil Armstrong and Edwin Aldrin by devoting its 1989 pages to our planet's big satellite. In this final issue of the year, we consider the Moon's alien surface features, (so different from those we're used to on Earth) and review the golden age of lunar exploration.

Earth and Moon Compared

The Moon's landscape is starkly different from the Earth's. Instead of being dominated by continents and oceans, the Moon's face is everywhere pockmarked by *craters* — circular pits or basins blasted out by high-speed impacts of interplanetary debris over the history of the solar system. The craters bear silent witness today to a time — billions of years ago — when collisions of such debris with larger bodies were much more common.

The Earth, too, must have experienced a wealth of such impacts, but our dynamic planet has several characteristics that *erase* craters relatively quickly (on the geologic time scale) — or even prevent them from forming in the first place:

- Earth's *atmosphere* burns up the smaller pieces of asteroidal metal and rock or cometary ice by friction. A typical speed of such a *meteoroid* is about 25,000 kilometers per hour — and intense heat from friction with the air vaporizes them; as they burn up, we see their quick fiery trails as meteors (sometimes called "shooting stars"). The Moon has no atmosphere, so even the tiniest bit of high-speed dust can hit the surface and cause a crater to form.

- On Earth, *erosion* due to water and wind eventually erases the craters caused by impacts of objects large enough to hit the ground. Depending on the climate conditions at an impact site, a crater about a kilometer across (such as the famous Meteor Crater in Arizona) can be eroded beyond recognition in a hundred thousand years or so. (Note that a hundred thousand years is only 1/10,000 of a billion years — and we believe the age of the solar system to be about four and a half billion years.) The Moon has no air or water to erode a crater away — it still bears scars billions of years old.

- *Surface activity* on the Earth — that is, volcanoes, earthquakes, and the slow motions of its crust called continental drift — eventually masks even the largest impact craters over periods of millions to hundreds of millions of years. The Moon is a geologically dead world now, so it lacks this "healing" process, too.

Crater Formation

We might expect that impact craters would have a variety of shapes, depending on the *angle* at which the bombarding chunk hit the ground — that only impacts from directly overhead would produce circular craters. However, all but a very few, small lunar craters are circular. (In fact, the circularity of the Moon's craters was long used as an argument against the so-called "impact hypothesis" for making the craters.)

However, the impacts that formed most craters on the Moon (and elsewhere) did so by literally exploding, not just by gouging up the ground. Craters formed by such detonations — similar to those made by artillery shells — are circular regardless of what direction the projectiles came from.

The energy source for an impact's explosion is the raw speed of the impacting object. An interplanetary chunk headed toward the Moon is accellerated by the Moon's gravity; astronomers' calculations indicate that an object falling from deep space will have a minimum speed of about 5,000 mph on impact. At that speed, the sudden collision of a meteoroid (as these cosmic pieces of debris are called) with the Moon's surface generates enough heat to vaporize much or all of itself and some of the ground it penetrates. The vaporized material violently expands — explodes — forming a circular crater.

Craters' Features

Along with heat and light, the force of an impact's explosion blasts a good deal of material out of the bowl and across the surrounding terrain. Sometimes this material spreads out in streaks or rays extending away from the crater.

Craters larger than about 10 kilometers across often have central peaks, which are hills or mountains pushed up by pressure within the Moon when the weight of the rocks that were blasted away was removed.

The very largest impact features on the Moon are the enormous impact basins: great circular plains from 300 to more than a thousand kilometers across. There are only about two or three dozen of these — and all of the largest ones are on the Moon's "nearside" (the hemisphere that faces Earth). Astronomers believe that many of these great basins formed about four billion years ago in a relatively short period time — only two-tenths of a billion years or so. Why the largest impacts took place only then is not certain, but it is clear that after that only smaller impacts took place.

Maria (the Lowlands) and the Highlands

The floors of the great basins on the side of the Moon that faces the Earth are covered by vast expanses of darker-colored rock. These great plains are relatively smooth and have fewer large craters than other regions of the Moon. They are called lowlands or (more commonly) maria, the plural of the Latin word mare (meaning ocean or sea), because Galileo and other early telescope users thought they resembled large smooth areas of water. Today we understand that they are not water, but instead are solidified lava that flowed across the lower-lying areas of the Moon after it was "wounded" by the great basin-forming impacts. Samples of mare material brought back by America's Apollo astronauts were determined to be from 3.9 to 3.2 billion years old, younger than many other areas of the Moon's crust.

The *highlands* make up about 80% of the Moon's surface (including virtually all of the farside) and are saturated with ancient impact craters.

History of the Lunar Surface

Our modern view of the history of the Moon is based largely on analysis of lunar surface samples and other data obtained by the U.S. and U.S.S.R.'s lunar probes in the 1960's and 1970's. It appears that the Moon formed at roughly the same time as the Earth and other planets, about 4.6 billion years ago. Early in its history, a rain of debris left over from the origin of the solar system bombarded and covered the Moon's surface with impact craters. The largest of these — the ones that blasted out the great impact basins —took place toward the end of the period of heaviest bombardment, about 4 billion years ago . For nearly a billion years after that, lava seeped out of the Moon's interior, flooding the lowlands and forming the maria. Since then, there has been little activity on the Moon's surface aside from sporadic, crater-forming impacts, generally by smaller pieces.

Much more recently, there were a few, brief visits by "objects" that left footprints instead of craters — twelve American astronauts.

Exploring the Moon

People have observed the Moon throughout the millions of years that our species has been on this planet. However, during a single, brief period of only 18 years, we sent a flurry of spacecraft to the Moon that told us more about our big satellite than we had learned in all those millennia that had gone before.

From 1959 (when the *Luna 1* probe made the first flyby of the Moon) until 1976 (when *Luna 24* returned the last lunar sample to Earth), 32 unmanned probes and 9 manned missions to the Moon or near-Moon space were successfully carried out. It was an intensely exciting time to be alive, as we human beings first exercised our ability to navigate the void of space. The accompanying tables list those 41 early missions to the Moon.

Notice that all of the Moon missions listed in this section's tables were launched by the Soviet Union or the United States. Much — if not all — of the impetus behind the 1959-76 rush of spacecraft to the Moon was political: space (and the Moon in particular) was looked at as a great proving-ground of the technological might of the "superpowers." In a sense, the United States "won" the race to the Moon; the Apollo program produced the only manned lunar landings so far. However, it can be argued that the Soviets were more consistent and persistent in their Moon program (their series of automated Luna spacecraft continued for four years after the Apollo program).

Among the genuine scientific benefits that came about as a result of this largely political contest was a much more detailed knowledge of our neighbor world's composition and structure, a clearer view of its geological history and future — and hundreds of thousands of breathtaking photographs. The photographs returned by *Apollo* crews, *Surveyor* robots, *Luna* orbiters and landers, and by all the others in these data tables constitute a landmark in the history of our species. They are our collective memory of our first visits to another world.

Automated Lunar Exploration: Notable Unmanned Spacecraft

Spacecraft	Date of Launch	Notes
Luna 1	01/02/59	First flyby of Moon
Luna 2	09/12/59	Impact on 09/14; first manmade object on Moon
Luna 3	10/04/59	Flyby; first photographs of Moon's farside
Ranger 7	07/28/64	First close-ups of Moon; impacted in Mare Nubium
Ranger 8	02/17/65	Impacted in Mare Tranquillitatis
Ranger 9	03/21/65	Impacted in crater Alphonsus
Zond 3	07/18/65	Farside photographs
Luna 9	01/31/66 (02/03/66)	First soft-landing on Moon —Oceanus Procellarum
Luna 10	03/31/66	First probe to go into orbit around Moon
Surveyor 1	05/30/66	Soft-landed in Oceanus Procellarum
Lunar Orbiter	08/10/66	Photographed proposed Apollo landing sites from orbit

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Luna 11	08/24/66	Orbiter
Luna 12	10/22/66	First Soviet Orbiter to return photographs
Lunar Orbiter 2	11/06/66	Photographs of proposed landing sites
Luna 13	12/21/66	Soft-landed in Oceanus Procellarum
Lunar Orbiter 3	02/05/67	Photographs of proposed landing sites
Surveyor 3	04/17/67	Soft-landed in Oceanus Procellarum, visited by Apollo 12 astronauts in 1969
Lunar Orbiter 4	05/04/67	Photographs for mapping the nearside
Explorer 35	07/19/67	Magnetic field studies from lunar orbit
Lunar Orbiter 5	08/01/67	Photographs for mapping the farside
Surveyor 5	09/08/67	Soft-landed in Mare Tranquillitatis
Surveyor 6	11/07/67	Soft-landed in Sinus Medii
Surveyor 7	01/07/68	Landed near crater Tycho
Luna 14	04/07/68	Orbiter
Luna 16	09/12/70	Lander; first automated return of soil sample to Earth (101 grams)
Luna 17	11/10/70	Automated Lunokhod (rover) traveled 10.5 km on surface
Luna 19	09/28/71	Orbiter
Luna 20	02/14/72	Lander; returned about 100 gram soil sample to Earth
Luna 21	01/08/73	Lunokhod traveled more than 35 km on surface
Luna 22	05/29/74	Orbiter
Luna 23	10/28/74	Lander; no sample returned
Luna 24	08/09/76	Lander; returned about 150 gram soil sample to Earth

[Spacecraft named *Luna* or *Zond* were Soviet missions; all others were U.S.]

The Apollo Project: Manned Lunar Landing Missions

Mission	Launch Date	Crew	Notes

Apollo 11	07/16/69	Neil A. Armstrong* Michael Collins Edwin E. Aldrin, Jr.*	First manned Landing, 07/20/69, in Mare Tranquillitatis
Apollo 12	11/14/69	Charles Conrad, Jr.* Richard F. Gordon Alan L. Bean*	Landed in Oceanus Procellarum
Apollo 13	04/11/70	James A. Lovell, Jr. John L. Swigert, Jr. Fred W. Haise, Jr.	Accident en route required return after one swing around farside
Apollo 14	01/31/71	Alan B. Shepard, Jr.* Stuart A. Roosa Edgar D. Mitchell*	Landed in Fra Mauro
Apollo 15	07/26/71	David R. Scott* Alfred M. Worden James B. Irwin*	Landed at edge of Imbrium Basin near Apennine Mountains
Apollo 16	04/16/72	John W. Young* Thomas K. Mattingley, II Charles M. Duke, Jr.	Landed in highlands near Crater Descartes
Apollo 17	12/07/72	Eugene A. Ceman* Ronald E. Evans Harrison H. Schmitt*	Landed in Taurus Littrow Valley
* Walked on Moon			

Activities & Resources

The Apollo Program: Men on the Moon

Now that two decades have passed since men first set foot on the Moon, the excitement of the time can be hard to remember. And for many young people today, the *Apollo 11* landing is just another historical fact, studied for school and of little personal consequence. Yet when you read the newspaper and magazine coverage from that era, the writers could hardly contain themselves and their optimism about the future.

It's especially instructive to get students to go back and survey their hometown newspaper or read the articles from major newsmagazines from 1968 to 1972. Many libraries today can also provide sound and video recordings from that era. NASA makes films available to schools on loan (for more information, contact the NASA center nearest you).

Books for Youngsters

- Apfel, N. *The Moon and Its Exploration.* 1982, Watts.
- Asimov, I. *The Earth's Moon.* 1988, Gareth Stevens.
- Bean, A.: *My Life As An Astronaut.* 1988, Simon & Schuster.
- Becklake, J. *Man and the Moon.* 1980, Silver Burdett.
- Branley, F. *The Moon Seems to Change.* 1987, Crowell.
- Branley, F. *What the Moon is Like.* 1986, Harper & Row
- Darling, D. *The Moon: A Spaceflight Away.* 1984, Dillon Press.
- Simon, S. *The Moon.* 1984, Four Winds/Macmillan.

Books About the Moon as a World and Its Exploration

- Cadogan, P. *The Moon: Our Sister Planet.* 1981, Cambridge U. Press. An introductory textbook, slightly technical in places.
- Cooper, H. *Apollo on the Moon and Moon Rocks.* 1970, Dial. Accounts of the Apollo 11 mission and the material they brought back from the lunar surface; written by a science journalist.
- French, B. *The Moon Book.* 1977, Penquin. A basic primer.
- Hockey, T. *The Book of the Moon.* 1986, Prentice Hall. Good introduction to Moon science and Moon lore.
- Lewis, R. *The Voyages of Apollo: The Exploration of the Moon.* 1975, Quadrangle. Another science journalist's account.
- Long, K. *The Moon Book.* 1988, Johnson Books, 1880 S. 57th Court, Boulder, CO 80301. Moon observing and Moon lore.
- Mazursky, H., et all. *Apollo Over the Moon: A View from Orbit.* 1978, NASA Special Publication SP-362.
- Moore, P. *New Guide to the Moon.* 1976, Norton. A basic book for beginners.
- Morrison, D. & Owen, T. *The Planetary System.* 1988, Addison-Wesley. A superb textbook on our solar system.
- Preiss, B., ed. *The Planets.* 1985, Bantam. Includes a chapter by G. Taylor: "Earth's Moon: Doorway to the Solar System."