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# Moon, Then and Now

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## FOREWORD

Dr. Mather wrote this article on the state of moon research in honor of the University of Arkansas Centennial Celebration and the special exhibition of lunar material at the University Museum in connection with the 1972 meeting of the Arkansas Academy of Science at Fayetteville. The paper was written at the express request of Dr. Samuel C. Dellinger, Emeritus Professor of Zoology and former curator of the Museum at the University of Arkansas. Dr. Mather taught geology at the University of Arkansas from 1911 to 1914, and later was professor of geology at Harvard University for nearly 30 years. He was awarded his Ph.D from the University of Chicago, was associated with the U.S. Geological Survey for nearly 35 years, and has received a number of honorary degrees. He has been a member and officer of numerous professional organizations, and is a past president of the American Association for the Advancement of Science. Dr. Mather is a prolific author, having produced many technical and popular works in the fields of geology, physiography, and education over the past half century.

The moon has changed scarcely at all since the University of Arkansas was founded in 1871, but our knowledge about it has increased by several orders of magnitude, most spectacularly as a result of the "moon walks" performed by Apollo astronauts since 20 July 1969. Anyone interested in selenology -- the geology of the moon -- cannot but be thrilled by even the most casual inspection of the samples of the moon's surface materials that they brought back to earth.

This is not to say, however, that not much was known about the moon a hundred years ago. Using his home-made telescope, Galileo (1564-1642) had published sketches of the moon's surface in 1609 showing several of its largest craters, mountain ranges, and irregularly circular plains. Those plains were designated as "maria" by Riccioli (1598-1671) in his notable "book about the moon," published in 1651. In it he named a large number of the craters for famous scientists and philosophers, and gave highly imaginative names to many of the maria. The majority of Riccioli's names are still used today and some of them are now familiar to millions of people as a result of coverage of the exploits of the Apollo crews by the news media; for example, Mare Tranquillitatis (the Sea of Tranquillity), Mare Imbrium (the Imbrium Basin), and the craters named Copernicus and Archimedes.

Likewise, the 16th to 18th century astronomers had computed with increasing accuracy the size, mass, and average specific gravity of the moon and its tidal effects on the earth as it revolved around our planet. The years since 1871 have witnessed only somewhat greater precision of measurements concerning those bits of information. On the other hand, completely new instruments and techniques for observation of such a remote object have been invented during those years and especially during the last 10 or 15 of them. Combining these inventions with the new physics and chemistry of "the atomic age" and the techniques of space transportation developed in the even newer "space age," modern science and technology have given us an amazing amount of information about the moon.

The colossal task of analyzing, correlating, and interpreting the vast store of factual data now available is proceeding in hundreds of scientific laboratories around the world, but it has by no means been completed. Some important questions about the moon and its history still remain unanswered. Even so, the wild, free-wheeling speculations, rampant a century or more ago, are now replaced by a few carefully restricted working hypotheses, and a number of significant generalizations may be stated with great confidence.

The moon is composed of rocks and minerals nearly the same as rocks and minerals found here on earth. It came into existence approximately 4.6 billion years ago, at the same time as the earth. Most selenologists consider that it was formed by accretion of planetesimals orbiting the growing earth and others orbiting the sun. During the first 1.5 billion years of its history, its thermal processes and internal activity were probably quite similar to those of the juvenile earth. Since then, unlike the earth, it apparently has been a slowly cooling body lacking any significant deep-seated internal activity. Furthermore, because of its small size, the moon has never had sufficient gravitational force to retain an atmosphere and hydrosphere that could engender processes of erosion and sedimentation like those that have played an important role in the evolution of the earth.

Evidence from three seismometers (instruments that measure moonquakes in the same way as earthquakes) left on the moon's surface by Apollo astronauts indicates that the moon has a layered crust approximately 65 km (about 40 mi) thick, and there is some suggestion from the remanent paleomagnetism detected in "moon rocks" that the moon has an iron core which was molten during its infancy. If so, that core cannot have a radius greater than 0.2 the radius of the moon and it is therefore relatively much smaller than the earth's core. However, there is nothing to indicate that the internal structure of the moon comprises a convective mantle resembling dynamically that portion of the earth between its core and crust.

Samples of the moon's surface materials from five rather widely scattered sites now have been studied directly here on earth. The specimens from one of the five localities were scooped up and retrieved by the unmanned USSR Luna 16 spacecraft; the others were collected by the crews of Apollo 11, 12, 14, and 15. The petrologists report that the specimens they have studied represent three major types of rock and fragments derived from them. The oldest are rather coarsely crystallized igneous rocks, such as anorthosite, composed largely of plagioclase feldspar, that were formed by comparatively slow crystallization from fairly large bodies of molten magma about 4 billion years ago. They are characteristic of the moon's highlands and include David Scott's "genesis rock" (identified

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by Scott as anorthosite while he was on the moon during the Apollo 15 mission; the designation "genesis rock" was promptly coined by a reporter in Houston and has since been widely used). They come as close to representing the components of the original lunar surface as we are likely to get. Intermediate in age is a basaltic type of fine-grained igneous rock, notably rich in potassium (symbol K), rare earth elements (symbol REE), and phosphorus (symbol P), and hence called "KREEP basalt." Many fragments of this kind of basalt were scattered around by the impact of incoming meteorites, most of which were much smaller than the huge projectile responsible for forming the Imbrium Basin, just beyond the rim of which Apollo 15 landed. The third major type of rock consists of basalts much more similar to those at many places on the earth's surface; they are sometimes referred to as "normal basalts" in contrast to the older "KREEP basalts." All of the rocks thus far dated by radioactive methods are between 3.1 and 3.7 billion years old. They occur characteristically as lava flows that flooded pre-existing basins -- most, if not all of which were formed by impacting meteorites -- to produce the existing maria.

Fragments of these ancient rocks were scattered by the explosive impact of meteorites bombarding the face of the moon during the last 3 billion years, in general in decreasing numbers as the millenia went by. In some places their distribution is in a pattern of rays, radiating from craters like Copernicus. In many places where they accumulated to a considerable thickness, the fragments form breccias, solidified by compaction under the weight of the overburden or by cementation by shock-melted glass. Some of the loose fragments in the rock collections are glazed on one or more sides by such glass. This material is particularly abundant in the "fines" of the lunar samples.

In general the relative age of the craters that pockmark the moon's surface can be inferred from the extent of rounding or softening of their originally sharp peripheral rims. Rocks are fractured and shattered by expansion and contraction due to the great changes in surface temperature between the excessive heat of the long days and the deep freeze of the long nights (each equal in length to 14 earth days). Gravity pulls the loosened particles down slope, even though its force on the moon is about one-fifth of its force at the surface of the earth. Lunar talus slopes and cones are similar to analogous landforms on earth. The impact of micrometeorites may move dust particles from place to place in much the same way as they are moved about by terrestrial breezes. Almost everywhere the solid rock of the lunar crust is veneered with lunar "soil" -- better designated as regolith -- from a few centimeters to many meters thick. Fortunately the loose particles of the lunar regolith are compacted rapidly under their own weight so that "moon walkers" and their vehicles leave footprints and tracks but do not sink far into the regolith.

The overwhelming majority of the lunar craters were formed by impact of meteorites or planetesimals; they are definitely not of volcanic origin. In fact, outpouring of lava and other kinds of volcanic activity seem to have ceased, for all practical purposes, some 3 billion years ago. Even so, there is still a slight possibility that some volcanic cones and/or craters may yet be identified as exploration of the moon continues, and that recent or even currently active volcanism may be detected somewhere on its surface. The report from the Soviet Union that an emission of gas from the crater Alphonsus was observed in 1958 should not be totally discarded as an aberration of instruments or men, even though that observation has never been confirmed or repeated elsewhere.

The age-old question as to whether there is life on the moon, even though it might be some kind of living creature wholly different from any known on earth, has now been answered quite definitely in the negative. According to N.W. Hinners (1971, p. 448): "...no life forms have been found, nor have organic molecules been unambiguously identified as being indigenous to the moon. The virtually complete lack of water and the four-plus billion years of exposure to a harsh space environment make eventual detection of lunar life unlikely."

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