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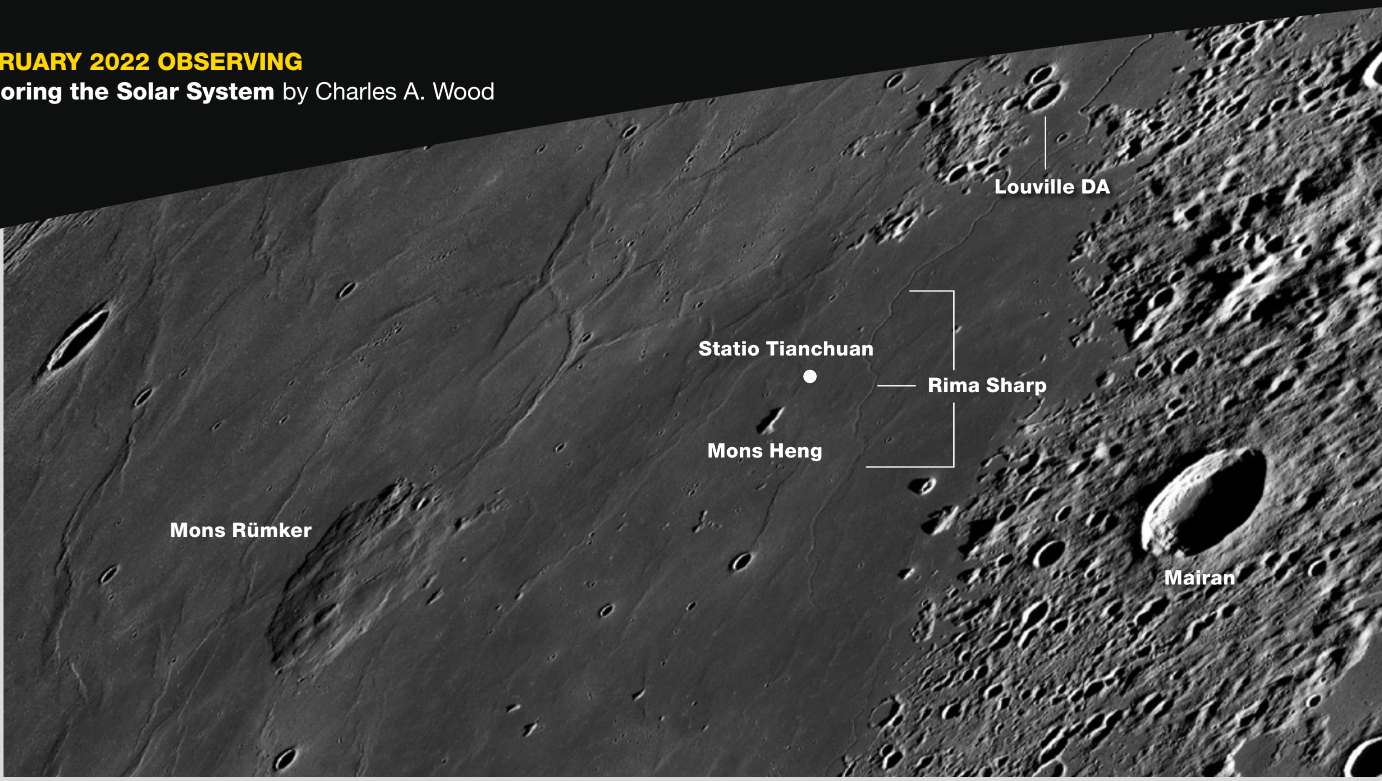


Chang'e 5 and the Age of Lunar Lavas

Does China's sample return mission change our understanding of lunar chronology?

Until recently, scientists since Galileo's time who studied the Moon were astronomers, not geologists. It wasn't until the late 1950s and early 1960s that Eugene Shoemaker and Robert Hackman of the U.S. Geological Survey (USGS) developed a lunar stratigraphic sequence based on telescopic and photographic studies of the spatial relations among lunar landforms. They chose the southeast quadrant of **Mare Imbrium** to determine sequences of events by mapping the overlap of deposits created by each event.

The most recent Imbrium episode that Shoemaker and Hackman recognized was the formation of the crater **Copernicus**, whose radiating bright rays and secondary craters adorn nearby Mare Imbrium, **Montes Apenninus** (Apennine mountains), and more distant terrains. Copernicus's formation must be the youngest major event in this area of the Moon, they concluded. The fact that rays and secondaries are on Mare Imbrium means that those mare lavas are older, and since the arc of the Apennine mountains borders the mare, the range must be older than the lavas. The USGS scientists considered the tall Apennines to be the rim of a giant crater or basin that the mare lavas erupted within. And the Apennines must have formed on some pre-existing terrain, which would be the oldest landform in the region.

Going to a deeper level of stratigraphy, the pair noted that the crater **Eratosthenes** lacks rays, but its small secondary craters are visible on Mare Imbrium. Eratosthenes is also overlapped by debris from Copernicus, so it must be older than Copernicus, and younger than the mare lavas. Going one step further, they saw that **Archimedes** has no rays or secondary craters and is almost completely surrounded by Imbrium lavas. Therefore, Archimedes must have formed on the giant basin floor or early lavas before Imbrium's later lavas flooded the basin and buried Archimedes' rays and secondary craters.

Over the next decade, USGS scientists mapped the entire Moon, producing a stratigraphy that delineated various young and old landforms. Unfortunately, they didn't know the absolute age for any of the features.

The solution at the time was to estimate absolute age by counting the number of craters on the maria. The idea was that impact craters continually accumulate over time. Thus, the heavily cratered, bright lunar highlands must be older than the sparsely cratered mare lavas. But to convert crater counts to absolute ages requires knowing the rate at which impact craters form — and that rate apparently changed from being very high just after the Moon's formation to the much lower rate we see today.

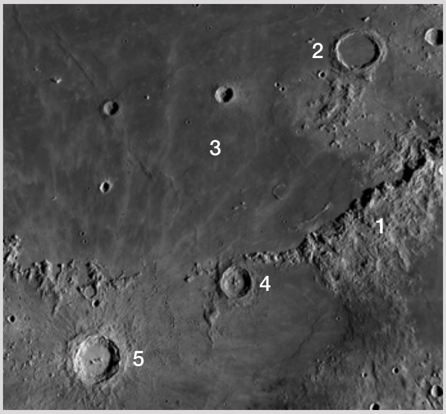
Before the Apollo program, Shoemaker, astronomer Ralph Baldwin, and graduate student Bill Hartmann independently estimated crater formation rates based on the number of impact craters of known ages on Earth, and from the predicted number of lunar impact craters formed by the collision of asteroids and comets. This kind of

▲ Seen above are the newly named lunar feature Mons Heng and Statio Tianchuan, where China's Chang'e 5 mission landed and collected samples.

NASA / ARIZONA STATE UNIVERSITY / APPLIED COHERENT TECHNOLOGY CORP research was new in the 1960s, so it's not surprising that the age estimates for lunar maria differed widely. Shoemaker and Baldwin predicted young ages for the lavas around the Apollo 11 landing site, as little as 0.6 billion years. Four years earlier, Hartmann derived an age of 3.6 billion years, exactly what the samples returned by the Apollo 11 mission turned out to be. Hartmann's success must have been a combination of expertise and luck.

Samples brought back from the Apollo 11 landing site on **Mare Tranquillitatis** provided the first calibration point for crater counting. Four more Apollo missions landed on maria and yielded additional calibrations for crater counts. But the mare ages of Apollo samples spanned only the period before 3.2 billion years ago. As a result, there were no calibration points for lunar crater counts covering 3.2 billion years ago to today — the most recent 60% of lunar history. This gap was creatively filled by radiometric dating of certain Apollo 17 samples thought to be Tycho ejecta, which provided an age of 0.11 billion years for Tycho and its crater counts. Similarly, the age of 0.8 billion years for Copernicus stems from dating an Apollo 12 soil sample inferred to be ray material from that giant crater. All the sparse and uncertain crater count/absolute age data are memorialized on a famous graph that remains the basis of lunar chronology, nearly 50 years after the end of the Apollo program.

The situation will drastically improve now that samples returned in December 2020 from northern **Oceanus Procellarum** by China's Chang'e 5 mission have been precisely dated. China selected the landing site (recently named Statio Tianchuan, after a Chinese constellation) because crater counts indicate that the mare lavas there, originating from the nearby sinuous rille **Rima Sharp**, are among the youngest on the Moon, forming sometime between 1.5 and 2 billion years ago. The laboratory-dated Chang'e 5 samples are 1.96 billion years old, which is consistent with the age derived through crater counting.



▲This image plots the order of major events in Mare Imbrium. Montes Apenninus (1) formed first, followed by Archimedes (2). Imbrium lavas then filled the basin (3). Later, impacts formed Eratosthenes (4) and finally Copernicus (5).

Adding a precise age and crater count number for such a young lava implies that the standard crater-counting/age models need only small corrections to the accepted lunar chronology (and all other chronologies across the solar system that are based on lunar results). The scientists who reported the new age also state that the samples are low in radioactive elements whose decay could provide heat for creating magma more than a billion years after most lunar volcanism ended. What this means is that scientists need to create new models of lunar thermal history. In science, data drive theories.

You can observe the key sites I've mentioned. The southeast quadrant of the Imbrium Basin where Shoemaker and Hackman established the first lunar stratigraphy is a familiar region, with prominent craters and mountains. Two details to notice are rays and secondary craters from Copernicus crossing Imbrium east of **Pythias**, and the lack of rays and secondaries radiating from Archimedes. The landing site of Chang'e 5 is not conspicuous but look east of **Mons Rümker** for the isolated peak **Mons Heng**, newly named after a Chinese mountain (see facing page). Northeast of Mons Heng is Statio Tianchuan and Rima Sharp. The rille is quite indistinct here but is more conspicuous 120 km (75 miles) further northeast near the 11-km-wide crater **Louville DA**.

The 1.96-billion-year age at Statio Tianchuan is considered young because the majority of the lunar surface is more than 3 billion years old, whereas the average age of Earth's surface is about 0.5 billion years. We live on a dynamic world that tends to erase ancient features. Fortunately, there's a museum of solar system antiquity orbiting just 226,000 miles away.

■ Contributing Editor **CHUCK WOOD** can't wait for more dated samples to fill in the crater curve gaps.

▶This graph updates the absolute lunar chronology, which plots the ages of measured lunar samples on the *x* axis against the cumulative number of craters larger than 1 km diameter per each square kilometer of lunar surface along the *y* axis. The ages of Copernicus, Tycho, and Nectaris are estimates, while samples returned by the Apollo missions (Ap), the Soviet Luna missions (L), and China's Chang'e 5 mission (Ch5) were directly measured. Gray bars represent the margin of error in the crater counts.