11

JAMES R. ARNOLD*

The Moon before Apollo

When Galileo first turned his telescope toward the sky, he made two major discoveries. One, the four large moons of Jupiter, is justly famous. The other, less familiar, is perhaps more important historically. He saw the Moon with enough resolution to conclude that it is not a ‘heavenly body’ as that term was understood, made of perfect and everlasting heavenly stuff, but a rough, cratered object more like the Earth – a real world rather than a figment of the human imagination. Its study moved from the field of theology to that of natural philosophy, now called science.

We are approaching the 400th anniversary of that important milestone in intellectual history. I give here a brief account of lunar studies before the first Apollo landing, in 1969. For this period I owe a great debt to Kopal (1969), to which the reader is referred for a more complete and authoritative history. Our knowledge of the Moon up to the modern era divides itself naturally, I believe, into two strands. The first to develop historically was a series of successively refined maps of its visible surface. The second was the growth of understanding of the orbital motion of the Moon, and of its physical nature.

Galileo’s first published maps (Kopal 1969, p. 226) were very crude. No known features can be identified on them. The first maps showing features recognizable to the modern student were those of M.F. van Langren in 1649 (Kopal 1969, pp. 228–9), quickly followed by others. The maps of G.B. Riccioli and his colleagues (Kopal 1969, p. 235) show Copernicus and other big craters clearly for the first time. More importantly, most of the feature names given by Riccioli still survive today. He seems to have been responsible for calling the low-lying, dark, relatively smooth areas *maria* or ‘seas’, names which are still attached to these huge basaltic flows. Although they are low-lying and rather flat, this name was not well chosen. ‘Deserts’ might have been better, ‘lava plains’ better still. In this period also the moon’s libration (see below), causing somewhat more than half the lunar surface to be visible, was first noticed and used.

The next step in quantitative precision came with Tobias Mayer (Kopal 1969, pp. 241–2), who in 1750 recorded rather accurate coordinates for 23 reference points on the lunar surface. Even so, actual maps using these data and new observations of similar precision did not appear until almost a century later (Beer and Mädler 1837). In Jules Verne’s deservedly famous science fiction novels *De la Terre à la Lune* (1865) and *Auture de la Lune* (1870), it was Beer and Mädler’s maps that were brought to lunar orbit by his three intrepid astronauts. They remained the standard well into the twentieth century. The only notable advance in this period was in the measurement of altitudes of various features using shadow lengths in early lunar ‘morning’ and late lunar ‘afternoon’.

The second area of research which was within the means of students of the Moon before the space age had to do with its large-scale structure and dynamics. These generally require much more precise quantitative study than the mapping of the surface, and so were slower to develop as areas of research. It is worth noting, however, that Newton’s calculation of the gravitational attraction of the Moon to the Earth, by his own account ‘agreeing pretty nearly’ with an inverse square law of attraction, was a critical early step in his development of his theory of gravitation.

The study of the Moon’s orbit may be said to have begun with G.D. Cassini in the mid-seventeenth century. Reasonably precise values of the Moon’s orbital motions, including the inclination of its orbital plane to the ecliptic plane (about 5.14º), the inclination I of its axis of rotation to its orbital plane (about 1.53º), the semimajor axis, the eccentricity, and quite a good ephemeris of its motion were determined by Lagrange and Laplace in the late eighteenth century.

* University of California San Diego, La Jolla, CA, USA

James R. Arnold, The Century of Space Science, 271–275

Darwin (1880) and some of his contemporaries opened up a new scientific frontier by calculating the history of the Moon's orbit, seeking light on the question of its origin. He concluded that the moon has been and is receding from the Earth, due to dissipative tidal forces exerted on the Earth by the Moon. This, he said, should cause the Earth's rotation on its axis to slow over time as a consequence of conservation of angular momentum. Had the Moon ever been as close to the Earth as a few Earth radii, the length of our day would have been only a few hours. This analysis has proven robust.

By the early twentieth century three possible scenarios for the origin of the moon had been proposed and explored to the limited degree possible with the meager data available. What we may call Darwin's (1880) 'fission hypothesis' held that the Moon had separated from the Earth when the Proto-Earth's rapid rotation caused it to deform and become unstable. This idea had been embellished somewhat, and the Pacific Ocean had been suggested as the scar of the fission process. An Earth–Moon 'double planet' scheme, analogous to the formation of double stars, had its advocates. Finally, a capture model, in which the Moon was thought of as a small planet born elsewhere in the Solar System, and later captured in a close passage by the Earth, was seen as a possibility. While many papers on lunar origin were published over the decades, all three of these models continued to be advocated up to and even after the Apollo missions. They were widely considered to be the only three possibilities. It seems now that nature knew better, but that is another story.

While the fact that the Moon's shape is not quite spherical was first deduced by Laplace, the first thorough study was done by Jeffreys (1924). The Moon was shown to have a bulge pointed toward the Earth, accounting for its synchronous rotation. This was consistent at that time with a model in which the bulge was caused by tides raised on a hot early Moon when it was much closer to the Earth. However, the situation is not so simple. Moments of inertia of the Moon around three mutually perpendicular axes can be compared using observations made from Earth: the one called A, pointing toward the center of the Earth; C, close to the rotation axis; and B, perpendicular to the other two. They are all slightly different. $(C-A)/B$ is the best-determined ratio, given by Urey (1952) as 0.000629. The less certain values of $C-A$ and $C-B$ are certainly different from each other, so that to a first approximation the Moon is a triaxial ellipsoid. This was already known by the time of Urey's book as inconsistent with a simple tidal model.

The ellipticity of the lunar orbit, and the inclination of its axis of rotation, combined with the parallax due to the Earth's finite size, give rise to the optical librations, or apparent rocking, of the lunar surface in latitude and longitude. Thus we can see more than half of the Moon's surface, in fact about 59%, at one time or another. There is also a physical libration, or actual rocking of the surface, but it is very much smaller.

We are ready, I think, to move on to the modern era. I choose to start the modern era as Harold Urey, the leading student of the moon 'before Apollo' always did, with the publication of a remarkable book by Ralph Baldwin (1949). In the brief span of 238 pages, Baldwin covered a lot of territory. First he reviewed the history of lunar studies to that point, with an excellent bibliography. Then he gave arguments, clear and convincing to Urey and others able to understand, for some key conclusions about the Moon. Not that he stopped the arguments! As it became apparent that they might soon be settled by direct observation, they in fact tended to grow more intense.

The most interesting of debates was over the mode of origin of the abundant lunar craters, and of the circular maria, such as Mare Imbrium and the 'bull's eye' of Mare Orientale. Baldwin (1949) summarized the nineteenth-century literature on this topic, pointing out that the generally accepted view, then and later, was that these features were volcanic. The other chief idea, that they were formed by the impact of stray bodies, had been proposed quite early, but was not taken seriously – it was even considered a curiosity – by most students of the subject.

The one clear statement of the case for impacts before Baldwin's was given by a geologist famous in his time, G.K. Gilbert (1893). Baldwin (1949) put forward three simple points. First, almost no lunar craters had anything resembling the conical outline familiar in terrestrial volcanoes. There are only a few small, inconspicuous domes. Second, the volume of the crater walls was always comparable, within the rather large errors associated with telescopic observations, to the volume of the central hole; averaged over many craters, the agreement was close. Finally, while the larger craters usually show central peaks, in no case does a central peak rise above the level of the surrounding terrain.

The discussions of this and other questions were interrupted by a major event: the launch of Sputnik 1 on 4 October 1957, followed on 3 November by the larger and more ambitious Sputnik 2. On 31 January 1958 the USA responded by successfully launching the very small but capable Explorer 1, which yielded James Van Allen's discovery of the Earth's radiation belts. It was immediately obvious that great new possibilities for space research were about to be realized. For planetary scientists the Moon was the inevitable first target.

Following the establishment of NASA in 1958, attention was given to the possibility of one or more lunar missions. Urey was particularly effective in advocating such missions. The first NASA committee to explore the subject was appointed early in 1959, with him as its most prominent member (and the author as a new recruit). What might be called ‘the first Moon race’ then began. The most obvious goal was to produce images of the then still invisible farside.

The mare named Moscoviensis and the large, dark-floored crater named Tsiolkovsky will allow younger readers to guess or remember who won that first race. Indeed, the Soviet Union held the lead for a long time. After two mission failures, their Luna 3 mission flew by the Moon on 8 October 1959 and obtained images of its hidden side, marking the first successful mission to another planetary body. The pictures released were not very clear. This allowed the illusion to persist in the West for a while longer that the Soviet space probes were of poor quality, or even that the images were fraudulent. A scientist working with a US intelligence agency undertook to evaluate the case. He gave a very entertaining talk on the results. His conclusion was that the pictures were retouched ‘by experts, as good as ours’ before publication. He was sure that the Soviet scientists actually had ‘genuine pictures better than the ones they released.’ The better pictures obtained later in fact confirmed their results. They could and did name the big features. The most notable difference between the nearside and the farside was the near-absence of maria on the latter.

NASA’s plans for lunar missions took some time to develop. They were overtaken by President Kennedy’s speech to Congress in May 1961, announcing to the world that he was committing the US Government to ‘placing a man on the Moon in this decade and returning him safely to the Earth.’ All plans were restudied and, where appropriate, revised. A manned flight on such a schedule required not only the development of advanced capabilities at an accelerated pace, but also their testing by precursor missions of unprecedented scope and complexity.

The new objective led to the announcement of three sets of unmanned NASA missions to the Moon. The first, the Ranger series, was at first largely unchanged from earlier plans. It included a series of impacts on the Moon’s visible face, with both scientific and reconnaissance objectives. The second, the Surveyor series, was to land small instrument-bearing spacecraft safely on the surface, again with multiple tasks. Both these programs were to be managed by the Jet Propulsion Laboratory in Pasadena, California. The third, the Lunar Orbiter series, was to produce a photographic map of the Moon, nearside and farside, as complete and detailed as possible. The goal was mainly to support the manned missions, but the data set would also be available for science. Responsibility for this was assigned to the Langley Research Center in Hampton, Virginia.

It was a bumpy road we started down then. There were numerous failures while scientists, engineers, and managers learned their new roles. What is important here is not the race, but what was learned and how that led to the remarkable scientific advances of the Apollo period.

The first NASA lunar mission program was named Ranger. It began badly. Rangers 1 and 2 were engineering test missions – both failed. Then missions 3–5, carrying cameras and scientific instruments and intended to approach and impact the visible face of the moon, also failed (in a different way each time.) However, the experience gained seems to have been useful. Rangers 6–9, launched in 1964–65, were redesigned to carry cameras only. These four succeeded in producing the first close-up images of the Moon, in the few seconds before impact.

These images were clear and in focus. The final frames showed features smaller than one meter, sometimes much smaller. Some of these were craters, not very different in appearance from the larger ones seen through Earth-based telescopes. This was no surprise to those who believed they were caused by impact of stray bodies, small fragments of asteroids or comets. They presented more difficulties to the volcano party.

One group of images displayed parts of bright rays originating from one of the Moon’s youngest large craters. These were full of small pits which were elongated in a common direction, appearing quite unlike the large primary craters seen through Earth-based telescopes. There could be little doubt that they were secondary impact features, formed as debris from the major crater-forming event moved out radially from it at subsonic speeds. It was also possible to conclude definitely what had already been inferred from measurements of temperature versus time on the lunar surface (Baldwin 1949, p. 10, Figure 1 and accompanying discussion), namely that the Moon was not covered with bare rock. What the Ranger cameras saw was fine-grained material. In general the surface in all three image sequences was remarkably smooth. Nonetheless, landing a spacecraft without human guidance was seen to have a finite risk of failure due to striking a rock.

Meanwhile the Soviet program was continuing to produce important results and some more ‘firsts’. Two long series of spacecraft, Luna and Zond, were launched throughout the 1960s and even later. Perhaps the most important was Luna 9, which was the first to soft-land on the Moon, on 3 February 1966, before the US Surveyor program had begun. It transmitted pictures back to Earth of its landing site in western Oceanus Procellarum. Luna 10, which followed, was the first spacecraft to be put in orbit around the Moon.

This Surveyor series had an ambitious aim. The spacecraft were to land softly and upright on the lunar surface, on three extended feet. They carried not only cameras but also other instruments (described briefly below). Their success rate showed impressive progress since the Ranger series. Of the seven spacecraft launched, only Surveyors 2 and 4 failed to achieve their landings and scientific objectives.

Surveyor 1 landed on 2 June 1966, at a near-equatorial western site not far from the crater Flamsteed in Oceanus Procellarum.* This spacecraft and Surveyor 3 carried vidicon TV cameras capable of producing a black-and-white TV image of 600 lines. The cameras could be rotated 360 degrees, raised and lowered, and zoomed in and out. Over 10,000 pictures of the site (and the sky) were obtained, covering a full lunar day cycle in each case.

A full report of Surveyor 1's findings is given in Jaffe (1967), with an accompanying photographic section. The coverage of surface features was of course far more detailed than that available from the Ranger pictures (or the earlier Soviet ones). One fear was laid to rest by both Luna 9 and Surveyor 1: The two spacecraft did not sink into the lunar surface (confirmed to be finely divided material, now christened 'regolith') as one scientist had warned NASA that it would. Again, the surface was seen to be generally smooth with low slopes, though there were rocks that could present serious obstacles to landing spacecraft. The principal scientific investigator was Eugene Shoemaker, in his first important role in the lunar program.

Surveyor 3 was on the whole a repeat of Surveyor 1, enhancing the database of surface images and strengthening the view that this sort of scene beheld by both craft's cameras might be typical of at least the lunar mare surfaces, which because they showed fewer large craters were preferred for the Apollo manned landings. In addition to the TV camera, Surveyor 3 carried a soil mechanics experiment, essentially a powered, fist-sized bucket with a range of capabilities. In the course of about 18 hours it carried out dozens of tests of soil properties, including bearing strengths and response to impacts. Perhaps most important, it could excavate a trench to a depth of 17 cm and display the sampled material. Shoemaker was again chiefly responsible for these experiments.

Surveyors 5, 6, and 7 landed at new and interesting spots on the nearside, respectively the prominent eastern Mare Tranquillitatis (already emerging as the most likely area for the first manned landing), Sinus Medii near the center of the Moon's face, and the northern rim of the crater Tycho in the south. The best reference for the later Surveyor missions is Jaffe (1969). Camera and soil property instruments were updated for these missions, but the most interesting new development was the inclusion of an alpha-scattering instrument for chemical analysis. This instrument was designed and built at the University of Chicago by a group headed by Anthony Turkevich (1967). It used Rutherford scattering of alpha particles produced by radioactive decay (the same process Ernest Rutherford had used to demonstrate the existence of atomic nuclei). It could identify the nuclei, and hence the elements from which the particles were scattered, using the principle of conservation of momentum. Housed in a box open at the bottom, the instrument was deposited on a flat spot on the surface. It accumulated a spectrum of energies of backscattered particles over many hours of exposure. The concentrations of all major elements (abundance greater than 1%) in the top layer of the soil it sampled were then derived from their scattered energy spectrum.

The Surveyor 5 results clearly identified the material at this mare site as a (ground up) basaltic rock, comparable in general to basalts on earth. However, it was unusual in having a high concentration of the element titanium, 6–8% by weight, which was beyond what geochemists were accustomed to on the Earth. The result, though it evoked a good deal of skepticism at the time, was fully confirmed when the Apollo 11 soil from the same area was analyzed in the laboratory. This was the first chemical analysis of the composition of an extraterrestrial material *in situ*. It was followed by quite a few others, and all the data showed clearly that the Moon is highly differentiated chemically. These and later analyses provided very useful constraints on the origin and history of the Moon.

Meanwhile, the Soviet lunar program had not been idle. A series of Luna missions and one mission called Zond returned important data and images, particularly of the hidden farside of the moon (e.g. Dolginov *et al.* 1967, Lebedinsky *et al.* 1967).

Like the other two US mission series, the Lunar Orbiters were important both as precursors of the Apollo landings, and for the database they provided. The method used to gather the data seems dated now, when CCD cameras and other advances have made to job much easier. But at the time it was ingenious, and above all it worked. So did the spacecraft, all five times. The first launch was in August 1966, the last in August 1967.

Cameras with long rolls of narrow strip film were used to take thousands of pictures of the lunar surface in a preplanned pattern, both of whole bands of the lunar surface and of particular candidate landing areas at higher magnification. These were developed chemically to bring up the images, and then scanned with beams of light to produce streams of intensity data from which the black-and-white images could be reconstructed back on Earth. Sequences were designed to optimize lighting, so that shadows could help to bring out detail. Many months of exposures were made and recorded. Well over 90% of the lunar surface was eventually covered during the five missions, giving rise to a remarkably valuable database of both the near- and farsides.

Calculations showed that the spacecraft would remain in orbit for a long time after the imaging had been completed,

* The convention used then and later reversed that used by astronomers in the preceding centuries, to one in which the direction is that seen from Earth, not as before by an observer on the Moon itself. It was adopted for the convenience of the Apollo program. After Apollo the new convention was adopted by the international astronomical community. Thus, for example, Mare Orientale, which in Latin means 'Eastern Sea' is now at the western edge of the visible hemisphere.

http://www.springer.com/978-0-7923-7196-0

The Century of Space Science
Bleeker, J.A.; Geiss, J.; Huber, M. (Eds.)
2001, XLIX, 1846 p., Hardcover
ISBN: 978-0-7923-7196-0