# 5

# The Ranger Transition
## *1964–1965*

### FIVE BLOCKS TO ONE (DECEMBER 1959 – FEBRUARY 1964)

While preparing for manned spaceflight, the United States had also been attempting, without much success, to explore the Moon with something better than telescopes. Project Ranger, initiated in December 1959 in response to the early Soviet successes in space, was thought to have the best chance to score a mark against them. It would eventually do so but only after a string of disheartening setbacks.[1] The name Ranger had been suggested by JPL Lunar Program Office Director Clifford Cummings and was strenuously opposed by the NASA Headquarters prime mover of the project, Abe Silverstein, because he once owned an intractable and cantankerous dog by that name.[2]

Sure enough, Rangers 1 and 2 failed in August and November 1961 because their Agena boosters did not restart in low Earth orbit. These "block 1" Rangers had been nonlunar tests of such innovations as parking a spacecraft temporarily in Earth orbit and stabilizing it by attitude-control jets instead of spinning, and their scientific experiments were designed entirely for the particles and fields of interplanetary space.[3] After May 1961, however, Apollo, the sun god who ruled the Moon, had taken over Ranger and the rest of the unmanned lunar program.[4] Its often-squabbling NASA and JPL parents conceived of Ranger as a versatile and complex spacecraft.[5] Rangers 3, 4, and 5, constituting block 2, were to crash-land on the Moon and carry an impressive array of planetology experiments. A gamma-ray spectrometer suggested by Jim Arnold was something the space physicists could understand. But their nightmares were coming true; there would be television cameras whose ravenous appetite for transmitted data bits threatened to exclude or limit other experiments. A balsa-wood capsule containing a seismometer would be thrown clear and braked by a rocket to a hard landing just before the main spacecraft "bus" crashed to its destruction. In October 1961 the Ranger science experimenters were drawn from our familiar list of lunar pioneers: Gerard Kuiper, Eugene Shoemaker, Harold Urey, and no physicists.

There was worse news for the sky scientists. The scientific payload for the block 3 Rangers would consist of the one instrument determined by the mid-1961 decision-making process to be most useful for Apollo support: television cameras. In 1962 the sky scientists fought to reinstate their instruments, and planetologists Harold Urey, Frank Press, and Jim Arnold also protested to a beleaguered Homer Newell about the excessive emphasis on pictures.[6] Urey recognized the value of pictures for "engineering purposes" but not for science. Kuiper and Shoemaker, of course, favored imaging.[7]

The three block 2 Rangers at least left the Earth—in January, April, and October 1962—but failed to achieve a single unqualified success (appendix 1). Heads rolled and goals jelled at JPL.[8] In December 1962 Cummings was replaced by Robert Parks, and James Burke was replaced as Ranger project manager by his longtime friend Harris "Bud" Schurmeier, even though Ranger's troubles were due more to bad luck and shifting mission objectives than to any incompetence on the part of Cummings or Burke. Jim Burke's sunny disposition had survived stints as a Caltech student, a naval aviator, and (barely) a referee in the battle between Apollo and sky science, and would survive Ranger's troubles. But the sky science experiments for block 3 did not; they were irrevocably canceled in the same December.

Hopes for Ranger's future and for early data useful for Apollo rode on the cameras of block 3. As a Ranger spacecraft raced toward its doom on the Moon, each successive image would show finer details than the previous one. The frames were supposed to nest so that each new scene could be located on the previous ones, and so backward to the more familiar telescopic views. Engineers hoped the last high-resolution shots would show blocks, boulders, slopes, soil structures, and other detail at the scale of interest to Apollo and its soft-landing robot precursor, Surveyor.[9] Scientists hoped that fragmental debris, lavas, and the more exotic surfaces could be distinguished.

The block 3 experimenter team was formalized in July 1963.[10] Homer Newell appointed Kuiper as team leader with the understanding that Shoemaker would get the parallel job with Surveyor. Shoemaker, Urey, and Ewen Whitaker were scientific coexperimenters, as was JPL engineer Ray Heacock, a specialist on the camera system. Optimum lighting angles and approach trajectories during a launch window determined the approximate longitude of each Ranger's target, but the experimenters had a say in the latitude. Whitaker prepared a table of favorable points that could be reached on each day during a launch window. Having taken over Ranger's objectives, Apollo engineers at MSC now lost interest in it. Nevertheless, Kuiper's team aimed the first Rangers at smooth maria more interesting to safety-minded engineers than to most scientists.

Block 3 included four spacecraft, Rangers 6–9. In late 1962, nine more spacecraft in two blocks had been planned to follow Ranger 9.[11] Block 4 was to get improved television imagery, Arnold's gamma-ray instrument from block 2, and a radar sensor that had been in the works for some time. Block 4 never really generated much enthusiasm, though, and was canceled in July 1963. Block 5, with six spacecraft renumbered Rangers 10–15, survived a little longer. It picked up the block 4 instruments and added the block 2 seismometers. In October 1962 Homer Newell's office had asked the seismometer's developer, Aeronutronic Division of Ford Motor Company, to study a capsule for landing a small television camera, but it was not approved. Time was passing, funds were shrinking, Surveyor was consuming JPL's resources, and a better mission than Ranger — Lunar Orbiter — was being hatched. Block 5 followed block 4 to the junkheap in December 1963. Only the four spacecraft of block 3 were left to carry out the reduced Ranger mission.

Make that three spacecraft. On 2 February 1964 the cameras of Ranger 6 failed to switch on before it crashed near its intended target in Mare Tranquillitatis. High-voltage electrical arcing shortly after launch had damaged the television system. The depression deepened at JPL.[12] A congressional inquiry aired the chronic difficulties between NASA Headquarters and JPL and wondered what return the program was getting for the large fee paid to Caltech.[13] Rangers 7, 8, and 9 would be the last of their breed. They had better work.

## THE FIRST CLOSE-UPS (JULY 1964)

They did. The Ranger program's first unqualified success came on 31 July 1964 at 1325 GMT when Ranger 7 returned more than 4,300 pictures of a ray-crossed mare area before it crashed within a dozen kilometers of its aim point.[14] Despite the early hour at JPL (6:25 A.M.), rooms full of engineers, secretaries, and technicians burst into wild cheering; the Ranger 6 champagne could finally be uncorked. The last picture was taken only 1.6 km above the surface. Features about a meter across were seen in the best pictures, a 200-fold improvement over the best telescopic horizontal visual resolution and better than that over telescopic photographs.[15] The pictures showed a surface dominated by craters, unsurprising from today's viewpoint but a disappointment to curiosity seekers in those days. Urey was "pleasantly surprised" that so much information could be secured from the pictures.

The nature of the surficial material that would or would not support the Apollo astronauts was now the main reason for Ranger's existence and was a lead item in the enthusiastic and lavish press reports of the mission. Less than 15 hours after the "landing," and only a few hours after receiving good copies of the pictures, Kuiper, Shoemaker, and Whitaker were showing slides for a press conference. A few blocks were seen in some of the approach views, though not the last shots, and Kuiper and Shoemaker reassured the reporters that the surface had a substantial bearing strength. The visible slopes would be satisfactory for Surveyor landings. Kuiper suggested that walking on the surface would be like walking on crunchy snow. Though not an experimenter, Gold also got some publicity and, notwithstanding the conclusions of most photointerpreters, had seen his "worst fears realized." He and the press were happy.

Formal reports on the mission elaborated on the nature of the surface material.[16] Urey used and, I believe, introduced the appropriate term *gardening* to describe how the surficial material was made: constant overturning by impacts. Drawing on the research that had been accumulating, Shoemaker characteristically specified the properties of the gardened layer of shattered and pulverized rock so accurately that one might conclude that the Moon had been explored five years sooner than was the case: (1) it rests on a cratered mare substrate with irregular relief and varies in thickness up to a few tens of meters; (2) about half of its fragments were ejected from craters less than a kilometer away, but some fragments could have come from anywhere on the Moon; (3) the number of times fragments are reejected and overturned increases greatly toward its surface; (4) its surface is pockmarked by craters of all sizes from submillimeter (called "zap pits" when they were later found) to tens of meters; and (5) only its uppermost few millimeters are the fragile and open network inferred by the astronomers; so (6) its bearing strength increases rapidly with depth, and the astronauts would be safe.

If I were describing milestones along some straight and obstacle-free path toward Truth, I would let the surface material rest at this point; only details remained to be filled in after this tele-exploration. But a historical account must tell how Kuiper's thinking evolved. He espoused a common idea of the time that the inferred porosity was in a "rock froth" that would form on lavas in a vacuum. Old-timers will remember "simolivac" (silica molten in vacuum), which was produced by exposing appropriate liquids to a laboratory vacuum. Kuiper guessed the thickness of the Moon's simolivac—based on the blocks that the surface supported and from the sizes of sharp craters (formed in the underlying solid rock)—to be as much as 5–10 m. At the time of Ranger 7, he agreed that the froth was probably covered by considerable impact-generated fragmental material. There was no real conflict yet with Shoemaker's conclusions.

A discovery made by Ewen Whitaker at the telescope, and not by Ranger, weighed heavily in Kuiper's report of the Ranger results. Color-blind Whitaker knew that the entire Moon has almost the same warm, relatively brownish or "reddish" tint, but that some spots, notably the Aristarchus Plateau, or Wood's Spot, are slightly redder than others. Even before moving to Tucson Whitaker had summoned his formidable photographic and darkroom skills to enhance these differences better than had been done before or has been done since. The resulting images provided important information on the Moon's history and surface properties. Shaler had concluded from the sharpness of albedo boundaries that the impact rate had never been great. Kuiper more precisely reasoned from the sharp, and often coinciding, color and albedo boundaries that the impacts had not been sufficiently numerous to obscure bedrock contacts in all the time since the maria were emplaced. The boundaries' sharpness implies that the Moon's surface is covered neither by cosmic dust nor by laterally migrating Gold dust. The color differences showed that no individual mare was formed all at once. Volcanism, not giant impacts, formed the maria, as Kuiper had believed for at least 10 years. He speculated less successfully on the cause of the colors, suggesting though not really believing that the red or "yellow" (his term) flows might be more highly oxidized or older than the less reddish ones usually called "blue." The significance of the colors remained a mystery for 5 more years.

Another discovery by a member of Kuiper's staff at LPL specified the kind of volcanism that made the maria. Gold once said that geology is so simple that someone like Kuiper could learn it in a day,[17] but apparently Kuiper did not completely agree, because in the summer of 1963 he had hired Robert Gregson Strom (b. 1933), a physicist-geologist (his term) who had been working on a gamma-ray experiment at the Space Science Laboratory of the University of California, Berkeley. Strom was one of the few geologists, hyphenated or not, who became interested in the Moon before it became fashionable. He came across *The Face of the Moon* in a bookstore in Karachi, Pakistan, in the 1950s and became another disciple of Baldwin. While still in Berkeley he had noticed lobate flow lobes in Mare Imbrium but was dissuaded by Urey from pursuing their implications (because, of course, the implications were that Mare Imbrium was volcanic).[18] Strom felt no such restrictions after arriving at LPL — quite the contrary, considering Kuiper's advocacy of volcanic maria. Strom and Whitaker quickly noted that some of the lobes and some of the color units coincide. Here was a major discovery whose ramifications are still being pursued today. Strom pointed out that the Imbrium flows are bounded by the steep scarps expected of lava, and not ashflow tuff; and that if they are lava, they are probably basalt, as Baldwin said, and not the more silicic rhyolitic rock favored by O'Keefe. He or

Kuiper also realized that mare wrinkle ridges cut across color boundaries and so are not edges of lava flow fronts but later structural modifications.

The Ranger pictures clearly showed that craters are concentrated along the light-colored rays, confirming that the rays were created by the secondary impact of ejecta thrown from larger craters, and not by such endogenic mechanisms as gas emissions along cracks. The rays as seen on telescopic photos before the mission pointed at their source craters. During the first quick-reaction studies, Copernicus, 600 km to the north, was named as the source. Secondaries of Tycho, 980 km to the south, were later also identified. The distinction could be made because the largest and most numerous secondary craters are usually found at the end of a ray nearest its source, as had been discovered where the source is obvious.

Kuiper had staked much effort and prestige on Ranger and searched dauntlessly for dramatic discoveries. Parts of the ray surfaces contained no craters. Already in his telescopic work he had concluded that some bright ray material came from the primary crater rather than the secondaries. Gases are very useful in lunar and planetary studies when all else fails. They can explode, seep gradually from cracks, discolor rocks, or spread far and wide to descend again where needed. They are the ideal *dei ex machina.* They could now be used to explain the difference between rayed and nonrayed secondaries. Urey and Whitaker had each suggested that rays are formed by gases blasting outward from cometary impacts, and Kuiper "examined [this idea] quantitatively and found [it] satisfactory." He therefore suggested that one could determine the ratio of cometary to asteroidal impacts from the numbers of rayed and nonrayed fresh craters.

Shoemaker, applying the old principle that the present is the key to the past, calmly stated that the rayed and nonrayed clusters had the same origin, just different ages—Copernican versus Eratosthenian in his stratigraphic scheme. The clusters outside rays originated in now-faded rays. He did not try to distinguish cometary and asteroidal impacts (although he is actively doing so today by more relevant means). He began to interject the observations of his staff into the postflight data analysis and proudly cited a telescopic observation by Mike Carr (confirming one of his own) that the secondaries of Eratosthenes are more highly degraded than those of Copernicus. We have here an excellent illustration of how the recognition of the time factor helps in interpreting origins.[19]

The Ranger experimenters and interested bystanders made much of what Urey called *dimple craters,* rimless craters up to about 150 m in diameter that seemed to have steep, conical interior profiles. Most people favored an origin as drainage holes for the fragmental layer. Some larger craters with mostly roundish but partly flat floors also lacked the sharp, round rims that Kuiper knew were signs of impact, and he proposed that these craters were collapse depressions like the sinkholes in certain limestone terrains on Earth (karst). Here again his failure to think historically got him into trouble. He did not see how both the dimples and the flat-floor craters could form on the same kind of surface unless they were covered by dust, a Goldian idea he did not believe. Apparently he did not realize that they could simply be different erosional stages in the degradation of primary and secondary impact craters. Crater counts by Bill Hartmann and Shoemaker showed too many craters smaller than about a kilometer across for the number of larger craters.[20] Kuiper claimed these excess craters for his collapse model, although he allowed Hartmann to give a more favorable slant to secondaries and impact in general, and a classic analysis by Shoemaker interpreted the excess craters as secondaries.[21] Collapse would get Kuiper into deeper and deeper trouble when he analyzed the Ranger 8 and 9 results.

The age of the mare revealed by Ranger 7 interested everybody interested in the Moon. Relative ages are determined by counting craters. Until samples are collected, absolute ages are determined by comparing the counts with the impact rate as guessed from the present rate of meteorite fall and the number of ancient craters on Earth (both poorly known even today). Ranger supplied the means to extend the counts to smaller sizes than those visible on telescopic photos. As a Ranger spacecraft falls toward the Moon, it sees at first the same widely scattered large craters that the telescope sees. As it gets closer, the smaller craters it can resolve rapidly become more numerous and soon cover the entire scene. Below the diameter range where the shoulder-to-shoulder craters appear — about 300 m for the Ranger 7 mare — each new impact not only creates a new crater but also destroys or partly obscures an old one. Here we have an important concept in the dating of lunar and planetary surfaces called the *steady state,* or cratering equilibrium.[22] Shoemaker knew there was no point in counting craters smaller than 300 m because the counts would not differ significantly for a 4.5-aeon-old mare and a 3.5-aeon-old mare. The steady state presents a stone wall to dating. Nor did there seem to be enough craters larger than 300 m to date the surface. Nevertheless Bill Hartmann took a crack at it. I have always thought that Bill has led a charmed life, although he may be just plain smart. Consider his reputation for discovering basin rings, his later prominence in the lunar origin debate, and the following number: 3.6 aeons.[23] This is the age he deduced for the surface of the maria around the Ranger 7 site and announced, through Kuiper, in the Ranger 7 report. Remember it when reading the account in chapter 11 of the dating of another mare with a similar crater frequency.

Ranger 7 generated enormous excitement in the data-starved lunar science community. At a special session of an IAU meeting in Hamburg on 31 August 1964, the target mare, once considered part of Mare Nubium, was officially renamed Mare Cognitum, the Known Sea, in honor of the new knowledge of the Moon. Kuiper also summarized the results at a conference of world-class earth science experts on the occasion of the dedication of the high-rise Earth Sciences Green Building at MIT in September 1964.[24] Ranger science was the glamour science of the hour.

## A BLUE MARE AND SOME CALDERAS (FEBRUARY 1965)

The Apollo people's heightened interest in Ranger meant that Ranger 8's impact point was chosen not by Ewen Whitaker but by high-level consultation.[25] The crater made by Ranger 7, the terrae, the crater Gassendi, and the Marius Hills were all suggested by Apollo managers or scientists. But Homer Newell acquiesced to George Mueller's insistence on a point on the mare in the near-equatorial zone considered accessible to Apollo. Harry Hess and Don Wise protested Ranger 8's "nonscientific" mission. Kuiper, however, accepted the decision because he was eager to look at a mare that was bluer than the red or "yellow" Mare Cognitum.

After a delay caused by the launches of other spacecraft, including the Mariner 3 and 4 missions to Mars in November 1964, the Ranger launches resumed on 17 February 1965. Three days later Ranger 8 cruised in a shallow trajectory over the highlands, taking ever-improving pictures until its crash in Mare Tranquillitatis less than 70 km from where Tranquillity Base would be established less than four and a half years later. To reach its target (24.8° E, 2.6° N), Ranger 8 slid "sideways" across many tens of degrees of longitude from the Ranger vertical-approach zone in the west—to such an extent that the last pictures did not nest and the very last pictures were smeared.[26] The best resolution was 1.5 m, as compared with the 0.6 m achieved by Ranger 7. This left the job of finding the impact point to computation and later scrutinizers of high-resolution Apollo 16 photographs.[27]

Lunar impact occurred at night by Pacific Coast time (1:57 A.M. PST; 0957 GMT), and I had the pleasure of watching for it with my beloved 36-inch telescope at Lick Observatory. Even reasonable people still thought that small impacts might throw up enough dust or create enough of a flash to be visible through a large telescope.[28] Here was a cheap way to learn something about the surficial material of the Moon. Attempts had been made to photograph the nearby Ranger 6 impact with a movie camera, but nothing was seen. Perhaps the greater acuity of a visual observer would succeed. I listened to a live radio broadcast from JPL to get the time of impact, and at just the right instant was watching just the right spot with just the right amount of averted vision to view it with the slightly off-center part of the retina that perceives detail better than the center. The atmosphere held steady at the right moment also. I saw nothing. Later I found out that other observers, including the experienced Alika Herring of LPL,[29] observing with the 84-inch reflector of Kitt Peak, did the same thing with the same negative results.

Scientists and engineers were looking for rocks on the surface, and more appeared in the Ranger 8 pictures than in Mare Cognitum. Rocks would sink out of sight in Gold's dust or thick lava froth, so their presence suggested a decent underfooting in Mare Tranquillitatis. Kuiper correctly interpreted the "hot spots" of Saari and Shorthill as exposures of bare rock and noted that more were here than in any other part of the Moon.[30]

Many secondary craters of Theophilus pepper the region of the Ranger 8 impact (a fact that would prove crucial in interpreting some exotic fragments later brought back to Earth from Tranquillity Base). Kuiper recognized some of these for what they are, though he ascribed others to collapse along lunar grid lineaments and then stated that their noncoincidence with rays confirmed his view that rayless craters like Theophilus were created by asteroidal, not cometary, impacts.

A bonus of Ranger 8's sideslip was better-than-telescopic views of the craters Sabine and Ritter. In the mid-1960s everything pointed to their origin as calderas. They are identical twins in morphology and size (29–30 km). They lack radial rim ejecta and secondary craters despite their apparent youth. They are positioned at the presumably active edge of the mare. They are even aligned along graben, the Hypatia rilles. Most significant, they lack the deep floors recognized since the days of Gilbert as diagnostic of impacts.

Which brings us briefly back to Jack Green. "Caldera Jack" was one of our science's most persistent gadflies in the 1960s. To him, rays are deposits of ashflow tuff, one of the many ideas he seems to have inherited from his hero, Spurr.[31] Anyone who attended Jack's lectures in the early 1960s was exposed repeatedly to his slide comparing the rayed lunar crater Kepler to an ashflow in Japan. In May 1964 he chaired a major conference in New York, presumably as a forum for his arguments.[32] Green had at least one soul mate in every scientifically active country. In Russia it was A. V. Khabakov and G. N. Katterfeld; in Germany, Kurd von Bülow; in Britain, Gilbert Fielder and G. J. H. McCall; in Italy, Pietro Leonardi; in Japan, S. Miyamoto. Some of these bedfellows formed a society called the International Association of Planetology, presided over by Green. Left in the dark, endogenic models of the Moon seem to grow like mushrooms. As an explanation for the great majority of craters, endogeny had been shown to be nonsense by the chain of arguments this book has been tracing.

Nevertheless, Jack will be pleased to learn that the "Green Fringe" had a great effect on the USGS lunar geology program in the mid-1960s. First, their steady pressure forced us to carefully weigh all alternatives during our geologic mapping and to conscientiously state volcanic interpretations along with our preferred impact interpretations.

Second, consider the training areas we took the astronauts to during the Ranger-era field trips. This second phase of the training was supposed to concentrate on field areas with lunar application. On two successive weeks in October 1964 two groups of geologists and astronauts visited the diverse volcanic terrain around Bend, Oregon, including the 40-by-64-km Newberry shield volcano, with its 8-km-long complex of nested calderas, extreme range of differentiated volcanic rock types, obsidian flows, ash flows, pumice cones, cinder cones, and tuff rings. Phase 2 unfolded much as had been planned in early 1964 except that the USGS participants had to fly from Menlo Park or Flagstaff instead of Houston. Although Al Chidester was officially in charge of astronaut training, Dale Jackson was still its guiding hand. Dale had rounded up from his long list of friends and colleagues a crackerjack assortment of expert geologists to lead or advise the field trips. The local expert for the Bend trip was volcanologist Aaron Waters of the University of California at Santa Barbara, with the assistance of Parke Snavely from Menlo Park. Unfortunately a planned third section of the trip was canceled because our list of students had been reduced by one. On 31 October 1964 the Grim Reaper of astronauts and cosmonauts had taken his first swipe and caught Ted Freeman and a flight of geese in the same airspace near Ellington Field.

Late in October and early in November, Roy Bailey and Bob Smith of the USGS led three groups of us through another classic caldera, the 25-by-30-km Valles, in the Jemez Mountains of New Mexico. A close look at Valles would give the astronauts a foretaste of any lunar caldera they might happen to visit. Even nonbelievers in lunar calderas could benefit from a trip to Valles. This was the epoch of widespread belief in *hybrids,* impact craters that became the sites of later volcanism, and the Valles possesses a great variety and abundance of superposed volcanic flows and landforms formed by magmas of changing composition.

It was fairly clear by 1964 that the Moon has plenty of basalt, so in January 1965 the astronauts and their teachers went to the "Big Island" of Hawaii under the guidance of another stellar crew that included current and future directors of the USGS Hawaii Volcano Observatory, Howard Powers, Don Peterson, and Jerry Eaton, and a future USGS director, Dallas Peck. Here, too, were calderas — the ones commonly favored as the closest terrestrial analogues to lunar craters.

Also here were many kinds of basaltic surfaces, from glassy smooth to chaotically rugged, which just might give the astronauts a foretaste of the lunar maria — though a better analogue proved to be the pleasant Hawaiian beaches.

In February 1965 both sides of the crater origin debate were covered by a trip to the Nevada Test Site, referred to in unguarded moments as "the Las Vegas trip." NTS contains not only doomsday craters and collapse depressions but also the complex, dissected, 12-by-20-km Timber Mountain caldera, which was being thoroughly mapped by a large USGS team including our trip leaders, Will Carr and Bob Christiansen. Timber Mountain, like many other western calderas, is also the source of those possible mare analogues, the ashflow tuffs. The impact side was covered in an extra trip on 22–23 April 1965, attended by some of the instructors and the "third" group of astronauts, in which Gene Shoemaker had to climb down the wall of Meteor Crater and point out the highlights for the umpteenth time in his life.

Almost all lunar craters the size of Newberry, Valles, and Timber Mountain are now known to have been created by impacts, but in the mid-1960s all bets had to be kept open in the interest of objectivity. I think we owe a debt to Jack Green for helping us keep our minds open. The impacters did not capture Sabine and Ritter from him for another five years.

Ranger 8 was probably the least exploited of the three missions, but some of its pictures provided tests of geologic mapping at new scales and for new purposes.[33] Dan Milton and I contributed "Geology from a Relatively Distant Ranger VIII Photograph"; that is, the smallest-scale map of the series. As I remember, our purpose was mostly to justify being paid — a common motivation for many scientific studies then and now. In rereading our report, however, I am pleased to find a preference for an impact origin of Sabine and Ritter and an early reference to Imbrium basin secondary craters, although we stated our then-current volcanic interpretations of terra plains and "domes." A large-scale map by Newell Trask explored how to map at the high resolutions of spacecraft images. The most novel new stroke was by Jack Schmitt. Drawing on his mission-planning work in Flagstaff, Jack used a high-resolution photo as the base not only for a geologic map but for a simulated manned mission. Traverses meander from the landing site of the LEM across features of geologic interest, just as they would on the maps packed in lunar modules a few years later.

## GASEOUS EMISSIONS (MARCH 1965)

As the maria at both the Ranger 7 and 8 sites appeared smooth enough for Apollo, the scientists succeeded in getting Ranger 9 sent to a "scientific" target with no immediate applicability to manned landings.[34] Jack McCauley was at the site-selection meeting and remembers that Kuiper so deeply resented the takeover of Ranger by Apollo that he threatened to resign if a scientific target was not selected. Apollo representatives agreed, though Surveyor representatives complained. Copernicus, Kepler, and Schröter's Valley were among the suggested scientific targets of no apparent use to early Apollos or Surveyors. Urey and Kuiper advocated the interior of the crater Alphonsus, a hotbed of special features, and Alphonsus won handily. Its floor contains irregular rilles and eight distinct dark-halo craters even today believed to be volcanic.

The main attraction was even more "special." Russian astronomer Nikolai Kozyrev, who had been in Stalin's gulag from 1937 to 1948,[35] had stirred up the scientific community and the aware public by announcing that on the night of 3 November 1958 he had obtained a spectrogram indicating the luminescence of molecular carbon gas ($C_2$) escaping from the volcanic central peak of Alphonsus.[36] Kozyrev was looking for something odd; he cited observations by Dinsmore Alter of apparent mists around the peak as the stimulus for his own concentration on Alphonsus. Urey, Baldwin,[37] and Öpik entertained his observations temporarily, though Öpik did not believe the spectrum indicated gas. "Transient phenomena" stimulated intense interest during the early 1960s. Amateur astronomer networks with names like Moonwatch and Astronet were willing and able to keep the Moon under constant surveillance. It was agreed that Ranger 9 would look for anything peculiar on the Alphonsus peak and would examine the dark-halo craters by plunging to a compromise intermediate point.

On 18 March 1965 Alexei Leonov became the first human to walk in space, and the first manned Gemini, Gemini 3, was scheduled to take Gus Grissom and John Young aloft a few days later. However, NASA Associate Administrator Seamans postponed the Gemini launch by a day so that the last Ranger could get off the ground.[38] Ranger 9 blasted off at 2237 GMT on 21 March, coasted to the Moon while Grissom and Young were orbiting the Earth, and brought the trials of Project Ranger to an end at 1408 GMT (06:08 PST) on 24 March 1965 as it crashed at 12.9° S, 2.4° W, only 5 km from the preselected point. A terminal maneuver was performed this time, and the last P frame showed features only a foot across, the highest resolution yet obtained. Ranger 9's approach to the Moon was shown as it occurred (in "real time") on commercial television. For the first time, TV audiences saw the words "Live from the Moon" on their screens. Jack McCauley was visiting Menlo Park, and those of us who did not own television sets went to his motel room to see the spectacular event. Carl Sagan has said that this is when imaging grew in stature in the minds of space scientists.[39] No cameras had been included on the Mariner 2 Venus mission in

1962 because images were thought to be good only for razzle-dazzle and public relations. But images show everything in the optical spectrum, including things that no one is wise enough to anticipate.

The press pumped Kuiper and Shoemaker for answers about the surface material (it looked alright for landings) and Kozyrev's gaseous emissions (no clue to their source). The reporters were also told that the walls of Alphonsus and the central peak turned out to be very smooth at high resolutions. Kuiper's explanation and his later scientific reports further revealed the geologic naïveté of this great astronomer. The peak was "white" because it was covered by a volcanic "sublimate"; there are no visible vents because the last eruptions closed them.

Although Rangers 8 and 9 took many more pictures than Ranger 7, most of them are redundant distant views. Also, interest was waning and time was flying. Therefore only selected pictures were published.[40] Ewen Whitaker went into action once again and supervised the reproductions. The experimenters summoned the energy for only one more report, combining the results from Rangers 8 and 9.[41] They showed distinct signs of Ranger burnout and relied more than ever on their previous results and on the work of their colleagues. Kuiper's concept of the surface material was evolving toward ever thinner fragmental material and wandering ever further from reality as he concluded that the frothy surface of the lava was eroded by impacts and "sputtering" but overlain by only about a centimeter of dust. Urey added little to his earlier ideas, which he restated by pointing out how they "bear on the problem of interpreting the photographs of the lunar surface," which he grudgingly admitted were a "good beginning for the investigation of a subject." He held on to one of his favorite ideas, that some of the sharper hills on the walls and elsewhere consist partly of iron-nickel meteoritic material — a bizarre notion important in Urey's thinking.[42] Whitaker tells us that by this time, after 10 years of feuding, Urey and Kuiper were capable of carrying on amiable conversations although they still disagreed about whether the Moon had ever melted.[43]

Kuiper had been dabbling in geology in the form of some lava flows in New Mexico. These confirmed and hardened his Ranger 7 conclusions. Craters are always less numerous on lunar slopes than on level terrain because slumping thick fragmental material fills and degrades craters. However, Kuiper compared lava-flow textures with a distinctive "tree-bark" textural pattern, seen first by Ranger and subsequently by all high-resolution photographs of lunar slopes, as confirmation that only a thin surficial fragmental deposit covers the lunar lavas. He cited collapse like that over near-surface lava chambers in New Mexico as the reason why the floor of Alphonsus has so many more craters than the walls; to him, the extra ones on the floor could not be impact craters because the wall craters "cannot" have been destroyed by slumping on the "gentle" (5°–20°) slopes. He even averred that collapse depressions are a hundred times more numerous than impact craters in the diameter range 30–1,000 m at all three Ranger sites. The craters collapsed while the maria were still in the plastic state. All those collapse depressions meant that the astronauts might be in danger. Impact was overrated as a lunar process!

Now to one of my biggest *bêtes noires,* lineaments. Strom plotted crater chains, elongate craters, shallow linear depressions, and ridges seen on the Ranger 7 pictures on rose diagrams, called them lineaments, and concluded that they have the same trends as the telescopic lineaments he had previously plotted.[44] Strom and Kuiper, like many others, believed that the telescopic "lunar grid" was created by a general north-south compression. This meant that lineaments are bedrock features, and since they are visible at the Ranger 7 scale, the surficial material must be thin or cohesive and strong. Shoemaker disagreed, saying there is nothing on the Ranger photos that resembles a lineament except lighting effects and secondary-crater chains and their ejecta, which have formed everywhere on the Moon since the beginning of time. Strom later found the same trends at the Ranger 8 and 9 sites. My annoyance about lineaments or lineations is not directed at Strom or Kuiper but at the overvaluation of quantitative analysis in subjects not amenable to it. Mike Carr fell into the same trap in the Ranger 9 report.[45]

Another special-feature interpretation in the LPL Ranger 8 and 9 report looks much better in retrospect. After the Ranger 7 mission, Kuiper and Strom were flying over Hawaii looking for something else (secondary craters created by volcanic bombs that had been noticed by a forester) when they noticed the many narrow channels and partly collapsed tubes that snake through the basaltic Hawaiian lavas.[46] These mark continued flow, at or below the surface, of the parts of each lava flow that remain fluid the longest. Kuiper and Strom became the first, I believe, to advocate a similar basalt-flow origin of the lunar sinuous rilles instead of by flow of water or hot ash. So Kuiper's and LPL's preoccupation with lava flows paid off.

Finally, the Ranger 8 and 9 report advanced the very geologic subject of ages. Newell Trask applied his considerable geological and mathematical skills to determining the relative ages of the units at all three Ranger sites and thereby began his definitive analysis of the steady state and mare ages that would bloom in the Lunar Orbiter and Apollo eras.[47]

The legacy of Ranger 9 is, as usual, only partly what the experimenters thought it would be. Alphonsus fascinated them because of all its special features. Its central peak was thought to be volcanic, but that idea began to be weakened by the Ranger 9 pictures. Kozyrev's gas lingered a little longer but finally dissipated. The dark craters on the floor were thought to be volcanic, and remain so today in the minds of most investigators. The floor was, and still seems, different from the maria. The Alphonsus walls were thought to contain old highland rocks, and still are. This list would be trotted out many times in subsequent years as the targets for Lunar Orbiter photography and the sites for Apollo landings were chosen.

## RESOLUTION VERSUS COVERAGE

The three Rangers had bridged the gap between the telescopic and spaceflight eras of exploration, both in the size of features that could be seen and in the historical sense. They fulfilled their main task by showing that slopes are typically gentle and surfaces are smooth and firm enough at all three sites for successful landings. In fact, all three areas look much alike at high resolutions. Few blocks or lumps were detected. Crater rays, mare surfaces, and at least one crater floor were no longer total mysteries. The foundation for dating surfaces on the basis of small craters had been reinforced. Methods of geologic mapping at large scales had been developed. More philosophically, we can say that the Rangers provided a new perspective on the old problem of crater origin and marked, I think, a decisive shift by fence-straddlers over to the impact side.[48]

The in-fall trajectories that harvested these successes also kept Ranger from achieving more. They achieved high resolutions, but for areas that became smaller and smaller as crash time approached. The limited coverage forced investigators to call on telescopic and Earth-analogue data in interpreting the Ranger pictures. Kuiper based more of his conclusions on telescopic photographs and Whitaker's false-color images than on Ranger. Shoemaker already knew plenty about secondary craters and the steady state from telescopic studies and theory. The approximately 200 Moon researchers who met at the Goddard Space Flight Center in April 1965,[49] ostensibly to evaluate Ranger, devoted at least as much attention to theory, Earth-based photography and remote-sensing, and laboratory and field impact experiments[50] as they did to the recently acquired Ranger photos.

One might unkindly say that the experimenters held to their preexisting prejudices, sensible or bizarre, little influenced by the new data. In Gold's admirable phrase, the pictures were a mirror that reflected their previous views (and he should know). But the nature of lunar science requires that low-resolution and high-resolution data and terrestrial studies be used in concert. As Kuiper, justifiably proud of his atlases, put it, "The Ranger results further stimulated an intensive re-examination of the Earth-based photographs, which, in turn, has decisively assisted in the evaluation of the Ranger data." And "since high-resolution photography will, for some time to come, necessarily be limited to selected regions of the lunar surface, Earth-based photography pushed to its highest attainable resolution has become a prime requisite." (Here he was alluding to the first large telescope ever dedicated to lunar and planetary work, then being built by his LPL with NASA funds.)[51]

Although all planets must be studied by an interplay of broad-scale and fine-scale data, the Moon's meters-thick surficial debris layer lessens the value of the highest resolutions. Pictures and maps at regional scales show the basic bedrock units. Close-up pictures and large-scale maps show the debris layer and features that contribute to its formation. If the debris layer had been as thin as Kuiper increasingly believed, then Ranger would have been as sensational as he hoped and claimed. As it turned out, Ranger successes and failures contributed the valuable lesson that the type of geologic unit one can study is related to the scale of the data.

ACIC sprang into action and published six airbrush maps at as many scales before the Ranger 7 report was published. Ultimately they prepared 17 airbrush *Ranger lunar charts* (RLCs) of the three sites at a variety of scales from 1:1,000,000 to 1:1,000.[52] The USGS sprang forward into action too, but then fell back; its Ranger geologic maps were not published until 1969 and the irrelevantly late date of 1971.[53] The main reason for the lack of hurry was a lack of interest. One of the Ranger 7 maps is listed as authored only by the U.S. Geological Survey because so many people had to be coerced into making it that the approved number of authors (four) was exceeded. The other was prepared by Spence Titley, who was well aware that he got the formerly glamorous job of making a Ranger map only because it was no longer glamorous. Newell Trask summarized the Ranger results in a 1972 USGS professional paper reluctantly because he felt that the scientific results of Ranger were trivial and passé. This paper, which I encouraged Newell to write for the record, includes a final illustration of what was wrong with Ranger: the construction of even the simple high-resolution maps required assistance from the later Lunar Orbiter coverage.

Nor was topographic mapping well served by Ranger. Although Ranger photos revealed much smaller objects than the telescope can, they could not reveal smaller elevation differences because they were not taken at exceptionally low illumination angles and because photogrammetry could not compensate for this.[54] Furthermore, values of bearing strength needed for Apollo could only be inferred from a photograph. In fact, the very fine surface roughness detail that was of most interest was scarcely glimpsed. Whereas Ranger showed few blocks, later Lunar Orbiter photos of other areas revealed them in carload lots. You simply needed to see more of the Moon — much, much more — than three or three dozen Rangers could show.

So I think that the cancellation of the subsequent Rangers was proper. The gamma-ray instrument would have suffered from the same limitation of areal coverage. Data from the radar instrument would have been quickly superseded by Surveyor. In retrospect, the seismometers might have contributed the most to our present knowledge of the Moon, if enough of them had survived to create a seismic network. But from the viewpoint of cost-effectiveness (a term being popularized at the time by Secretary of Defense Robert McNamara's Whiz Kids), Ranger had to go. The program cost $267 million in 1965 dollars – quite a slug of money. Better missions were already in the pipeline.