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Looking southwest toward Copernicus crater from Apollo 17. http://science.ksc.nasa.gov/mirrors/images/html/as17.htm

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IT WAS CALLED THEN LUNIK

By Francis Graham

"They were the first that ever burst into that silent sea"
--Samuel Taylor Coleridge

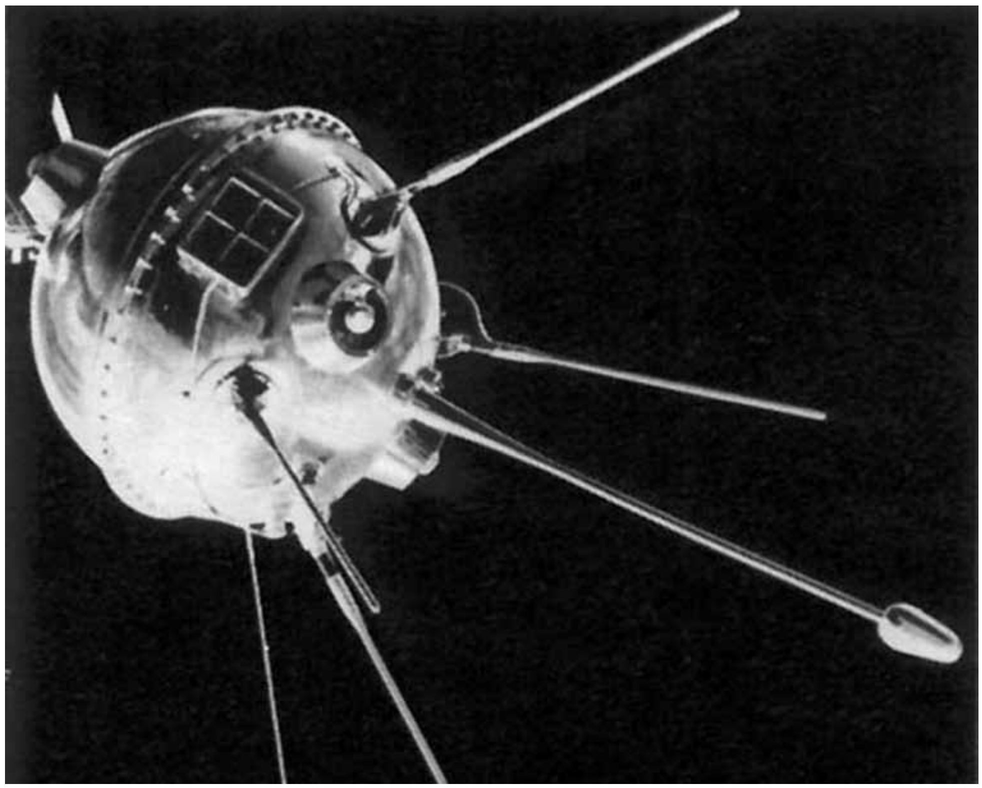
The year 2009 marks the 50th anniversary of perhaps the geometrically most important step of humanity: escape from the Earth by the Soviet probe Luna 1 on January 2, 1959. Why geometrically? Because up until that point, all manmade objects either fell back on Earth or went around it. Luna 1 was the first object to escape from the Earth forever, at escape velocity, so that it never returned, an artificial planetoid around the Sun. Further, it was the first probe to go to the region of the moon, although it did not actually impact the lunar surface.

Launch of Luna 1. From Robert Christy's website http://images.google.com/imgres?imgurl=http://www.zarya.info/Diaries/Luna/Luna1launch.jpg&imgrefurl=http://www.zarya.info/Diaries/Luna/Luna1.php&usg=__MevUcPClSj3sscRgxd7IdjgCc1c=&h=378&w=300&sz=51&hl=en&start=1&tbnid=oez1FmhCJy8alM:&tbnh=122&tbnw=97&prev=/images%3Fq%3Dsite:www.zarya.info%2Bluna%2B1%26gbv%3D2%26ndsp%3D20%26hl%3Den%26safe%3Doff

Luna 1, when launched, was simply called The Cosmic Rocket, and also promoted as Mechta ("Dream"). It was dubbed Lunik in the American press. It clearly was to impact the moon and had the hammer-and-sickle aegis of the CCCP aboard it, but it did not impact the moon due to a guidance error in the final stage on the R-7 Vostok-type booster rocket (Siddiqi, 2003). But its trajectory as an artificial planetoid around the Sun was assured, with a perihelion of 1.464 x 10^6 km and an aphelion of 1.972 x 10^6 km and an inclination of 1° and a period of 450 days (Petrovich, 1969). This means that it returns to close with the position of the Earth on January 1 about each 14 years, its next being about 2015.

The Luna-1 contained six scientific instruments in its 361.5 kilogram sphere. It included a cosmic ray counter that used the Plexiglas/Cherenkov system (built and installed by Lidiya Kurnasova) which confirmed the size and extend of the Van Allen Radiation Belts discovered earlier by Explorer III (Van Allen, 1961). It had a flux gate magnetometer (designed by S. Dolginov) which discovered, for the first time, that the moon had no magnetic field like the Earth (which would have been detected as Luna 1 flew by the moon at 5000 km had the moon had one. It had a bank of 4 ion traps which measured ions that were slow-moving. It had a dual plate micrometeorite detector using the piezoelectric principle (built and installed by Tatiana Nazarova) that confirmed, in interplanetary space, there was no significant danger of micrometeorite impacts that would preclude manned spacecraft passage. It contained a sodium-iodine scintillation counter for cosmic rays. It contained, finally, 2 interior Geiger counters, built and installed by Sergey Vernov. All these were wired to three transmitters that transmitted at 19.993 Mhz, 39.986 Mhz and 183.6 Mhz, providing plenty of redundancy.

In addition, the Block II booster unit, which trailed behind the actual Luna 1 sphere, contained instruments as well. It had a cesium-iodide scintillation counter and had 19.995 MHz and 19.997 Mhz transmitters. It also released a 4 kg mass of sodium, which was vaporized by thermite and glowed in the sunlight to emit sodium vapor light at 5889 Angstroms and mark its presence; this was released en route to the moon 112,654 km from Earth. The study of the nature of this sodium release could be used to assist in the determination of fields and particles in cis-lunar space. This study was done by Vladimir Kurt and Josef Shkovsky (who would later co-author "Intelligent Life in the Universe" with Carl Sagan). Luna 1 then passed the moon at a distance of about 5000 kilometers (Riabchikov, 1971) . The sphere plus the final stage (called the Block II) which also went into heliocentric orbit were designated 1959m1 and 1959m2 in the satellite designation system used at that time and had a mass of 1472 kg empty (Gatland, 1972). Luna 1 was therefore a class act for the technology available at the time.



Luna 1. http://images.google.com/imgres?imgurl=http://solarsystem.nasa.gov/multimedia/gallery/luna-1-browse.jpg&imgrefurl=http://solarsystem.nasa.gov/multimedia/display.cfm%3FIM_ID%3D6486&usg=__4nDNekdR_Ao_zS3ofAIHd5jd6xI=&h=400&w=500&sz=45&hl=en&start=4&tbnid=FYq0_ELkrS1PvM:&tbnh=104&tbnw=130&prev=/images%3Fq%3Dluna%2B1%26gbv%3D2%26ndsp%3D20%26hl%3Den%26safe%3Doff%26sa%3DN

The failure of Luna 1 to actually impact the moon was due to a human error in pre-setting the R-7 booster's radio guidance system by 2 degrees of arc, or, the width of a Pizza slice after it had been divided into 180 even portions. This underscored the accuracy required to hit the moon with anything.

As it penetrated interplanetary space, Luna 1 continued to function as an artificial planetoid, so the failure to hit the moon was in some way assuaged by the additional data returned about the interplanetary environment. But, designed to hit the moon, Luna 1 ran on batteries, not solar cells, and the batteries failed 62 hours after launch. Luna 1 was then at a distance of 597,000 kilometers from the Earth, almost twice the lunar distance.

Note, also, that in 1959 the design of Luna 1 involved many female as well as male scientists and engineers!

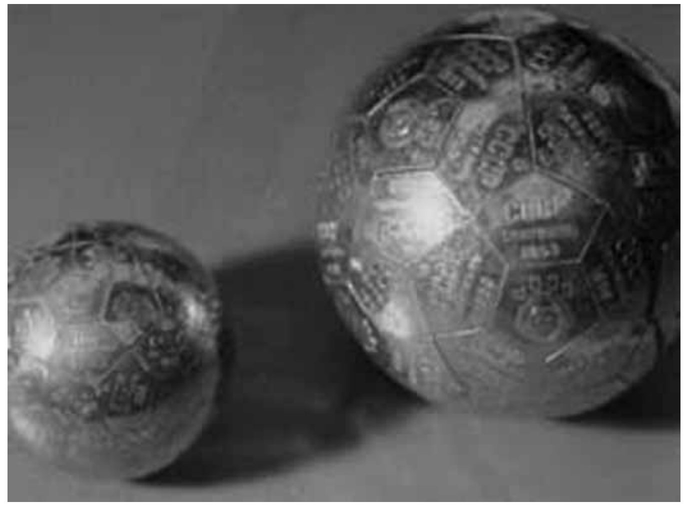
Luna 1 was followed on September 12 (later that miraculous year of 1959) by Luna 2 which became the first human-made artifact to reach another celestial object. Almost identical to Luna 1, there were some differences. Luna 2 used 3 interior

Geiger counters and 3 exterior ones. To the Block II, it added a Cherenkov-Plexiglas detector and a sodium-iodide scintillation counter. Its Block II transmitted at 19.997 and 20.003 MHz and 183.8 MHz to avoid confusion of the Block II with the impact sphere.

Like Luna 1, Luna 2 released a sodium vapor cloud en route to the moon, but at 152,000 kilometers from Earth. The discharge was observed at Almaa-Ata Observatory and from three Tupelov-4 bombers with telescopes installed, observing from an altitude of 10 km.

Luna 2 impacted the moon at 3.3 kilometers per second velocity, and carried two metal commemorative spheres made up of pentagonal surface pieces with Hammer and Sickle pendants of the Soviet Union and Communist Party. There spheres, 7.5 cm and 12 cm in diameter, were filled with a shock explosive in a liquid so that they would explode on impact and send the pentagonal pendants around the impact site. Luna 2 impacted the moon at 21:02:24 UT September 13, 1959 near the lunar crater trio Aristillus, Archimedes and Autolycus, near Palus Putredinus, at about 30 degrees north latitude, Luna 2 was also observed striking the moon by astronomers at the Konkoly Observatory in Hungary. The large dust cloud raised by the impact was noted at 25.7° N 4.97° E, consistent with the tracking data. Interferometric radio observations of the 183.6 telemetry transmitter signal were conducted by Boguslavsky on Mt. Kosha and the Lebedev Institute which also determined the impact point in terms of a diagonal swath across the moon. A flash noted by British astronomer Sir Patrick Moore using a 12-inch reflector, and H. Percy Wilkins using a 15-inch one, near the Schneckenberg Mountains of the moon, was likely an unrelated meteor. This is likely because the Konkoly observation, the ballistic tracking data, the interferometric radio data, and the Jodrell Bank observations all coincide, but the Moore and Wilkins observation are out of the region common to all the other methods.

Because the impact would generate an energy of 1.2 megajoules, and a temperature as high (but briefly) as 4200 Celsius, it is unknown what con-



On impact, Luna 2 scattered Soviet emblems and ribbons across the lunar surface. They were assembled into spheres which broke up upon impact. http://images.google.com/imgres?imgurl=http://www.zarya.info/Diaries/Luna/Luna1launch.jpg&imgrefurl=http://www.zarya.info/Diaries/Luna/Luna1.php&usg=__MevUcPClSj3sscRgxd7IdjgCc1c=&h=378&w=300&sz=51&hl=en&start=1&tbnid=oez1FmhCJy8alM:&tbnh=122&tbnw=97&prev=/images%3Fq%3Dsite:www.zarya.info%2Bluna%2B1%26gbv%3D2%26ndsp%3D20%26hl%3Den%26safe%3Doff

dition the pentagonal pennants would be in when they were scattered about on the moon. They could have been vaporized or severely deformed so that the symbols would be illegible.

The impact of Luna 2 on the moon was followed by the Block II upper stage about 30 minutes later, in roughly the same area.

This stunning success was followed a month later on October 4 by Luna 3. Differently configured than Lunas 1 and 2, this probe went to view the far side of the moon to photograph it for the first time from an altitude above the moon of 66,200 km on October 7. Luna 3 used solar cells, which made possible long term monitoring. Its imaging procedure was crude by today's standards; it used actual chemical film to take 10 shots of the lunar farside which were then processed as black-and-white film automatically aboard Luna 3 in a system designed by Petr Bratslavets. Then, the film negatives were scanned by a photomultiplier which rendered a transmitted signal to Earth. In spite of the lack of technical sophistication, the greatest lunar mystery since the moon was first telescopically observed was suddenly solved: we knew what the farside of the moon looked like! This was rendered into a beautiful Atlas by the USSR Academy of Sciences (Barabashov, et al, editors, 1961).

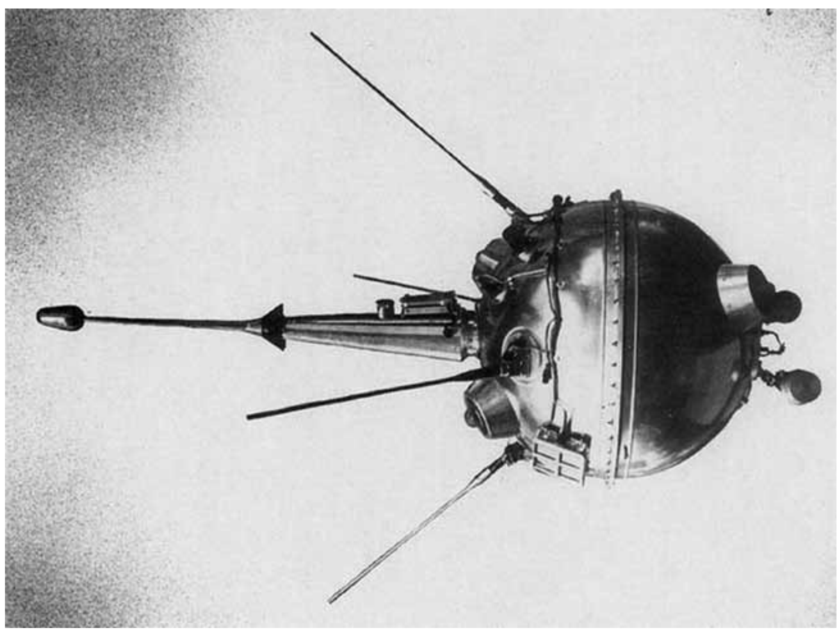
The United States, which would eventually send a fabulous series of manned missions to the moon, was very far behind the game in 1959. Its primary lunar probe program used the Thor-Able booster, which, later, would develop into the highly reliable Delta booster. The early attempts to access the moon were failures, but, as some went into suborbital flight deep into cislunar space, they did return some data on the Van Allen belts. Pioneer 4 did repeat the lunar flyby of Luna 1 on March 3, 1959, but it was several years before the USA managed to reach the moon with an unmanned probe (Gordon and Scheer, 1959).

The stunning success of space technology in 1959 by the Russians completely transformed the geopolitical scene. Certainly, no one was telling ethnic jokes anymore which regarded the Russians as somehow a stupid people. The United States was at the height of its industrial power and would very soon catch up, but space technology engineers and space scientists in the USSR walked in 1959 with pride. In a mere 14 years since their country was utterly devastated by Nazi Germany, a war in which they suffered the most casualties, Russia had picked up itself from the ashes and went to the moon.

At the time, the USA and USSR were locked in a global influence competition unprecedented in history (except for the cases of all-out war). The United States' press largely touted its own very limited success in this period and as much as possible downplayed the Soviets' stunning achievements for science in that time. The Soviet probes were called with derision, "Lunik", a play on the proper Russian word "Sputnik".

This style of public relations writing, which fails to mention the importance of preliminary work of others, still exists in NASA press releases and has infuriated others (Klerkx, 2004). This downplay even of Luna 2 continues to this very day. Claims were made of the observation of Smart 1's impact as the first observation of the impact of an artificial object on the moon. This ignored seven observations of Luna 2's impact in 1959 (Mitchell, 2008).

In a recent book, Friedman (2009) examines possible scenarios for the rest of the 21st century. In one scenario he favors, Russia, after a short period of political success, declines into an economic recession similar to that in 1992-97, and this, about 2020, because it cannot outpace the United States in international trade. But in the same book Freidman writes of a master stroke that could alter the probable course of history. A master stroke



Luna 2. http://images.google.com/imgres?imgurl=http://solarsystem.nasa.gov/multimedia/gallery/luna_2.jpg&imgrefurl=http://solarsystem.nasa.gov/multimedia/display.cfm%3FIM_ID%3D1891&usg=__s6k90ur971soTXU-j1fS_cbJWlQQ=&h=576&w=429&sz=40&hl=en&start=2&tbnid=g3xB_xtr6P0wFM:&tbnh=134&tbnw=100&prev=/images%3Fq%3Dsite:solarsystem.nasa.gov%2Bluna%2B2%26gbv%3D2%26ndsp%3D20%26hl%3Den%26safe%3Doff

is possible. In the 15th century, Spain and Portugal could not cheaply trade with China because access to the Silk Road was blocked by the superior military forces of the Ottoman Empire. In a master stroke, they decided to try to reach China by sailing west, and, in the process, they “discovered” the American continents, which had enormous ramifications for Spain and Portugal.

The United States will retire its Space Shuttle Fleet in 2010 and will not have another possible manned space access until 2017 or 2018. This is a wide field of opportunity for Russia to reclaim the space frontier. It already has boosters that could reliably send a Soyuz on a circumlunar mission, such as a Soyuz spacecraft refitted in Zond fashion, and boosted by a Proton , and Russia should do so. And, in addition, although it would require many resources, it could develop lunar landing capability. This may lead to unforseen positive consequences in the establishment of a space-based economy, for Russia, for the USA, and for other nations of Earth.

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A History Of Lunar Exploration

By Steve Boint

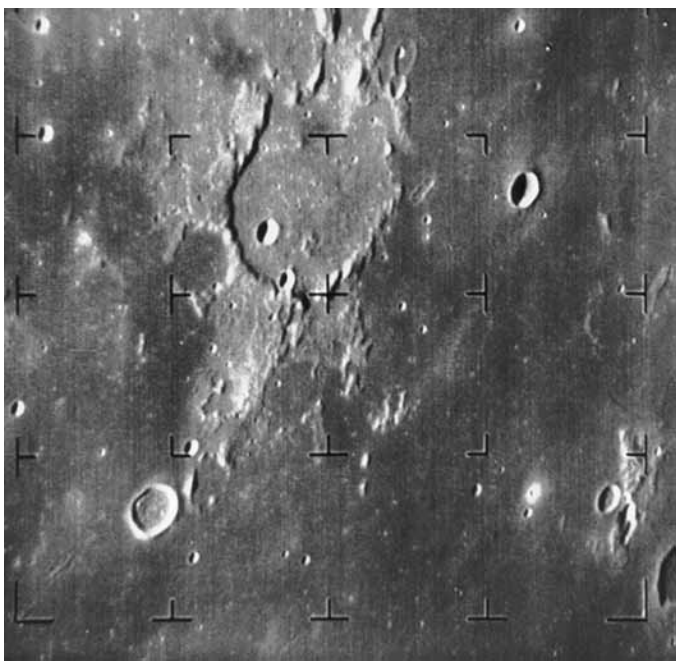
There is a renaissance of interest in scientifically exploring the moon through remote probes and possibly, in the future, through human presence. Google’s challenge to place a camera on the lunar surface may even produce a non-governmental lunar presence. While early efforts were concentrated among the super-powers of the Cold-War era, current investigations are multinational. The history of robotic and manned lunar exploration is fascinating. However, many probes produced so much scientific data that it is impossible to recount their scientific contributions in detail without producing a book. This is especially true of the Apollo program. Emphasis will be placed here on the accomplishments most accessible to lay people and most interesting to the author. Selenology would welcome articles exploring the scientific legacy of any single mission or program in detail.

With the Soviet launch of Luna 1 in 1959, exploration of the moon entered a new era. No longer would lunar exploration be bound by the limits of Earth-based observation. Luna 1 sailed past the moon detecting no lunar magnetic field[1]. Later that same year, three other probes surveiled the moon: Pioneer 4, launched by the U.S.A., which detected no radiation emanating from the moon[2]; Luna 2 which impacted in Palus Putredinus substantiated the lack of lunar magnetism and radiation[3]; and Luna 3 which photographed the lunar farside although only a few of the images were transmitted intact to Earth[4].

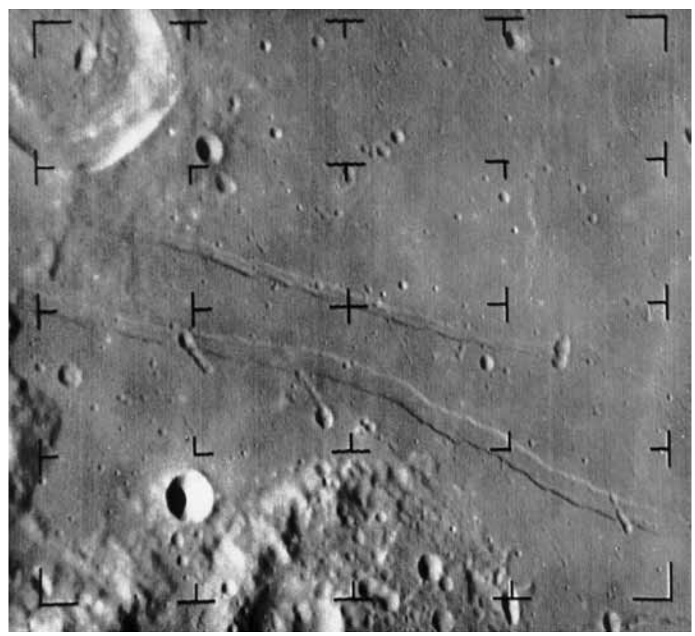
Comparatively high resolution images of the moon became more plentiful when, in 1964, Ranger 7 impacted the moon and succeeded in transmitting 4308 photographs in its last 17 minutes[5]. The U.S. Ranger probes provided a dramatic increase in high-quality lunar photographs in 1965 when Ranger 8 sent back 7137 images in its last 23 minutes (the final one only 1.5 m above the surface)[6] and Ranger 9 produced 5814 photographs before crashing near Alphonsus crater[7].

1965 was not as successful a year for Soviet lunar science. Luna 5 suffered gyroscope difficulties and crashed into the moon near 31˚S 8˚W[8]. Luna 6 passed by the moon after receiving an incorrect command from mission control, a command which caused it to fire its thrusters until running out of fuel. It did, however, succeed in rehearsing a number of maneuvers necessary for a soft landing[9]. Poor positioning of an optical sensor led to Luna 7's crash into Oceanus Procellarum. And, after a damaged airbag caused it to spin out of control, Luna 8 crashed west of Kepler crater[10]. However, 25 good photographs of the lunar farside were transmitted by Zond 3 as it passed within 9100 km of the moon[11].

February 3 of 1966 saw Luna 9 become the first probe to achieve a soft lunar landing. Resting at 7.13°N 64.37°W, it sent back three television transmissions and proved the lunar surface could support substantial weight[12]. Two months later, Luna 10 became the first artificial satellite to orbit an astronomical body other than Earth. It studied infrared and other radiation from the moon as well as gravity, determining most lunar rocks were basalt and discovering lunar mass concentrations[13]. Luna 11 studied the mascons in more detail[14] and Luna 12 sent back many lunar images (of which only a fraction were published) from its orbit around the moon[15]. At the end of the year, Luna 13 landed in Oceanus Procellarum at 18°52' N, 62°3' W. It studied the structural strength of the lunar surface, density of the regolith, infrared radiation, and other radiation levels. It found the average noon tempera-



"Ranger 7 B-camera image of Guericke crater (11.5 S, 14.1 W) taken from a distance of 1335 km. The dark flat floor of Mare Nubium dominates most of the image, which was taken 8.5 minutes before Ranger 7 impacted the Moon [in]1964. The frame is about 230 km across and north is at 12:30. The impact site is off the frame to the left. (Ranger 7, B100) http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/ra7_b100.html"



"Ranger 8 image of the Mare Tranquillitatis area taken from 511 km about 4 minutes before surface impact. The 30 km diameter Sabine crater is at upper left. Note the two linear features at the center of the frame and rugged region at the bottom. The frame is about 95 km across and north is up. The Apollo 11 landing site is about 30 km to the right of this area. (Ranger 8, B045) http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/ra8_b045.html"

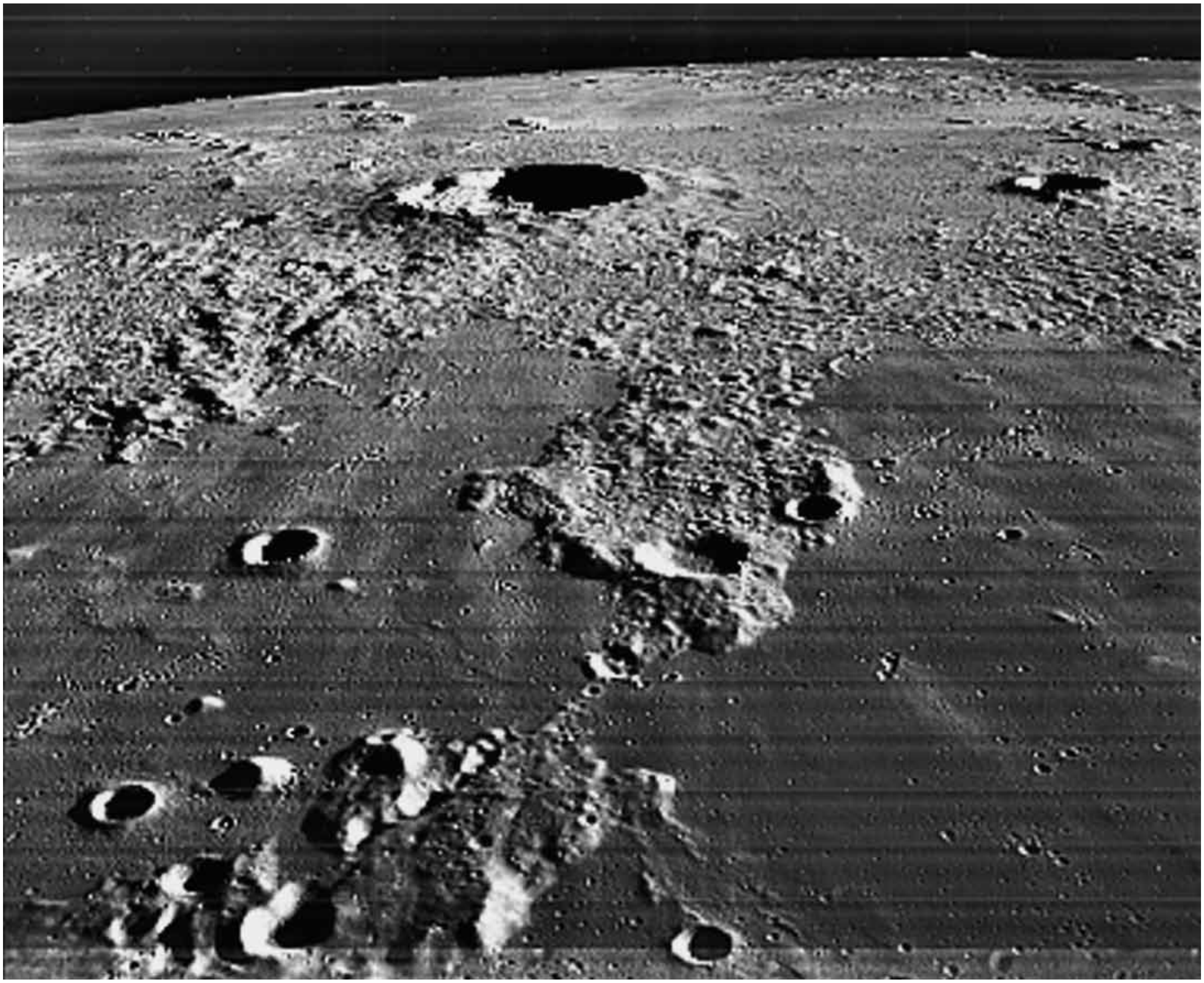


Image of Kepler crater from Lunar Orbiter 3. http://astrogeology.usgs.gov/lo-cgi-bin//vhFrameListPage.pl?mission=3&frame=162&site=S-26&siteName=Kepler%20Oblique

ture at the lunar surface to be 117˚C. Luna 13 transmitted 5 panoramas of the mare surface[16].

1966 also saw American probes investigating the moon. Surveyor 1 landed at 2.45°S, 43.22°W and transmitted 11237 images of the lunar surface[17]. Surveyor 2 crashed near Copernicus after failure of one engine[18]. Lunar Orbiter 1 produced 413 images of the lunar nearside's central quarter (within 5 degrees of the equator)[19]. Lunar Orbiter 2 was largely a duplicate of 1 (both were prep for Apollo). It produced roughly 200 images[20].

And 1967 belonged solely to the U.S. Surveyor 3 sent back 6315 images of Mare Cognitum. Using a scoop attached to an arm, after landing it dug 4 trenches and held the regolith in front of the camera for detailed inspection. To conserve battery power it was shut down during the 14 days of lunar nightfall but could not be restarted afterward[21]. Surveyor 4 ceased transmitting shortly before landing on the surface[22]. After landing in Mare Tranquilitatis (1.41° N, 23.18° E), Surveyor 5 returned 19049 images. It used an alpha particle backscatter spectrometer to determine that the regolith was basalt[23]. Surveyor 6 sent back 30,027 images from Sinus Medii (0.49°N, 1.40°W). It performed soil analysis and a lunar liftoff (for proof of concept)[24].

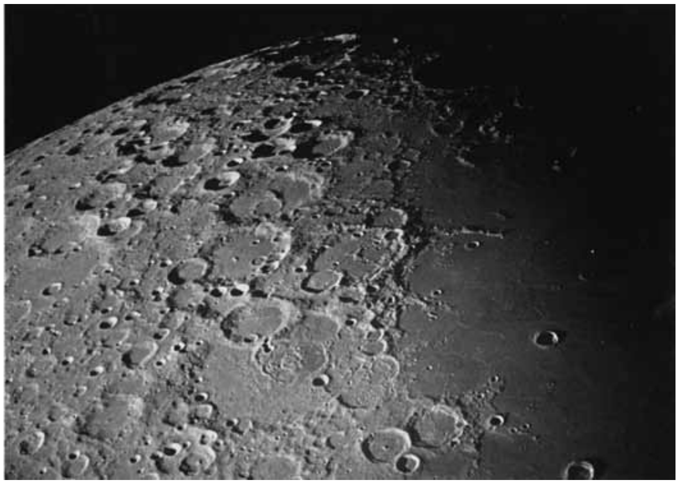


Image from Zond 7. http://www.mentallandscape.com/C_Zond07_B.jpg

Detail from an image by Zond 8. http://www.mentallandscape.com/C_Zond08_59detail.jpg

Lunar Orbiters 3 – 5 continued photographing the moon with Lunar Orbiter 4 thorougly imaging the nearside.

Surveyor 7 landed on the rim of Tycho crater in1968, operating for 16 days and returning 21091 photographs before succumbing to the bitterly cold lunar night. It detected a faint glow on the moon's horizon which is currently believed to be from electrostatically levitated dust flowing across the terminator[25]. The Soviet space program surged forward as Luna 14 orbited the moon, tested communications abilitites in prep for a manned landing, and charted gravity anomalies[26]. Later, Zond 5 circled the moon, photographed it, and carried the first biological payload around the moon and back. At splashdown, the turtles, mealworms, plants and bacteria were found to have survived well[27]. Zond 6 which also circled the moon, again obtaining photographs and carrying living beings, crashed upon landing with only one photograph surviving[28]. But humanity's attention was captured by Apollo 8 which orbited the moon ten times while carrying a crew of 3. Photographs were taken and communications and equipment checked out. Live TV images were transmitted back to Earth[29].

1969 started with Apollo 10 practicing maneuvers in orbit around the moon and taking still as well as motion pictures[30]. At the same time, Luna 15 robotically orbited the moon (its flight path was sent to NASA since Apollo 11 was also orbiting the moon). Eventually Luna 15 crashed into the lunar surface near Mare Crisium[31]. Then lunar explora-

Detail of an Apollo 14 panorama. File: ap14_H The panorama was collected by Edgar Dean at station H. Alan Shepard is to the left of the lander aiming the TV camera at the MESA. The panorama is made from the frame set AS14-68-9477 to 9491 http://astrogeology.usgs.gov/Projects/LunarAtlas/panoramas/

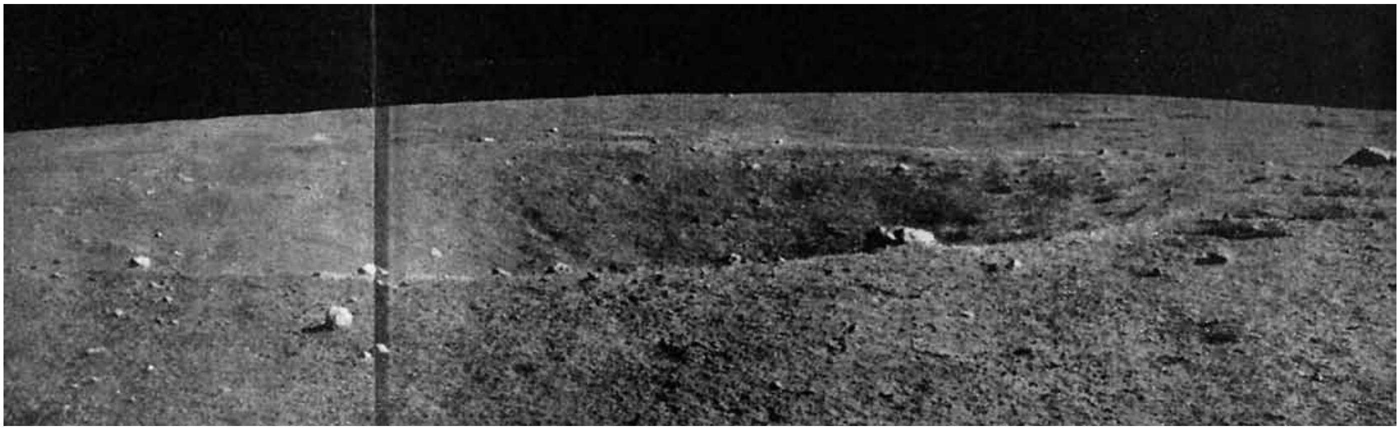
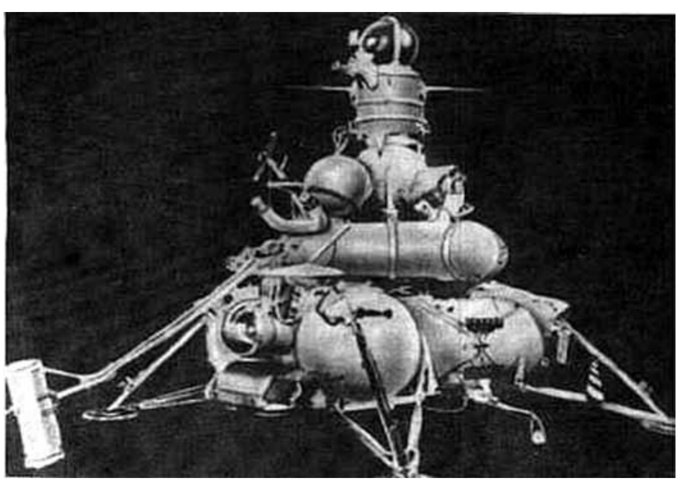


Image from Luna 17. http://www.mentallandscape.com/C_Luna17_Horz13.jpg

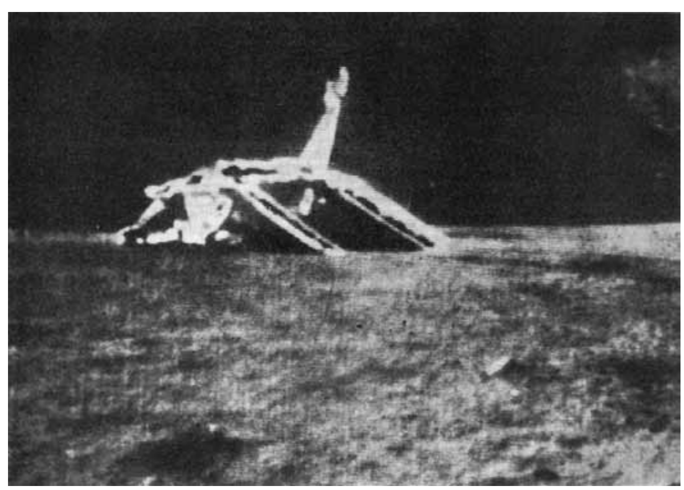
tion changed when Apollo 11 placed 2 people on the edge of Mare Tranquilitatis for 21 hours and 36 minutes and returned them, photos, and 21.55 kg of rock and soil samples to Earth. It also left a number of experiments on the surface of the moon. The command module with one astronaut on board circled the moon during this time, carrying out even more experiments and recording many more images[32]. [This operation of the command module occurred for all Apollo missions].Zond 7 flew within 2000 km of the moon and returned pictures to Earth[33]. Then Apollo 12 placed two more people on the moon, landing in Oceanus Procellarum where it remained for 31hours and 31 minutes. Apollo 12 brought back many photos, 34.35 kg of soil samples, and pieces of Surveyor 3 beside which it had landed[34].

In 1970, Luna 16 accomplished the first robotic sample return from the moon and the first soft landing in the lunar night in the northeastern section of the Sea of Fertility. It drilled a 35cm, 101 g, core sample. Luna 16's lower level remained on the moon and monitored radiation and temperature levels. It also took photographs[35]. Zond 8 transmitted images from a little over 1100 km of the moon. Luna 17 landed in Mare Imbrium, 38°17' N, 35° W, and released the Lunokhod 1 rover. The vehicle was powered by a solar cell array and carried cameras, soil density, soil property detectors, and an x-ray spectrometer, as well as other tools. Lunokhod operated until October 1971, having travelled over 10 km[36].

Apollo 14 landed near Frau Mauro in 1971. Photographs were taken and 42.28 kg of samples were collected over 33h, 31m on the surface. The astronauts became lost, failing to find and explore a



Luna 16. http://nssdc.gsfc.nasa.gov/image/spacecraft/luna-16.jpg



Lunokhod image of Luna 17. http://www.mental-landscape.com/C_Luna17_Video.jpg

Detail from an Apollo 15 panorama. http://www.lpi.usra.edu/resources/apollopanoramas/images/print/original/JSC2007e045379.jpg

nearby large crater. They also failed to photograph the lunar context of the samples, dramatically lessening their scientific value. The commander did, however, find time to hit a golf ball[37]. Apollo 15 landed Scott and Irwin on Hadley Rille. Using the Lunar Rover, they traversed over 27 km and collected 77.31 kg of samples. They spent 66h, 55m on the surface[38]. Luna 18 determined the mean density of the lunar topsoil before crashing near the Sea of Fertility[39]. Luna 19 provided panoramic photos of the regions between 30-60S, 20-80E, studied the solar wind, mascons, and gamma rays reflected by the lunar surface[40].

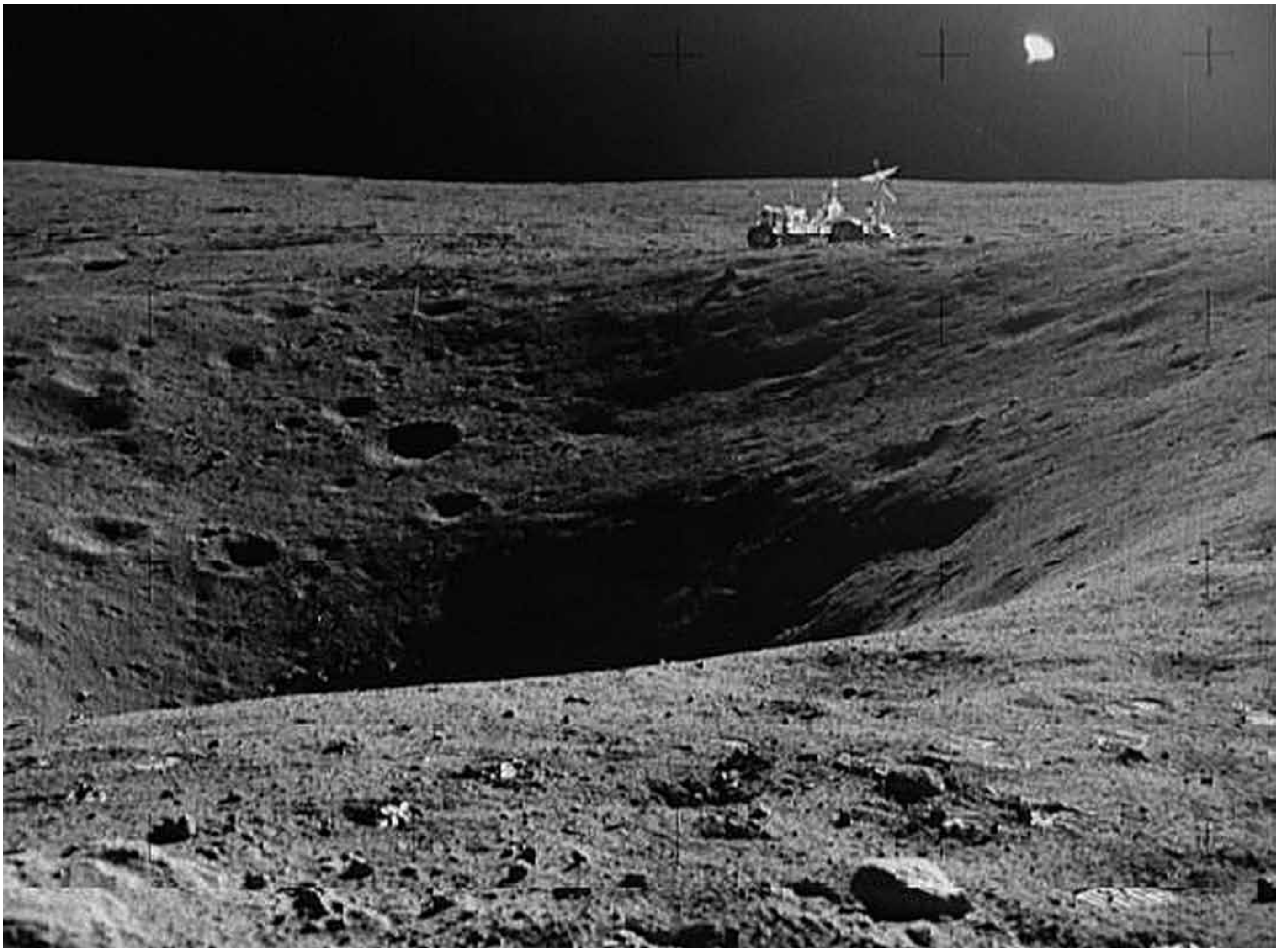
In 1972, Luna 20 landed in the Apollonius Highlands near the Sea of Fertility, 120 km from where Luna 16 had landed. Cores were drilled and 30g of samples collected. These were returned to Earth. While on the surface, TV images were taken[41]. Apollo 16 landed in the Descartes region. Using a Lunar Rover, over 27 km were traversed and 95.71 kg of samples were collected. Many photographs were taken. They spent 71h, 2m on the moon[42]. Apollo 17, the last manned mission sent by the U.S., finally took a geologist to the moon. The astronauts spent 75h on the lunar surface at Taurus Littrow, took many photos, and brought back 110.52 kg of samples[43].

In 1973, Luna 21 landed inside LeMonnier crater and deployed a robotic rover, Lunokhod 2. Lunokhod 2 took 80,000 TV pictures, 86 panoramas, and performed hundreds of chemical and mechanical tests of the soil. Almost 4 months later, it accidentally fell into a crater and contact was lost[44].

Landing in 1974, Luna 22 functioned for 15 months, providing photographs, micrometeorite counts, searching for a lunar magnetic field, measuring solar and cosmic radiation, and examining the magnetic field[45]. Luna 23 landed in the Sea of Crises but damaged its ability to collect samples. It operated for 3 days[46].

As the last act of the U.S./Soviet exploration of the moon, in 1976 Luna 24 landed near Luna 23 and returned a 2m core weighing 170 g to Earth[47].

After this, little scientific attention was paid to Luna until in 1990 and 1992 the Galileo probe heading to Jupiter took two sets of multi-spectral photographs as it whizzed past[48]. In 1991-1993, Hiten, the first Japanese lunar probe, failed to send its separate orbiter probe to the moon and so, in order to save the mission, itself entered into lunar orbit. It lacked the fuel to take the traditional route and so became the first spacecraft to attempt low-energy transfer—a path requiring less fuel and no change of velocity in order to enter lunar orbit, but taking far longer. It succeeded and also checked the L4 and L5 points for extra trapped dust. None was detected. It was crashed into the moon between



View of Plum crater photographed by Apollo 16 crew during EVA. The Lunar Rover is parked on the far side of the crater, which measures approximately 40 meters in diameter. NASA Photo ID: AS16-114-18422 File Name: 10075849.jpg Film Type:70mm Date Taken: 04/21/72 http://science.ksc.nasa.gov/mirrors/images/images/pao/AS16/10075826.htm

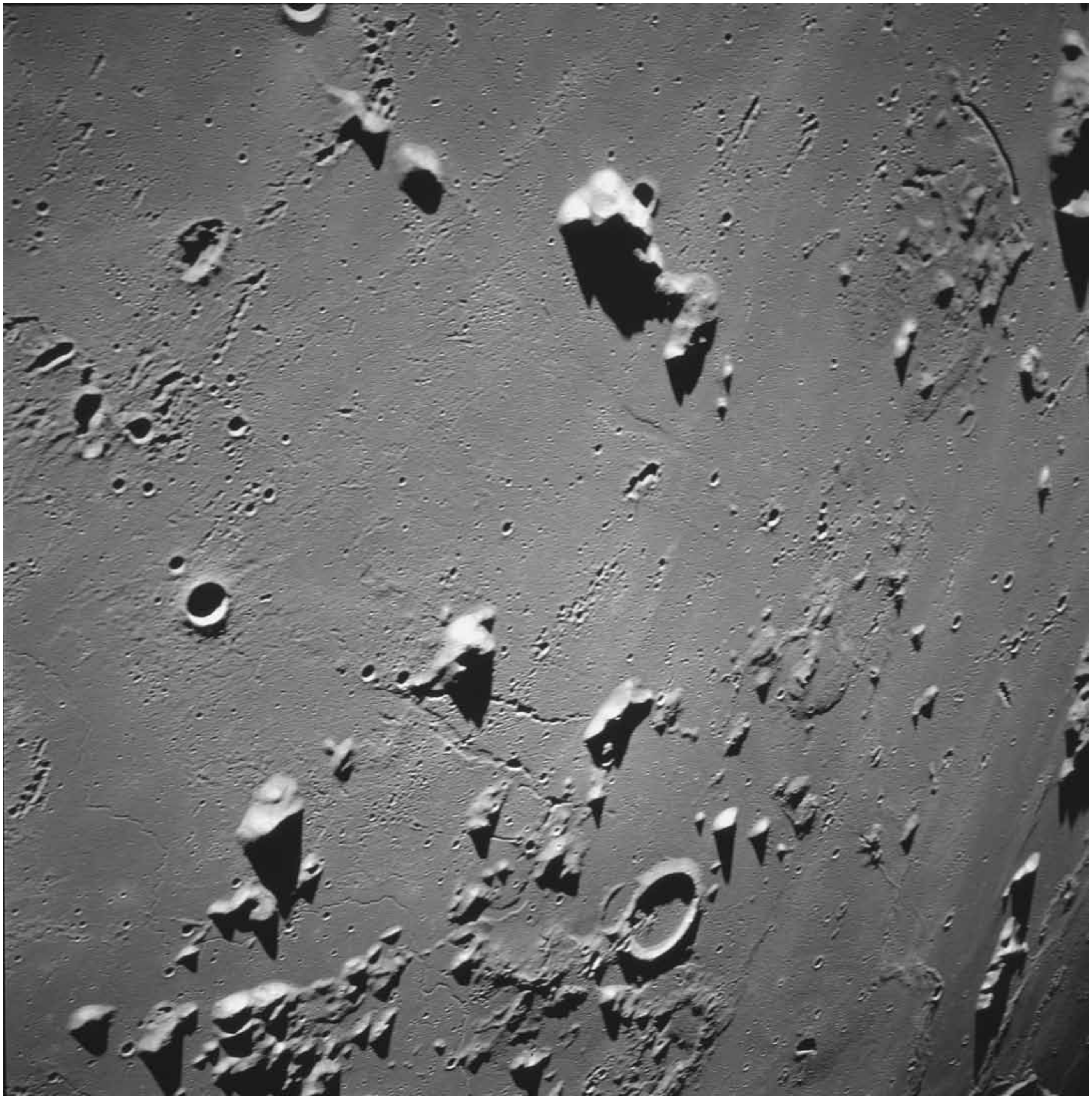
Furnerius and Stevinus[49].

In 1994, the Clementine probe calibrated its sensors on the moon before attempting rendezvous with an asteroid, taking thousands of lunar images at varying wavelengths. It also took altimeter measurements. Bouncing its radio signals off the floors of permanently shadowed craters and having the characteristics of the reflected wave read by the Deep Space Network led to the possible discovery of water ice[50]. However, later similar tests by Arecibo produced similar signals from areas where water could not possibly persist.

Clementine's discovery of possible water ice on the moon prompted renewed interest—if true, the presence of water made human travel to the moon more financially accessible. In 1998, Lunar Prospector followed up on the Clementine data and found evidence of water ice on the lunar poles, but thin amounts. It failed to raise a water spectrum when it crashed into Shoemaker crater near the south pole. It also mapped surface composition[51]. SMART-1, a European Space Agency probe that arrived in 2003, was primarily concenrned with testing its solar-powered ion thruster, but it also mapped the moon in x-ray and infrared. It used infrared to look for water in polar craters. Exact results of this study are not easy to find on public websites. It was crashed into the lunar nearside at

34.4 S, 46.2 W [52].

2007 began a new era in lunar study. Japan's Kaguya (SELENE) probe began orbiting 100 km above the moon. It consisted of a main satellite and two polar orbiters. Lunar Prospector's results suggested there were small amounts of water ice on the floor of Shackleton Crater but SELENE showed this must be mixed in with the sand instead of being pure and exposed[53]. China's Chang'e 1 probe also arrived. In 2008, India's Chandrayaan-1 probe arrived[54]. In 2009 Chang'e 1 was purposely crashed into the moon near crater Messier J[55].



Hasselblad photograph of Euler P crater from Apollo 17. http://www.lpi.usra.edu/resources/apollo/images/print/AS17/151/23268.jpg

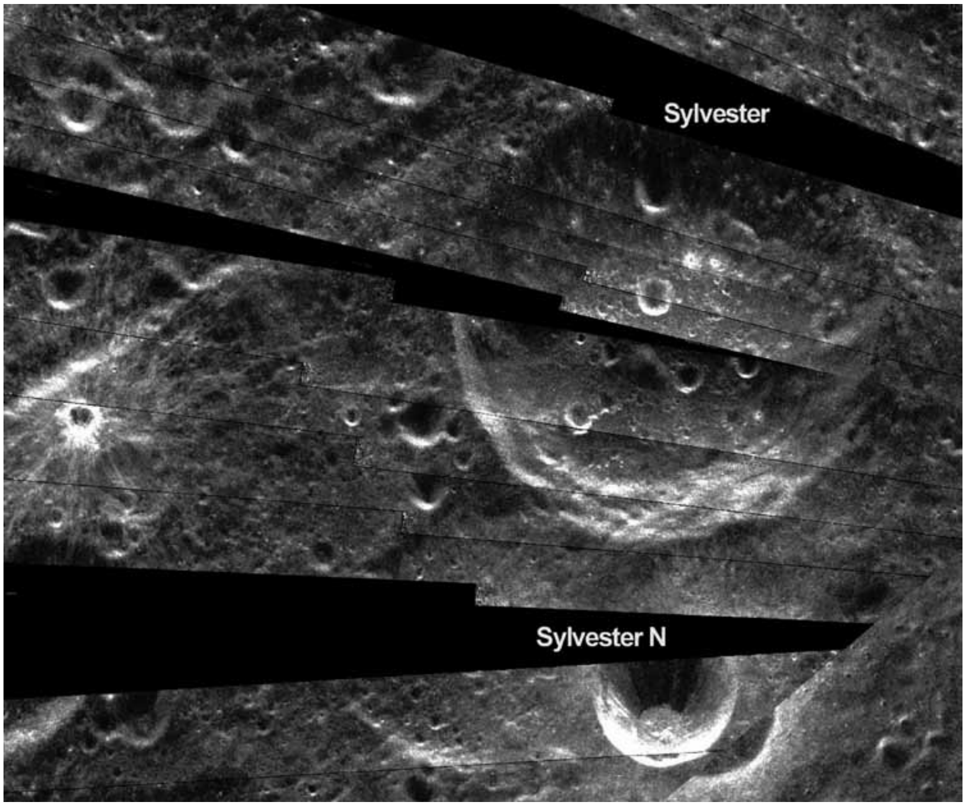
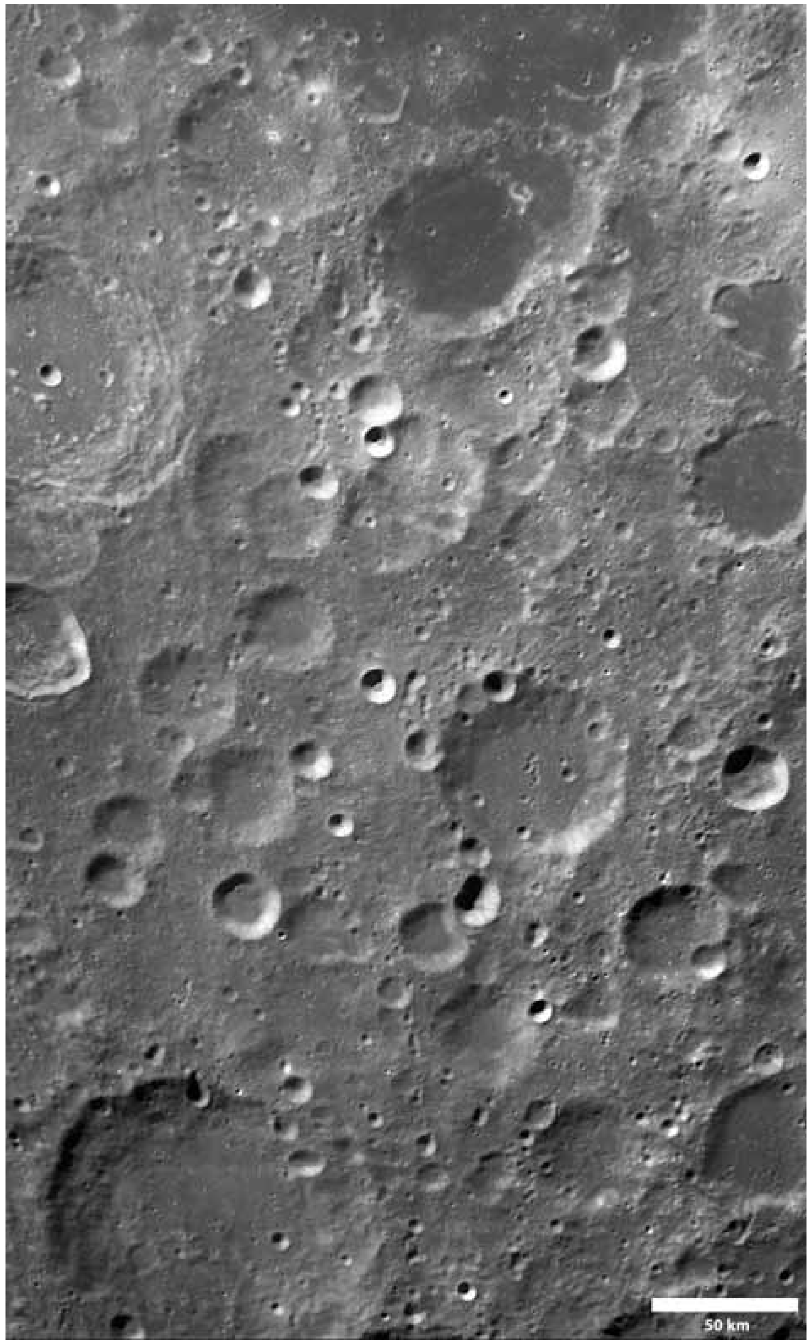


Image from the radar probe run by the U.S. and mounted on Chandrayaan-1. "The old crater Sylvester (58-kilometer [36-mile] diameter) is on the western limb of the moon, near the north pole. It shows many younger craters on top of its flat floor. Credit: ISRO/NASA/JHUAPL/LPI." http://www.nasa.gov/mission_pages/Mini-RF/multimedia/1st_map_cycle_3.html

SELENE image of the schrodinger basin on lunar farside. http://wms.selene.jaxa.jp/selene_viewer/en/observation_mission/hdtv/hdtv_042.html



Chang'e image of a region near Mare Australe. "The 19 separate images that compose this view were captured over two days, November 20 and 21. Each image was 60 kilometers wide; the entire image is about 460 kilometers long and 280 kilometers wide, located within a box from 54 to 70 degrees south latitude and 57 to 83 degrees east longitude. It includes mostly areas of highlands but contains some of the dark basalt plains of Mare Australe at the upper right. The scale bar at lower right is 50 kilometers long. The 66-kilometer-diameter crater Gill is just to the lower right of center in this image. Cut off at the upper left edge is 91-kilometer Pontecoulant. At the bottom edge is 94-kilometer Helmholtz. Credit: CAST." http://www.planetary.org/blog/article/00001242/

Unfortunately, the non-U.S. probes have had little of their collected data released to the public. What they have discovered will, aparently, be slowly revealed through the normal publication of scientific data over the next decade.

All the current players in remote lunar exploration have expressed an interest in continued work and the possibility is held out that manned exploration will commence before 2020. The future of lunar science looks interesting, even promising.

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FROM THE PAPERS…

By Eric Douglass

In this quarterly column, we will explore recent papers from the Lunar and Planetary Conferences. Our focus in on presenting topics of interest to the broader lunar community. The summaries presented here contain not only the results of the paper, but also background information that connects the results to broader lunar topics and background information.

Paper: M. D. Norman; "The Lunar Cataclysm Hypothesis: Status and Prospects;" Lunar and Planetary Science Conference XXXIX; 3/2008; paper #1126.

In this paper, the authors address the notion of the Late Heavy Bombardment (LHB). We begin this discussion by examining the Apollo data. When the Apollo missions brought back samples from the moon, these sample were dated using radioactive dating measurements. In this technique, the comparison of radioactive parent and daughter elements (the relative amounts of each) reveals the age since mineral formation. These 'radioactive clocks' are reset when an impact occurs, due to the high pressures generated at the point of impact (shock metamorphism) and the wholesale melting of the target materials (impact melt). In the lunar samples, such dating techniques revealed a clustering of ages between 3.75 and 3.95 Ga (billions of years of age), suggesting that the highland was resurfaced by impacts 3.75-3.95 billion years ago.

This was an unexpected finding. One way of explaining this finding was to propose that a heavy bombardment of the moon occurred in this period, creating a regolith/megaregolith from the 3.75-3.95 Ga period that covered over the older surface. Certainly, many of the recent basins date from this period. For example, the Imbrium basin is dated to 3.77-3.85 Ga, while the Serenitas basin at 3.87-3.89. This apparent increase in the cratering rate is often called the late heavy bombardment (LHB). This stands in contrast to the Early Heavy Bombardment, which refers to the initial impacts that created the planets and swept up most of the debris in their orbital paths.

The current authors model impact rates, and conclude that, at this point, it is impossible to decide if there was a cataclysm called the LHB with a dramatic decrease of impacts into the next geologic period (the Erathosthenian), or if there was simply a slow tapering off of the cratering rate with no LHB. A close clustering of the basins at the 3.9 Ga period would suggest the former scenario (LHB), while a wider spread would suggest the latter (no LHB). Thus the answer lies in the dating of the oldest, and most degraded basins (such as the South Pole-Aitken basin). Unfortunately, we have no samples from these oldest visible basins. The authors note that one Apollo sample does have an age of 4.2 Ga, and this suggests that no LHB occurred… though a single sample is hardly definitive. This controversy will only be answered by a return to the moon, and a gathering of samples from the oldest basin's ejecta. Until then, the notion of an LHB will remain a hypothesis.

Paper: P.G. Lucey and G.J. Taylor; "The Science of the Lunar Poles;" Lunar and Planetary Science Conference XXXIX; 3/2008; paper #1480.

The authors of this paper have a particular interest in the lunar poles, and in particular in the craters that exist permanently in shadow. It is in these craters that lunar ice is thought to exist. The evidence from this comes from the Clementine mission and the Lunar Prospector mission. The Clementine mission's bistatic radar showed the type of scattering that would be expected by a thick layer of ice. The Lunar Prospector's neutron spectrometer measured the energy of neutrons released from oxygen atoms (due to cosmic ray bombardment), and found the lower energies typical for oxygen in water molecules. These data, especially when taken together, strongly suggest the presence of ices in the permanently shaded craters of the lunar poles.

Given this material, the authors then ask about the sources for these ices. The following is the list found in the paper: (1) Ice-rich comets and ice-laden astreroids: when these impact on the moon, the ice volatilizes into water vapor and spreads out across the lunar surface. Some eventually reaches polar craters. These craters are extremely cold, as they don't receive direct sunlight and the moon has no significant atmosphere in order to distribute heat to the poles. These craters, then, act as cold traps for water, and any water vapor entering them becomes trapped in their regolith. (2) Hydrated interplanetary dust particles (IDPs) and ices in molecular clouds: these particles would also impact on the moon. As the moon has no significant atmosphere, their impact on the moon is not reduced by atmospheric friction (lunar escape velocity is 2.4 km/sec), so that the ices on these particles would be volatilized. After volitalization, these would also find their way into cold traps at the poles. (3) More unusual mechanisms for the generation of ices include the weathering of iron. The authors explain that meteorite impacts result in the reduction of lunar ferrous iron to iron, through the process of sputtering (the release of an oxygen atom due to impact processes). The oxygen so released is then free to combine with hydrogen from the solar wind, and so form water. This water could then become trapped in the polar craters. (4) Another exotic mechanism includes earth-based ions being trapped in the earth's magnetosphere, and being transferred to the moon when it passes through earth's magnetotail. Such ions are created when ultraviolet radiation splits a hydrogen from its parent water molecule (similar processes were involved in the loss of water from Mars). This hydrogen gets caught in the magnetosphere and ends up on the moon. Here the hydrogen combines with the oxygen created by sputtering process (noted earlier).

Finally, the authors note that ices can be lost from cold traps on the moon, through processes not related to solar radiation. Examples include sputtering, impacts, and sublimation. These primarily affect surface ices, so that ices at distance from the surface are protected.