Our nearest neighbour, the Moon
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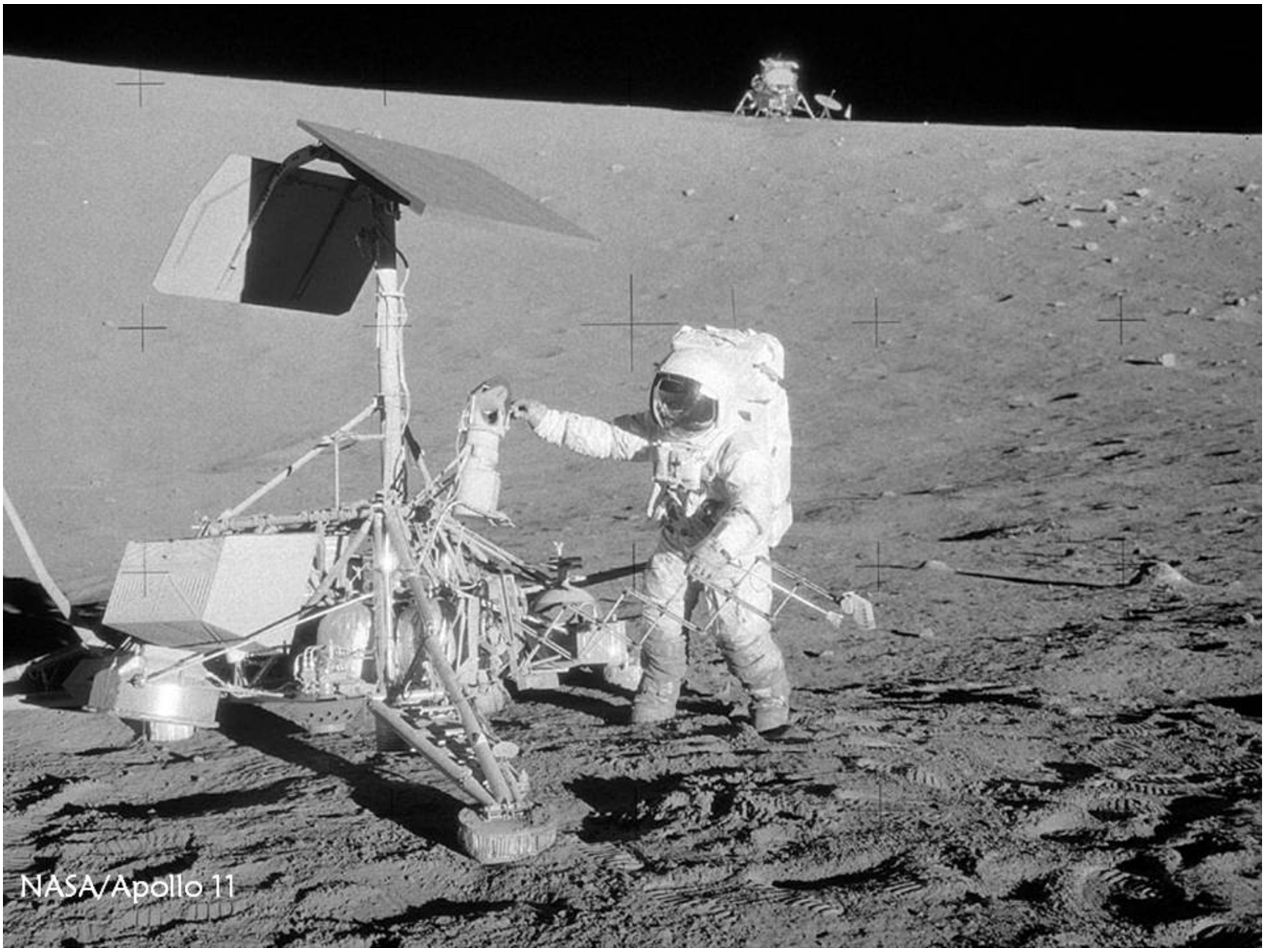

10 October 2012

Our Nearest Neighbour, The Moon

Professor Carolin Crawford

The Moon is the closest astronomical object to us, and it dominates our night sky. With a diameter of almost 3,475km (about a quarter that of Earth), it is the fifth largest satellite within the Solar System. It orbits the Earth at an average (centre-to-centre) separation of 384,400 km, a distance thirty times the Earth's diameter. The Moon's surface area is less than a tenth that of the Earth, and is only as large as that of Russia, Canada, and the United States combined. With a volume of only 2% and a mass of only 1% that of the Earth, the pull of gravity at the lunar surface is greatly reduced at only about one-sixth of that at the Earth's surface.

The Moon has come to mean so much more to us than being merely our nearest astronomical neighbour. As the only planetary body that we can see as a globe with the unaided eye, it has been observed by humankind for tens of thousands of years. The lunar surface is covered by large and uneven patches of light and dark, which to some eyes resemble a man's face, or (in many Asian societies) a rabbit. For most of humanity's existence, the Moon has been both an important cultural symbol, and an integral part of daily life. Early societies were closely tied to the rhythm of the Moon and the way it visibly changed its shape from one day to the next: sailors used it to monitor the tides it produced; farmers used it to guide them in both planting and harvesting their crops; and it provided the light that it could enable safer travel at night. One of its most important functions, however, was as a way to track the passage of time on any timescale longer than a day.

Early Observations of the Moon

The oldest known recorded observations of the Moon are prehistoric, carved into bones dating from 37,000 to 30,000 years ago: a baboon fibula found in a cave in Swaziland known as the 'Ishango' bone (though this interpretation is disputed) and – perhaps more clearly – on an eagle wing bone found in Dordogne in France known as the 'Abri Blanchard' bone. The latter is marked with 29 notches that appear to describe how the phases of the Moon repeat over a 29 day period. Prehistoric (7,000 - 3,000 BCE) stone monuments such as megaliths mark observation points all over Europe from which to monitor not just the Sun, but also the progress of the moonrise and moonset round the sky during a year. The Babylonians were the first human civilization to keep a detailed record of lunar observations, about 3,000 years ago, making clay tablets that recorded times and dates of moonrises and moonsets, and the movement of the Moon across the fixed patterns of stars in the Sky.

The first comprehensive attempt to record the lunar face that we know of was made by William Gilbert at the beginning in 1603, and his map details thirteen features easily identifiable with the unaided eye. Significant improvement came soon afterwards with the development and use of the telescope for astronomical observation. The first known view of the Moon through a telescope was sketched by the Englishman Thomas Harriot in July 1609… although it does not seem to be very informative! Only a few months later, however, Galileo not only provided beautiful illustrations of the lunar landscape but was the first to attempt to interpret what he observed. He understood that the Moon is 'rough and uneven', with mountains and plains like those on Earth; from the length of the shadows cast along the terminator (which divides day and night on the Moon) he estimated the heights of the mountains and crater walls. Galileo also correctly deduced that the darker patches of the lunar surface were lower than the light-coloured regions, and like Gilbert before him, he interpreted them as dark oceans surrounded by continents. Indeed, today we still describe such features with names such as 'Mare' or 'Oceanus', even though astronomers have long since known that there is an absence of seas on the Moon. A proper mapping of the Moon began by the late 19th Century, once astronomers started to use cameras to record photographic images through telescopes. By 1900, some 30,000 features on the Moon had been recorded and named.

The Motion of the Moon around the Earth

The phases of the Moon… and Earth

The most notable feature of the Moon is the way it appears to change shape in a repeated pattern of waxing and waning over the course of a month. These phases result from the way we don't always see the half of the Moon that is directly illuminated by the Sun. The geometry of theEarth-Moon-Sun system repeats every 29.5 days: when the daytime side of the Moon faces us we see it as 'full', and it lies to the opposite side of the Earth from the Sun; when the Moon and Sun are to the same side, the illuminated half is completely turned away and is known as a ‘new’ Moon. The remaining lunar phases depend on how much of the daytime half of the Moon we can see at that point.

Of course, this also means that the Earth displays phases to the Moon in return. When the Moon appears to us as an incredibly slender crescent, just after or before it is new, a dazzlingly bright, and nearly full Earth would be seen from the lunar surface. Sunlight reflected from the full Earth to the night side of the Moon, illuminates it as Earthshine, sometimes known as the “old moon in the new moon’s arms”.

There is a mismatch between the time the Moon takes to complete an orbit once round the Earth (27.3 days, known as the *sidereal* period) and the slightly longer time needed until it shows the same phase to Earth (29.5 days, known as the *synodic* period). This is because the Earth does not remain static while the Moon orbits, of course, as it is itself continually moving in its orbit about the Sun. The Moon thus has to travel a little further along its orbital path before the exact geometrical alignment of the Earth-Moon-Sun system required for a particular phase is repeated.

Eclipses

Eclipses occur only when the Sun, Earth, and Moon are completely aligned. Solar eclipses are possible at the new moon, when the Moon lies directly between the Sun and Earth, and it is only an incredible coincidence how the Moon’s apparent diameter in the Sky exactly matches that of the Sun to cover it completely. Eclipses don’t happen at every new moon, however, because the Moon's orbit around the Earth is slightly inclined by about 5° relative to the orbit of the Earth around the Sun. Total Solar eclipses can be seen about 3 times every decade and then the Moon’s shadow projects onto a relatively narrow path across the Earth’s surface. The Earth casts a much larger shadow across space, so the lunar eclipses that occur at full Moon are more common, occurring perhaps once or twice a year.

The Apparent Size of the Moon

As with most astronomical orbits, the Moon follows a slightly elliptical path, which means that its distance from the Earth varies by 43,000km between the closest (*perigee*) and furthest (*apogee*) points of its orbit. The ellipse of the orbit itself shifts slowly round the Earth in a cycle lasting just under 9 years, due to the influence of the Sun’s gravitational tide. This change in real distance can affect the real size of the full moon in the sky, as the further away something is, the smaller it appears. The difference in apparent size between the full moons when they occur at the apogee and perigee points is an appreciable 12% of the diameter. (This is not to be confused with the ‘moon illusion’ whereby the Moon appears larger near the horizon than it does higher up in the Sky.)

Tidal Effects

On the Earth…

The gravitational pull of the Moon creates the ocean tides on Earth. More particularly, they are due to the way the strength of gravitational pull from any object drops off sharply with the separation away from it. This means that the Moon pulls slightly harder on the sea that is on the nearest face of the Earth than it does on the underlying near surface of the planet. The ocean is pulled up to form a bulge of water that forms the high tide, appearing to travel round the Earth’s oceans, tracking the near point to the Moon as the Earth rotates underneath. There are, of course, two high tides a day; the second is created by the way the bulk of the Earth is then pulled more strongly towards the Moon than the water in the ocean on the far side. This creates a second bulge of high tide always located on the far side from the Moon (there may also be a slight centrifugal component). The high tides thus occur simultaneously and symmetrically on opposite sides of the Earth, and return every 12 hours and 25 minutes to any location. This is more than half a day because again, we are not dealing with an entirely static system. The Moon’s revolution around the Earth is in the same direction as the Earth’s rotation on its axis, so the Earth needs that extra 25 minutes of rotation to return to the same position under the high tide bulge. The largest ranges in tides are produced when the Moon and Sun are aligned, and their gravitational tidal pulls have a combined effect. Similarly, the least range in tides will happen when are at 90 degrees to each other from the Earth.

The movement of the tides in the oceans have a braking effect on the Earth’s rotation on geological timescales. The Earth rotates faster than the Moon moves around in its orbit, and hence faster than the bulk of the water is pulled around. This daily interaction produces friction and resistance to the Earth’s rotation and acts as a brake, dissipating energy at the expense of the Earth’s speed of spin. The day is lengthening at the rate of 2 milliseconds per century, a rate that is imperceptible over a human lifespan but accumulates over 2500 years to put the Earth’s rotation about a quarter-turn out from where it would otherwise be. Indeed, historical observations of eclipses are only consistent with where and when they were seen from Earth if the day was shorter in past. More indirectly, we can use growth patterns in fossil corals from hundreds of millions of years ago to measure the change in a day's length. Like tree rings, the coral displays both daily ridges and annual bands; while the years remain the same length, the number of days in a year increases as we go back in time. 400 million years ago day was only 22 hours long, and fossilised algae known as stromatolites also show layers indicating that 2 billion years ago the day was only 10 hours long. Computer simulations modelling the braking process infer that the day was only about 6 hours long when the Earth was formed some 4.5 billion years ago.

… and on the Moon:

As it slows down, the Earth loses angular momentum and energy. These are both conserved quantities within any closed system, so that lost by the rotating Earth goes into accelerating the Moon out into a slightly higher orbit. As the Moon pulls on the tidal bulge on the nearside of the Earth, the return effect pulls the Moon slightly forward to speed it up slightly in its orbit, and thus (due to Kepler's laws of planetary motion) it moves to a marginally higher orbit. The Moon is gradually spiralling outwards away from away from Earth at a rate of about 3cm per year. This motion has been directly measured by experiments that track the Earth-Moon separation by reflecting laser light from instruments left on the Moon by *Apollo* astronauts.

It's not that the Moon will ever move so far away that it will leave the Earth. Long before that happens, the Earth will have been completely slowed down such that the two are *tidally locked* to each other. Currently, only the Moon is tidally locked to the Earth; it always keeps the same face turned towards us, rotating about its spin axis at the same rate that it takes to revolve around the Earth, a process known as *synchronous rotation*. This is because in the formative days of the Earth-Moon system, there was also a braking effect exerted on the Moon by the Earth. The early (and partially molten) Moon was distorted into a slight oval shape by the Earth's gravitational tide, stretching it along the direction extending to and away from the Earth. Bulges were created within the Moon's outer layers both on the near side that felt the Earth's gravity more strongly, and on the far side where the Earth's gravity is weaker. In the same way that the high tides on Earth follow the Moon round, these two lunar bulges travelled through the moon's surface tracking the far and near sides to the Earth. Originally there would have been a mismatch between the rate the moon is spinning and the speed at which it orbits the Earth – and thus the rate that the tidal bulges are being pulled around after the Earth. A torque – a twisting force – arises to stabilise the situation. If the moon is rotating faster than it orbits, the torque acts to slow down the Moon's rotation; if it rotates slower, the force twists it forward to quicken the rotation. Regardless of the initial situation, the outcome is to rapidly synchronise the moon's rotation with its orbital period.

The 'far side' of the Moon

Consequently, there is a far side of the Moon that is always turned away from us (which is not the same as the dark side, which changes depending on which bit of the Moon is facing the Sun). The far side was first photographed by the Soviet *Luna 3* probe in 1959, and only directly seen with human eyes when the *Apollo 8* astronauts orbited the Moon in 1968. It is very different from the near side, showing a much more densely cratered surface interspersed by only a few maria (which cover 2.5%, compared to 30% on the near side). We can periodically glimpse about 9% of the far hemisphere from Earth in a process called 'libration'. Noticed originally by Galileo, this effect arises due to the way that the slight inclination and ellipticity of the Moon's orbit leads to small variations in the angle from which the Moon is seen from the Earth.

The Geology of the Moon

The geology of the Moon is appreciably different from that of the Earth. Without an atmosphere and oceans, there is no erosion due to weather; it also has a much lower gravity, lacks tectonic plates and its smaller size means it cooled far more rapidly. Its topography ranges over 16km in altitude, and one of the most notable features on the far side of the Moon is the huge Aitken basin, over 12km deep and 2600km in diameter.

The lunar surface displays three characteristic features:

Mare

The large dark maria are flat lowland plains made of solidified lava. They are relatively featureless, apart from twisty *rilles* scoured by long-past but turbulent flows of high temperature, fast-moving lava and straighter *wrinkle ridges* revealing where the lunar surface long ago buckled as the Moon cooled and shrank.

Highlands

The maria are all surrounded by much lighter-coloured highlands (sometimes referred to as *terrae*) that connect to form mountain ridges. These regions are comparatively iron-poor, consisting of minerals such as anorthosite, calcium-rich feldspar.

Impact Craters

The most notable geological feature, however, are the round craters that pock-mark both the maria and highlands. They come in all sizes, and about half a million have a diameter more than a kilometre across. Originally thought to be due to volcanic activity, the realisation that lunar craters were impact features only became accepted in the 1940s. They are formed when a piece of space debris – such as a comet, asteroid or small space rock– slams into the lunar surface at high velocity (typically around 17km/s). A vast amount of kinetic energy is released on impact, which not only vapourises the impactor, but creates a shock wave moving radially away from the point of collision to compress and remould the surface. The subsequent rarefaction wave propels molten ejecta out to create radial rays, and secondary craters around the original impact. In a large event, a final rebound of the surface rapidly creates a central mountain peak rising up from the crater floor. Once formed, the inner walls of a large crater slump down under gravity to create terraces and ledges.

The lack of weather and water means that the craters are well preserved, and record the full history of impact events on the Moon throughout its lifetime. The largest impacts occurred when the Moon was young, and they have since been superposed by later, smaller craters, showing a trend of decreasing crater size with time. A recently formed crater starts with sharp-edged rims, which are gradually overlain and softened by subsequent impact activity, including a constant bombardment of micro-meteorites. All the billions of years' worth of collisions have completely pulverised the surface of the Moon to form a thick blanket of fine dusty material known as *regolith*. The regolith is much thicker on older lunar surfaces such as the highlands (10-20m deep) than down in the younger maria (3-5m deep). It contains both mineral fragments of the local lunar surface as well as glassy particles formed during the impacts. The *Apollo* astronauts described the lunar surface as feeling like snow, and smelling like used gunpowder.

The Formation of the Moon

The Earth is unique among the rocky planets in having a relatively large and massive Moon. Furthermore, the Moon has a much denser mix of rock and ice than do the other large moons in the Solar System; its orbit is also unusually tilted so that it is not directly above the Earth's equator. The oldest rocks on the Moon are a similar age to the Earth, and their chemical properties (such as the balance of elemental isotopes) imply a common ancestry, suggesting they formed in the same part of the original Solar nebula. A lot of these features can be explained if we appeal to a special one-off event to account for the creation of the Moon in a giant impact.

Giant Impact Theory

During the very early period of Solar System evolution, matter in the Solar nebula accreted together under gravity and other forces to form proto-planets. We can expect such bodies took a while to settle into their final orbits, and as they did so large collisions will have occurred, even when the planets are comparatively well formed. We infer that some 4.6 billion years ago there was a major collision occurred between a body about nine-tenths the size of the current Earth, and another about the size of Mars (and about a quarter of Earth's current mass). Both proto-planets were still partially molten, consisting of a rocky crust wrapped round an iron core. The smaller protoplanet ('Theia') is thought to have struck the proto-Earth a glancing blow that shattered them both. Large amounts of debris from the collision was ejected far out into orbit around the Earth, where it eventually condensed together to form the (molten) Moon. Much of the original impactor is incorporated into the Earth – in particular, much of the cores of both protoplanets combine, explaining why the Earth has exceptionally metal-rich core, and stronger magnetic field than the other rocky planets.

Subsequent Geological History

Our understanding of the subsequent geological evolution of the Moon has been guided by detailed analysis (including radioactive dating) of the lunar rock samples returned by the *Apollo* and *Luna* missions. Broadly speaking, there are three main types. The material originating in the lighter-coloured lunar highlands are the oldest rocks – indeed, at an age of 4.6 billion years, they are older than any found on Earth, and are comprised of lightweight material that has been melted and then cooled. The regolith contains breccias, pre-existing rock changed by the crushing, melting and welding action of energetic meteorite impacts about 3.9 to 3.8 billion years ago. Finally, the maria are filled with basalts, a vaneer of volcanic lava that spread out over the Moon's crust and which at 3.2 to 3.9 million years, is the youngest material.

An ocean of molten magma covered the surface of the freshly-formed Moon to a depth of at least 500km, slowly cooling to crystallising out some 4.6 to 4.4 billion years ago. The heavier minerals such as the iron and magnesium silicates were the first to form, and sank down towards the interior through the surrounding molten material. The less dense minerals floated like froth once crystalline, forming a layer about 50 km thick which cooled to form a low-density lunar crust and the precursor material for the rugged lunar highlands. Soon after the magma ocean cooled, a hail of debris remaining over from the formation of the planets caused a short-lived and intense period of impacts known as the 'late heavy bombardment'. Intense showers of meteorites and comets, smashed into the Moon's surface about 3.9 billion years ago to crush the crust and produce the slightly younger breccias. The larger of the impacts punched holes in the light crust, pushing it up and to one side to create the mountainous highlands around the impact basins. Finally, the heating of the lunar interior by radioactive decay of long-lived unstable elements led to an era of volcanism 3.9 -3.2 billion years ago. Lava broke through the crust where it was thinnest, underneath the large impact basins. Rather than piling up to form volcanos, it slowly and smoothly spilled out and across to flood the large impact basins and cool to create the large dark maria. The Moon is small, and cooled down fairly rapidly from the outside in, to become solid and geologically quiet. Only the steady rain of smaller, mostly less dramatic impacts have continued to change the surface since.

Water?

All the lunar geological samples returned to Earth were noticeably dry – and any trace amounts of water were attributed to terrestrial contamination– and so for many years we have inferred that there was no water anywhere on the Moon. We suspect that much of Earth's ocean water was added by cometary material during the late heavy bombardment, so it would seem likely that this event would have also delivered small amounts of water to the lunar surface. However, the lack of atmosphere exposes the lunar surface to the full force of energetic sunlight which can split the water molecules into its constituent elements of hydrogen and oxygen; these easily leak away into space, as the Moon's weak gravity being unable to retain them. Stable pockets of water ice close to the surface might, however, still exist in any pockets of permanent shadow in deep recesses of craters near the South pole.

Indeed, recent satellite measurements are forcing a reassessment of lunar chemistry, with at least three recent missions detecting clear evidence for water ice to be widespread in the lunar surface. For example, India's *Chandrayaan-1* lunar orbiter analysed the reflection of sunlight from off the lunar surface – absorption of infrared light near the lunar poles was at wavelengths with the presence of consistent with hydroxyl- (OH) and water-bearing minerals in the uppermost few centimetres of surface soil. Although it was originally thought impossible to have water surviving in the hot sunlight, water and hydroxyl molecules seem to show up at all latitudes, even at the equator. There are not vast amounts of water - a recent estimate is only ½ litre in every 450 kg of surface soil near the moon's poles, dropping to two tablespoons per 450kg at the equator. This is less than is found even in the driest deserts on the Earth. Still the estimates may well rise with a more detailed mapping of the polar craters, or sampling of conditions much deeper into the regolith.

Lunar Reconnaissance Orbiter

Lunar water would, of course, be of major benefit if humankind is to ever return and settle on the Moon. Even now we are entering a new era of lunar exploration driven by various nations, including Russian, America, China, Japan and India. One such mission is NASA's *Lunar Reconnaissance Orbiter* (*LRO*), which is currently surveying the lunar surface to help with the identification of lunar resources, potential landing sites and effects of the lunar radiation environment. It has been following a polar orbit around the Moon since 2009, flying closely above the surface and carrying a payload of six instruments performing a whole range of science. For the purposes of this talk, we will examine the spectacular high-resolution images (resolving features only 0.5m across!) obtained with its narrow-angle and wide-angle cameras.

Craters

Tycho Crater

Tycho Crater is one of the most prominent craters on the Moon, appearing as a bright scar in the southern highlands surrounded by long bright rays. It's a relatively young crater (about 110 million years old), and thus fairly well preserved. 5km deep and 86km across, it is sufficiently large that the crater walls have slipped and slumped under gravity. At the centre is a mountain made from material that rebounded back up after being compressed in the impact. Close inspection reveals a 120-m wide boulder sitting at the top of the central peak, surrounded by impact melt deposit. This indicates that the central peak formed very quickly, as it would have to be there by the time that debris (such as this boulder, and the melt apparent close to it) returned down after being thrown straight up.

Kepler Crater

Although smaller (32 km across, 2.5km deep), Kepler is typical of older and more complex craters with central peaks, terraces, and flat floors. *LRO* images of the steep inside wall of the crater reveal a layer of exposed bedrock near the top of the rim. This has stayed intact, although it is being undermined as rocks and dust slide out from underneath, pulled down the slope by gravity to collect at the base of the crater wall. This material is gradually loosened by the shudders of both nearby impact activity and small moonquakes – very gentle seismic activity that seems to follow a cycle related to the gravitational tidal pull from the Earth.

Boulder Trails

Indeed, many craters show regions where boulders have rolled down from high on the rims and onto the crater floor. They often leave clear trails in the regolith, enabling scientists to determine their origin by back-tracking along the path. The spacing of the marks made as the boulders bounced downslope can reveal much about the mass of the boulder, and its speed as it bounced downhill. Even differences in the reflectance of the trails can trace differences in the way they travelled, some heavier boulders perhaps disturbing deeper layers of regolith.

Pits

The lunar mapping is turning up unexpected geological features of interest, including a whole variety of deep pits in the mare. Images taken when the Sun is overhead show the illuminated floor of the pits, estimated to be about 100-120m deep from the length of the shadows of the boulders. The walls of the pit cut through the basalt of the mare, showing shelves of layered lava flows. Some pits have been found close to systems of volcanic rilles, suggesting that they are created when the roof of an underground rille collapses.

Fresh Impact Craters

The detailed survey of the lunar surface allows a direct comparison to past photographs from the era of *Apollo* and *Luna* exploration, which in turn permits identification of craters that have been formed during the last forty years. This gives a much clearer estimate of the present-day cratering rate on the Moon and thus of the current level of bombardment in the inner solar system. The new craters stand out because of their bright ejecta, where the impact has exposed fresh and more reflective material from underneath the surface; gradually it will fade as it undergoes ‘space weathering’ by the harsh Solar radiation environment. But not all of the fresh impacts are entirely natural in origin. For example, one very fresh crater about 30 m in diameter was created when the third stage of the Saturn launch vehicle for *Apollo 13* impacted the lunar surface (this is the final stage or the rocket, and was used to propel the docked *Apollo* Command Module and Lunar Module from Earth orbit into a lunar trajectory, and discarded once its mission was complete). The radio signals of all such rockets were tracked and astronomers have by now identified most of their associated craters. It is also true that everything that humanity has sent to the Moon remains there still, and is observable from the *LRO*’s close orbit.

Space Hardware

Soviet UnionLunar Rovers

For example, the Soviet robotic lander *Luna 17* landed on Mare Imbrium in November 1970. From the *LRO* zoom you can see the double ramp leading down from the lander, and the tracks of tyres made by its passenger, the first successful remote lunar rover, *Lunakhod 1.* Compressed regolith appears darker than the undisturbed surface. *Lunakhod 1* travelled over 10 km across the Moon during the next ten months, and if you follow its tracks, it can be spotted where it finally came to rest. Its successor, the *Lunakhod 2* rover and its *Luna 21* lander are also observable on the Moon. Each of the rovers were about 2.3m long and 1.5m tall.

Surveyor 6

NASA’s *Surveyor* programme sent seven spacecraft to characterise lunar surface properties and test landing systems in advance of the piloted *Apollo* programme. The first landed in May 1966 and the final mission was *Surveyor 7* which landed in January 1968. The *LRO* image of *Surveyor 6*, which landed in November 1967, shows it casting an 18m long shadow in the evening Sun. *Surveyor 6* is of interest as near the end of its fortnight-long mission, it was commanded to fire its engines to rise 4m from the surface and land 2.5m away – thus it made the first successful liftoff from the lunar surface, and is the only spacecraft to have landed twice on the Moon.

The Apollo Landing Sites

Each one of the *Apollo* landing sites has been extensively and repeatedly observed by the *LRO*. Images taken with the Sun at different altitudes to the lunar surface can highlight completely different features.

Apollo 11

The most famous of the landing sides is of course *Apollo 11* in Mare Tranquillitatis. From *LRO's* close orbit the Lunar Module is clear on the northeast flank of West crater, at 'Tranquility Base'. The footpads of the LM are clearly discernible, showing up in contrast to the surrounding lunar soil, appearing dark where it has been churned up by the footsteps of the astronauts. All their footprint tracks can be followed from here: the path taken to set up the TV camera; to where they deployed scientific experiments on the lunar surface; and Neil Armstrong's excursion to look inside Little West crater some 50m to the East.

Apollo 12 Landing Site

A similar view of the *Apollo 12* landing site in Oceanus Procellarum also clearly shows the trails of astronauts Charles Conrad and Alan Bean from the Lunar Module *Intrepid*, which landed only a few months later in November 1969. The astronauts performed two moonwalks, each about 4 hours in duration. First they set up the *Apollo* Lunar Surface Experiments Package (which returned scientific data directly to Earth for more than seven years afterwards) and then continued to the north-west to collect about 15kg of geological samples of lunar soil and rock. The second excursion set them travelling west, around Head crater and south to Bench and Sharp craters. As it was still relatively early on in the *Apollo* programme, the location of the landing was chosen to be a flat lava plain, that had been tested by a landing of the robotic *Surveyor 3* spacecraft two years earlier only 200m away at the edge of what was later called Surveyor crater. After visiting Sharp craters, they made their way across to examine the *Surveyor 3* and remove parts for return to the Earth. It was from this location that one of the iconic *Apollo* images of an astronaut examining the robotic spacecraft with the Lunar Module in the background was taken.

To revisit these LRO images – and discover many more! – I thoroughly recommend the following website:

www.nasa.gov/mission_pages/LRO/multimedia