Geologic Processes on the Moon

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I INTRODUCTION

This paper deals with the processes that formed the features we see on the Moon. The primary geologic processes that shaped the Moon are the formation of craters, volcanic activity, and tectonic activity. Each of these will be dealt with in their respective sections below.

II CRATERING ON THE MOON

Introduction

Craters cover the surface of the Moon. They are the result of hyper-velocity impacts by meteorites. The velocity of meteorites upon impact varies, but is generally between 10 and 40 km/sec. This number is a combination of the 'approach velocity' and the 'escape velocity.' The approach velocity of objects refers to the velocity of the object with respect to the Moon. This varies with the type of object (for example, long period comets generally have a higher approach velocity than short period comets) and the direction with which it approaches the Moon (for example, if it approaching the Moon 'head on,' it will have a higher approach velocity than if it is 'catching up' with the Moon in its orbit). The escape velocity is a measure of the extra velocity an object gains as it accelerates in the gravitational field of an airless Moon/planet. For the Moon, this number is 2.4 km/sec

The velocity of a bolide (the technical name for a body that strikes any planetary surface) is important for it is the major determinant of the amount of energy released upon impact. Bolides possess 'kinetic energy', and the value of this is proportional to the mass of the bolide multiplied by the square of the velocity. Thus, if two meteorites of the same mass strike the lunar surface, but one has twice the velocity of the other, than the faster one possessed four times (not two times) the kinetic energy of the slower one.

Upon striking the Moon, the kinetic energy is transferred to a massive shock wave which both goes down into the Moon's surface and rearward into the bolide itself. The shock wave that goes rearward is so powerful that it excess the strength of the rock--indeed, most of the bolide vaporizes. The shock wave that goes forward into the Moon vaporizes part of the surface of the Moon (several times the mass of the bolide), melts the layers of rock below this (up to 100 times the mass of the bolide), and shocks (fractures) the surface deeper yet. This period in the cratering process is called the 'contact and compression' phase.

The next period in the cratering process is called the 'excavation' phase. This phase begins with the formation of a release (rarefaction) wave that develops at the edges of the impact, and forms a route of escape for some of the vaporized/melted/shocked rock. This escape of material produces the crater itself, and the material that escapes forms the ejecta that goes outward onto the Moon surface. Finally, the decaying shock wave continues to travel through the bedrock of the Moon, creating effects further away (such as activating older faults, creating landslides, etc.

The third period in the cratering process is called the 'modification' phase. Here the liquid materials on the crater's sidewall (impact melt) and semi-stable rim materials slip down to the crater's floor. Additionally, in larger craters, this is the time that the central peaks and sidewall terracing occur.

From this brief description on the mechanics of crater formation, we will now look at the types of craters and the unique morphology of each. While craters are variously classified, based on their size and morphology, I am going to use the most common classification: simple craters, complex craters, and basins.

Simple Craters

Simple craters are bowl like depressions in the lunar surface. They occur from submillimeter size to approximately 15 km in diameter (15-20 km is the transition zone between simple and complex craters).

Simple craters form when small meteorites strike the Moon at high velocities. The bolide is vaporized along with the surface struck (the target). This vaporized rock is injected into the floor of the crater, and follows the release wave to escape to the outside where it will be emplaced as ejecta. As the shock wave begins to dissipate, the next layer of target materials will not be vaporized, but only melted (called 'impact melt'). This material is also injected into the crater's floor and escapes to the outside as ejecta. As the shock wave further dissipates, it is no longer able to melt the target materials, but instead only fractures the rock. This fractured rock is again pushed in both directions.

The crater itself is formed by decompression along the sides of the crater, allowing these vaporized, melted, and shocked fragments to escape. This material will lay itself down as the ejecta blanket, which has four distinct parts. Just outside of the crater rim is the zone of continuous ejecta, which is formed from the last material ejected from the impact. The next layer out is the discontinuous ejecta, which interfingers with the surrounding lunar surface. Further out yet is the bright ray system, which is formed from the first material ejected. The fourth part of the ejecta is found in the area of the discontinuous ejecta and just beyond it--this is the area of 'secondary cratering', which results from 'chunks' of rock which are thrown out from the crater. This secondary cratering typically forms a 'herringbone' pattern on the lunar surface, with multiple craters in a line having small 'v' shaped lines emanating from them.

Once the ejecta has exited, the remaining crater is called the transient crater, for other processes will modify its final form. For simple craters, this final 'modification' involves the sliding down of impact materials (impact melt and unstable rim/wall materials) onto the floor of the crater. For craters in this size range, these materials generally fill the lower third to half of the transient crater's depth. This will result in the crater's final form.

Observation of such a crater will reveal a bowl shaped depression with a sharp rim, some rim deposits (blocks of material thrown out at the end of excavation), a discrete ejecta blanket grading from continuous to discontinuous, and a bright ray system. Across time, parts of this crater will degrade due to the erosive rain of micrometeorite impacts. The first to go will be the ray system, followed by the discontinuous ejecta and the sharp rim. This process will continue until only a bowl shaped depression with a gentle slope remains.

Complex Craters

Complex craters begin at 20 km (transition zone from simple to complex is 15-20 km in diameter). They are characterized by the morphology of a bowl like depression with a central uplift of one of more massifs (small, mountain like structures) and terracing on the sidewalls.

Complex craters form when medium sized meteorites impact on the lunar surface. The impact occurs as discussed in the simple crater above, though the energies involved are much greater. The real differences begin after the formation of the transient crater. At this point the rim is more massive than in a simple crater. Because the subsurface rock is extensively fractured, this rim material cannot be supported. It slides down these fractures (called 'slumping') creating a series of 'terraces' on the crater's inner walls. Central peak or peaks also form at this time. Peaks form because the impact compresses the underlying rock, and this rock rebounds after the shock energy is dissipated--much like a bedspring that is compressed and then released (the size of the central peaks is also modified by slumping of the rim material, which pushes rock towards the central uplift). At the same time this slumping and peak formation occur, the impact melt on the sides of the crater is sliding down along with other unstable side/rim material. This again covers the bottom of the temporary crater and ponds in some of the terraces. This produces the 'final' form of the crater

The parts of the complex craters are, then, the central uplift, which can be one or several peaks that may attain heights of over a 1000 meters. This is followed outward by a flattened floor of impact melt which grades into the terraced sidewalls. The rim occurs at the top of the crater and grades out into the continuous ejecta, the discontinuous ejecta, the larger secondary craters (which now can be seen by Earth based telescopes; for e.g., see those around Copernicus), and the bright ray system.

Degradation occurs in complex craters as in simple craters. First the ray system goes, followed by discontinuous ejecta and the sharp rim. The continuous ejecta erodes later along with the terracing and central peak. Across geologic time, the crater will become a simple bowl like depression.

Basins

Basins begin around 200 km in diameter (note: given the length of this article, I will not further divide basins into peak-ring basins, central-peak basins, and multi-ring basins; the reader is referred to more detailed texts here). They are characterized by a series of rings (instead of a single rim). Multi-ring basins are the largest cratering events on the Moon, spanning up to 2500 km in size. The formation of multi-ring basins is poorly understood, and competing theories exist. The problem is that the amount of kinetic energy released is so large that it is difficult to predict how a solid surface behaves under its influence. The model we present assumes that the energy causes the solid lunar surface to behave as a substance with little inherent strength (i.e., a fluid surface), and so the rings form like a stone dropped into still water.

When a massive impact occurs on the Moon, the transferred energy produces a massive shock wave. This vaporizes most of the bolide and part of the Moon's surface. As in the simple crater, this material is both injected into the next layer and allowed to escape out as ejecta. The next layers of melted rock and shocked rock do the same. The transient crater which then forms is in the shape of a shallow bowl. Next a central uplift occurs from rebound of the underlying rock. This rebound cannot come into equilibrium in the fluid-like medium, and so collapses, with the rebound-material forming a wave that propagates across the transient crater's floor. The wave freezes in place as its kinetic energy is dissipated by friction. Multiple rings may form in this fashion.

The morphology of a multiring basin is best illustrated by the Orientale basin. While it is the most recent of the large basins, only a fraction of it can be seen from Earth. Fortunately, it is well photographed by spacecraft. The center of the basin is flat, and probably covered with impact melt (it has since been modified by volcanism). Further out, at a general spacing ratio, one comes to each successive ring. Beyond the outer rim, we find the usual ejecta blanket, with continuous/discontinuous/secondary impacts. However, here the ejecta is much more massive and extensive (the secondary craters can be 10-20 km across, and the continuous ejecta can be hundreds of meters thick). Also, note that the ejecta forms a 'hummocky' terrain (examples of this can be seen around the Imbrium basin as the Fra Maruo formation, and around the Nectaris Basin as the Janssen Formation).

Across time even these massive basins are eroded away by the rain of micrometeorites. Indeed, as the basins are all very old, this erosion has already erased all evidence of their ray systems.

III OTHER EFFECTS OF CRATERING ON THE MOON

Impacts do more than just produce craters. To these effects we now turn our attention. First, the cratering event creates a shock wave that doesn't 'stop' in the impact's general area, but continues to travel out across the Moon. If this wave contains sufficient energy, it will cause faulting in the bedrock (the Straight Wall is an example of this). It can also activate faults that already exist. Finally, it can loosen semi-stable materials on crater rims, producing landslides. An example of this is the landslide in Copernicus that was caused (it is thought) by the shock wave from the Tyco impact.

Upon impact, basins spread a thick ejecta blanket over a huge section of the Moon. These blankets accumulated into a layer several kilometers thick, called the megaregolith. On top of it is a layer of fine, dusty material called the regolith. This was produced by smaller meteorites/micrometeorites pulverizing the upper layers of the megaregolith. The regolith can be over 15 meters thick on the lunar highlands, and up to 8 meters thick on the mare. Because the regolith is so thick, it acts as a protective shield to the underlying structures (megaregolith, lava flows). Micrometeorites and small meteorites are not able to pierce it. Only meteors around 3 meters in diameter can now reach the megaregolith (depending on their velocity).

In earlier sections, we noted that micrometeorite impacts eroded the craters and basins. This degradation occurs in an orderly fashion, so that one can detail the age of a crater by examining its state of degradation. Thus medium sized craters that have a sharp rim, rim deposits, terracing, a central peak, a continuous and discontinuous ejecta and a bright ray pattern are the youngest. These are in the 'Copernican Period', which extends from the present to 1.2 billion years of age. Medium sized craters that have all these parts except the bright ray pattern are in the next in age. These are from the 'Eratosthenian Period,' which extends from 1.2 to 3.2 billions years of age. Medium sized craters that have lost their bright ray pattern and the discontinuous ejecta are much older. They come from the Imbrium Period, which is from 3.2 to 3.85 billion years of age. Medium sized craters that have lost their continuous ejecta and their 'sharp' rim are from the next period, called the 'Nectarian Period.' This period extends from 3.85 to 3.92 billion years of age. Medium sized craters that appear as simple bowl shaped objects without any rim or ejecta are the most ancient of all. They come from the 'Pre-Nectarian Period,' which extends from 3.92 billion years of age to the beginning of the Moon's solid surface.

Note, here, that crater dating has some limitations. First, small craters degrade more quickly than larger ones. Second, ray systems degrade faster on mare surfaces. Third, apparent degradation can occur when large ejecta sheets or a volcanic flow obscure a crater's parts. However, even given these three problems, we can still tell much about the age of craters from the amount of erosion each one exhibits.

IV VOLCANISM

Volcanism is the next major geologic force on the Moon. Radioactive elements (such as uranium, potassium, and thorium) reheated areas of the lower crust and upper mantle, creating a series of partial melts. These melts were less dense than the surrounding rock, and so began rising toward the surface. The eruption of lava preferentially occurred in basins, and that for two main reasons: first, these massive impacts sent faults deep into the Moon's surface (tens of kilometers), providing conduits for the rising lava. Second, the mantle underneath the basins rose closer to the surface (isostatic compensation), making the path to the surface much shorter.

As lava erupted into the basins, it sometimes flowed long distances before finally 'emplacing'. It could do this because lava on the Moon has a low viscosity (it is very thin and runny). Indeed, when lava materials were melted on Earth, it was shown to have the consistency of motor oil. This is because lunar lava is low in silicates ('mafic' lava). By contrast, the lava on Earth's shields is higher viscosity--making it more like toothpaste--as it is higher in silicates ('felsic' lava). These lunar lavas generally erupted from fissures, which poured out and ponded in the geographically lower plains. However when erupted onto an inclined surface, the lava could flow downhill and even create river-like channels from thermal erosion. On the Moon, these formations are called 'sinuous rilles'. Some run up to several hundred kilometers before finally spilling their lava onto flatter surfaces.

This process of mare flooding resulted in large, flat lava sheets that covered the basins. Because the basins were concave in shape, lava was thicker in the center of the basin and thinner towards the edges. Now lava is denser (heavier) than the surrounding crustal rock, so it 'compresses' the bedrock underneath (a process generally called 'subsidence'). The thicker areas in the center do this more than the thinner areas out at the edges. This changes the shape of the basin from a 'flat' surface to a very gently sloped 'bowl' shaped surface. This produces three unique formations.

First, it created unique, 'target like' surfaces. As the first lava flow subsided, the center would 'sink' and the outer areas remain raised. The next flows preferentially filled the lower central areas. Since each large eruptive event(s) had a slightly different composition, the 'colors' of the flow would also follow that pattern. This produced a 'target like' appearance to certain of the maria, with the outer bands representing the older flows, and the inner bands the younger ones. One of the best examples of this is seen in Mare Serenitatis.

Second, lava subsidence produced stresses within the lava bed itself. As the lava in the center sank, it produced a compressive force where the thicker lava beds (on the sides of basin rings) met the thinner lava beds (on top of basin rings). These forces caused the lava to 'buckle' (perhaps due to blind thrust faulting) producing mare ridges over the basin rings. While there are several types of mare ridges (discussed below), these are identified by forming a ring within the mare, and are often associated with small peaks that represent the highest points of the flooded basin ring (e.g. Mons Piton). Third, this process of subsidence put stresses on the lava bed and in the bedrock underneath. This rock was already deeply fractured from the basin impacts, and these new downward and inward stresses caused some of those faults to activate. They opened up creating a series of 'grabens' (grabens occur where two parallel faults are 'pulled apart,' with the center section falling down; this produces a flat bottomed valley). On the Moon, these are specifically called 'arcuate rills'. These are only found around the edges of lava filled basins (the best examples are those around the Mare Humorum).

To this point we have discussed the usual schemes for lava filling of the basins, along with the formation of sinuous rilles, arcuate rilles, and mare ridges. Next we need to examine a few other features produced by the volcanic process.

The first of these are lunar volcanoes, which are called lunar 'domes' (not to be confused with volcanic domes on Earth, that have steep inclines). Lunar domes are smooth sided with low levels of incline. This is because lunar lava has such a low viscosity (as noted earlier). Most lunar domes are 5-20 km across, and often have a small pit crater at their summit. Note that a few lunar domes are steep sided (especially in the Marius Hills region), and thus offer evidence for changes in the lava's characteristics--such as cooling and lower rates of eruption.

The next features are called 'dark mantling' areas. These were formed by the process of 'fire fountaining'. When lava is in the Moon's mantle, it is under considerable pressure. As it rises to the surface this pressure falls off, allowing gasses trapped in the lava to escape (called degassing). These gasses--thought to be carbon monoxide or carbon dioxide--act as propellants, shooting the lava high above the lunar surface. There the lava cools as dark, glassy beads. Upon falling back to the lunar surface, these beads produce large patches of 'dark mantling'. The Apollo missions returned some of these glassy volcanic beads (the first ones identified were dubbed 'orange glass'). Visually, these patches appear as large, very dark areas with low crater counts, and occur around basin edges. Some excellent example can be seen around Mare Serenitatis.

Finally, there are two unusual lunar features produced by volcanism. Endogenous craters, such as Hyginus Rille, are interpreted as volcanic in origin, and probably formed as collapse features ('collapse pits'). Only a return to the Moon with further geologic work will fully resolve their origin. The other unusual feature is the 'dark halo' crater. Two types of 'dark halo' craters occur, and both are associated with volcanic products. In the type found in Crater Alphonsus, the halos are associated with rilles, and likely represent places of eruptive degassing with fire fountaining. Thus it is no surprise that their halos are reminiscent of dark mantling materials. The other type of dark halo crater occur where a bright ejecta blanket covers an older lava flow. When a recent impact occurs here, it pierces the thin veneer of the bright ejecta and unearths the darker lava flow beneath it. The ejecta from this crater will include those darker materials (an example of this was Crater Shorty, which was visited by the Apollo missions).

V TECTONIC PROCESSES

Tectonism refer to those forces that deform the lunar surface. These can be endogenous (such as thrust faults) or external (such as the creation of faults by impact events).

Crater Induced Processes

Impacts create a shock wave that propagates through the lunar surface. If of sufficient energy, these waves can induce faulting in the subsurface bedrock, can reactivate faults located elsewhere, and can induce local changes in semi-stable materials (e.g.: produce landslides in crater walls).

Examples of faulting in the subsurface layers are seen around a variety of basins. Such faulting can be radial (straight out from the basin's center) or concentric (around the basin's sides). Examples of concentric faulting include 'arcuate rills' (discussed above). They were only later 'activated' by the stresses of volcanism. Good examples of these are seen around Mare Humorum and Mare Serenitatis.

Faulting radial to a basin was also caused by the initial basin impact. Here the shock wave created faults in the subsurface rock at some distance from the basin. While initially covered by ejecta, these were later reactivated by other processes (such as volcanism). Examples of these include the Straight Wall, the Cauchy Rilles, and the rilles in Lacus Mortis.

Semistable material can be made unstable by a shock wave, creating a landslide in a crater. An example of this is the landslide in Copernicus, that was thought to be triggered by the Tyco impact.

Volcanism as a Tectonic Process

Other types of tectonic activity are found in association with volcanism. Lava, by coming from the mantle, is denser than the overlying crust. As noted earlier, this denser rock creates local stress fields in the underlying bedrock, producing mare ridges and arcuate rilles as the lava subsides. Here, however, we need to discuss the way other types of mare ridges form.

Mare ridges can also form over crater/basin rims. Such a situation occurs when a lava bed fills and covers a crater/basin rim. Now we have a shallow shelf of lava over the rim and a much deeper shelf where the rim falls off. The dense lava will subside more over the deep area and less over the shallow area, inducing local stress fields in the cooling, plastic lava. At such a point a mare ridge will form. Indeed, it is by examining mare ridges that we can tell where submerged basin rings exist! Two other processes that form mare ridges are a volcanic intrusion just under a shelf of cooling lava and activation of a fault due to lava loading, with slippage and subsequent lava deformation. Thus, mare ridges are the end result of a variety of tectonic processes.

Tidal Interactions

Tidal forces refer to the stresses induced by gravity between planetary bodies. For example, the Earth's tides are caused by the tidal stress induced by the Moon. As Earth is larger, it induces proportionally larger stresses on the Moon. In fact, the Earth exerts sufficient force to distort the Moon's shape, so that it is not perfectly round. Before the Moon was in locked rotation with respect to Earth (the same side of the Moon always faces the Earth), this distortion likely produced Moonquakes and subsurface faulting. However, this distortion also caused tidal slowing--the friction of these events slowed the Moon's spin. Eventually, the Moon locked into synchronous rotation. Interestingly, the Moon is also causing tidal slowing of the Earth, and our spin is ever so minutely slowing across time.

Now, if the Moon were completely locked into rotation with Earth, one might expect little seismic activity on the Moon. However, the seismic monitors left by the Apollo missions revealed small Moonquakes--Richter Scale 2-3. This is because the Moon still has some wobble (librations), which causes changing tidal stresses, resulting in these continuing Moonquakes (note that there are also thermal causes from secular cooling of the Moon).

Endogenous Forces

The only new endogenous tectonic force is that induced by the Moon's continued secular cooling. With this cooling comes shrinkage of the more plastic mantle. However, the rigid crust cannot shrink with it. This creates local stress fields, which are eventually released by thrust faulting (the crust on one side of the fault slides up diagonally). Similar faults exist on Mercury where the shrinkage has been even greater. While these faults are small, there are many of them, and they are continuing to form (according to experts like Dr. Alan Binder).

VI CONCLUSION

In the end, we find that the Moon's surface was formed through a diverse set of processes. While these are not as complex as the geologic forces on Earth (the Moon lacks plate tectonics, hydrological and aeolian forces, or a significant geochemical cycle), it is still a fascinating world. And precisely because it lacks this extra complexity, it allows us to study these simpler processes in isolation. While it might seem that we understand everything about the Moon, let me remind the reader that there are still many mysteries about the Moon that are unsolved, and that the simplified scheme presented here is bound to be exactly that--too simple! May we one day return to the Moon and learn more about our daughter world.

APPENDIX - NB. * = highly recommended for the reader who can’t buy them all! [PK]

BOOKS ON MAPPING THE MOON AND LUNAR NOMENCLATURE

Mapping and Naming the Moon : A History of Lunar Cartography and Nomenclature
by Ewen A. Whitaker (Author) (Paperback)
Other Editions: Hardcover | Paperback
Paperback: 264 pages; Dimensions (inches): 0.64 x 9.74 x 7.44
Publisher: Cambridge University Press; (December 11, 2003)
ISBN: 0521544149

Who's Who on the Moon: A Biographical Dictionary of Lunar Nomenclature
by Elijah E. Cocks, Josiah C. Cocks
Hardcover: 600 pages; Dimensions (inches): 1.75 x 9 x 6
Publisher: Tudor Publishers; (August 1995)
ISBN: 0936389273

LUNAR SCIENCE

*** To a Rocky Moon: A Geologist's History of Lunar Exploration**
by Don E. Wilhelms
Dimensions (inches): 1.50 x 9.25 x 6.25
Publisher: University of Arizona Press; (January 1994)
ASIN: 0816514437

Lunar Exploration: Human Pioneers and Robotic Surveyors
(Springer-Praxis Books in Astronomy and Space Sciences)
by Paolo Ulivi, David M Harland (Paperback - January 2004)
Paperback: 300 pages
Publisher: Springer Verlag; (January 2004)
ISBN: 185233746X

Moon Morphology: Interpretations Based on Lunar Orbiter Photography
by Peter H. Schultz
Publisher: Univ of Texas Press; (June 1976)
ASIN: 0292750366

The Lunar Rocks
by Brian Harold, Mason, William G. Melson
Textbook Binding: 179 pages
Publisher: John Wiley & Sons; (January 1970)
ASIN: 0471575305

Planetary Science: A Lunar Perspective
by Stuart Ross, Taylor
Hardcover
Publisher: Lunar & Planetary Institute; (March 1982)
ASIN: 0942862007

Lunar Science - A Post-Apollo View
by Taylor
Publisher: Pergamon Press; (October 1975)
ASIN: 0080182739

Moon Rocks and Minerals: Scientific Results of the Study of the Apollo 11 Lunar Samples With Preliminary Data on Apollo 12 Samples
by Alfred Abraham Levinson
Publisher: Pergamon Press; (December 1972)
ASIN: 0080166695

The Geologic History of the Moon
U.S. Geological Survey, Professional paper 1348
United States Government Printing Office
Washington, 1987

Handbook of Soviet Lunar & Planetary Exploration
by Nicholas L. Johnson (Hardcover - December 1979)
Hardcover: 276 pages
Publisher: Univelt; (December 1979)
ISBN: 0877031053 |

The Book of the Moon: A Lunar Introduction to Astronomy, Geology, Space Physics, and Space Travel
by Thomas A. Hockey
Paperback: 273 pages
Publisher: Simon & Schuster (Paper); (June 1986)
ASIN: 0130799637

21st Century Guide to the Clementine Lunar Mission and Images, Finding of Ice at South Pole, Albedo Maps
by World Spaceflight News (CD-ROM)
CD-ROM: 1456 pages
Publisher: Progressive Management; (January 27, 2003)
ISBN: 1592481361

Space Manufacturing 5: Engineering With Lunar and Asteroidal Materials
by Gregg Maryniak (Hardcover - June 1986)
Hardcover: 268 pages
Publisher: American Institute of Aeronautics and Astronautics; (June 1986)
ISBN: 093040307X

Lunar Sourcebook : A User's Guide to the Moon
by Grant Heiken (Editor), et al
Hardcover: 756 pages; Dimensions (inches): 1.69 x 10.33 x 7.44
Publisher: Cambridge University Press; (April 26, 1991)
ASIN: 0521334446

*** The Once and Future Moon**
by Paul Spudis
Smithsopnian Institution Press
Washington, 1996
ISBN 1-56098-634-4

What If the Moon Didn't Exist?: Voyages to Earths That Might Have Been
by Neil F. Comins
Paperback: 336 pages; Dimensions (in inches): 0.75 x 8.00 x 5.25
Publisher: Harperperennial Library; Reprint edition (January 1995)ASIN: 0060925566

BOOKS ON OBSERVING THE MOON

*** Welcome to the Moon: Twelve Lunar Expeditions for Small Telescopes**
by Robert Bruce Kelsey (Paperback - June 2003

Exploring the Moon Through Binoculars and Small Telescopes
by Ernest H. Cherrington, Paperback: 240 pages

*** The Modern Moon**
by Charles A. Wood
Available from Sky & Telescoepe
http://SkyandTelescope.com/shopatsky/

ATLASSES

*** Atlas of the Moon, by Antonin Rukl**
published by Kalmbach Books
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