L11 The selenologic column and time scale

< X-ray fluorescence, radiometric dating >

Arthur Koestler's wonderment was that "the book that nobody read" (Copernicus' book arguing for a Sun centered rather than an Earth centered planetary system) had any impact. It didn't, under Catholic censorship in Italy, but, Adrian Johns, who reviews Owen Gingerich's *An Annotated Census of Copernicus' De revolutionibus: (Nuremberg, 1543,* and *Basel, 1566),* 2002, writes:[2] "contra Koestler, Copernicus' book [saw publication due to the dedicated efforts of young Georg Joachim von Lauchen, also known as Rheticus (1514-1574), author of *First Account*. and][3] was not particularly rare—its print-run of 400-500 was quite usual for the period—and astronomers, at least, did indeed read it."[4] And a Guardian of the Truth and Traditional Wisdom, Martin Luther (1483-1546), leaped to contradict: "This fool wishes to reverse the entire science of astronomy."[5]

1608 Hans Lippershey invents a refracting telescope in Holland.
1609 Galileo improves telescope, observes and measures mountains on the Moon.
Johannes Kepler (1571-1630) publishes first two laws of planetary motion.
1610 Galileo discovers the moons of Jupiter.
—chronology from *Galileo's Daughter* by Dava Sobel, 1999.[6]

Finally ... I progressed so far that I constructed for myself an instrument so excellent that things seen through it appear about a thousand times larger and more than 30 times closer.
—Galileo, Jan. 7, 1610, *Sidereus Nuncius* [7] (usually translated as *The Starry Messenger* but historian Edward Rosen offers *Message from the Stars* as more apropos).[8] Would Moon be lost if Earth moved as Copernicus claimed? No, decided Galileo, for in the week of January 7, 1610, he had seen Jupiter (which everyone agreed moved) "herd" its orbiting moons.[2]

O telescope is not he who holds thee in his hand made king and lord of the works of God?
—Johannes Kepler, his words quoted by Richard Panek in *Seeing is Believing*, 1999.[9]

Hadean rocks, by the definition of that eon, no longer exist on Earth except for meteorites and some *Apollo*-returned lunar rocks (Moon rocks).

Earth can gravitationally hold an atmosphere and a hydrosphere. Large meteorites explode on impact with Earth. Boulder-sized fast moving meteors are crushed by atmosphere pressure but the slow moving, cushioned in their fall, land as meteorites. Small stony, iron, and *all* cometary-ice, meteors that enter the atmosphere burn up as shooting stars. Moon has no shielding atmosphere. All meteors, of what ever size, on impact with Moon, explode.[10] Earth-based telescopic observations long ago detailed craters and rock formations on Moon's nearside (***Figure L11.1***). Orbital photographs show the same (craters fewer) exist on Moon's farside (which continually faces away from Earth).

Moon's crustal rocks have everywhere been meteorite impacted, but not obliterated, and to a minor degree are chemically altered where they have been, or are, exposed to solar wind (accumulating ore-potentials as ^{3}He)[11] and cosmic ray flux. Mechanical weathering produces, by micrometeorite impact (micrometeorite "gardening") the "lunar soil" (the thin, loose, surface layer, compactable to a depth of less than an inch as was shown by the astronaut's footprints) and by meteorite impact, the underlying "lunar regolith," which is a mixture of fragmental breccia and packed powdery material that contains glass droplets and shards with the compositions of lunar rocks and impactors. A consequence of micrometeorite gardening is that from Earth-based observations, large Moon craters can be sorted into two broad age-categories: young, starkly outlined, craters (as Copernicus, with high albedo ejector aprons and associated secondary-impact ejecta craters and rays); and, old, partly obliterated, craters (as Eratosthenes, with slumped rims and no clearly visible rays). The outlines of the old craters are also typically deformed by small scale fault offsets. The principle of crosscutting relationships can establish relative ages of craters that intersect. That local age information can be extend regionally, by applying the principle of superposition to crater ejecta blankets and rays.

Samples of lunar rocks totaling 700 kg have been returned from the sites of the Apollo space mission's six landings between 1969 and 1972 on Moon's surface. These were loose rocks (ejecta from impact sites). Petrology finds lunar rocks to be igneous and sodium poor relative to similar Earth rocks. Their variety (all of them are breccias) can be matched with lunar formations of different albedo (***Footnote L11.1***) as seen from Earth. X-ray fluorescence data collected by orbital remote sensing allows mapping of surface-rock compositions of the whole of Moon. Radiometric dating of *Apollo*-returned lunar rocks has added a time scale to the selenologic column.

For its last two and a half billion years, Moon has been dead as an igneous body. During that time, meteorite (asteroid and comet) impacts of all sizes (but smaller than planetesimal) continued to occur.

Moon's shadings November 30 and at four other times as phases changed during December, 1609, were cartooned by Galileo who interpreted the shifting shadows to mean the surface is "not robed in a smooth and polished surface [of its quintessence, which either mirrors Earth's features back to us or, in the preferred explanation, is of varying density (?)], but is rough and uneven." Single mountains (craters) were first named in a 1645 map by Michael Florent van Langren. Giovanni Battista Riccioli in his *Selenographia*, 1651, misleadingly labeled sunlit-grayish smooth (little cratered) areas "maria" (seas) and sunlit-whitish rough (much cratered) areas "terrae" (continents).[12]

The maria formation, where it exists, covers over the terrae formation. By inference, using the principle of superposition, it is the younger formation. Also, as lunar craters are impact craters (not an assumption since *Apollo* photographs nixed middle-crater "volcanic"peaks earlier sketched by V. A. Firsoff),[13] the younger age of the maria formation is corroborated by the terrae formation being fifteen times more cratered (in the count of craters 10 kilometers or larger in diameter).

Plate tectonics has not been operational on Moon. Evidence for it would be trenches, composite (andesite) volcanoes, rise-ridge systems, rifts and transform faults. Moon's landscape shows no such features. On Earth, the rock cycle, which includes plate tectonics, has erased the first half-billion years of Earth's stony history. A comparable rock cycle never did operate on Moon.

Crater counting, and knowing the relative age of the Copernican and the Eratosthenian craters and the absolute ages of the maria and the terra, finds that the flux and size range of infalling material (meteorites, planetesimals) has decreased exponentially since Moon's rock record began.

Unlike Earth, Moon's earliest history is yet recorded in its rocks. Knowledge of the origin of lunar rocks of Hadean age can shed light therefore on aspects of the first stages of the formation of a stony planet. ❑

Footnote L11.1 Before the serendipitous invention of the telescope, ca. 1600, by spectacle-maker Hans Lippershev, and Galeleo's soon manufacture and use of one, Moon's different shadings were thought to be reflections of Earth in the mirror of its body made of quintessence (dodecahedrons). That element was held by early Greek philosophers to constitute heavenly bodies, which are perfect in their purity in contrast to our sublunary (imperfect) world composed of the four combining Platonic elements of Anaximenes (coopted from Empedocles who had differed from other 6th century BCE declarations by Thales that everything was made of water for demonstrably under some conditions does it not form a liquid, under others a solid as ice or snow, and under others a gas as steam or vapor?) that are: earth (cubes), air (tetrahedrons), fire (octahedrons), and water (icosahedrons). As these accounted for the world, much consternation, for ancient Greek philosophers had been their discovery of yet another regular polyhedra (***Figure L11.2***), the dodecahedron. This dangerous knowledge was a long kept secret for whereas the other four 'elements' accounted for the mundane (and this still taught, 2000 years later, in 19th century American schools!) it was surely the immutable element of which, Aristotle had claimed, the heavenly bodies are made. There are no other regular polyhedra. **Leonhard Euler** (1707-1783) (blind in his right eye) found this to be so in 1752 when he (cont.)