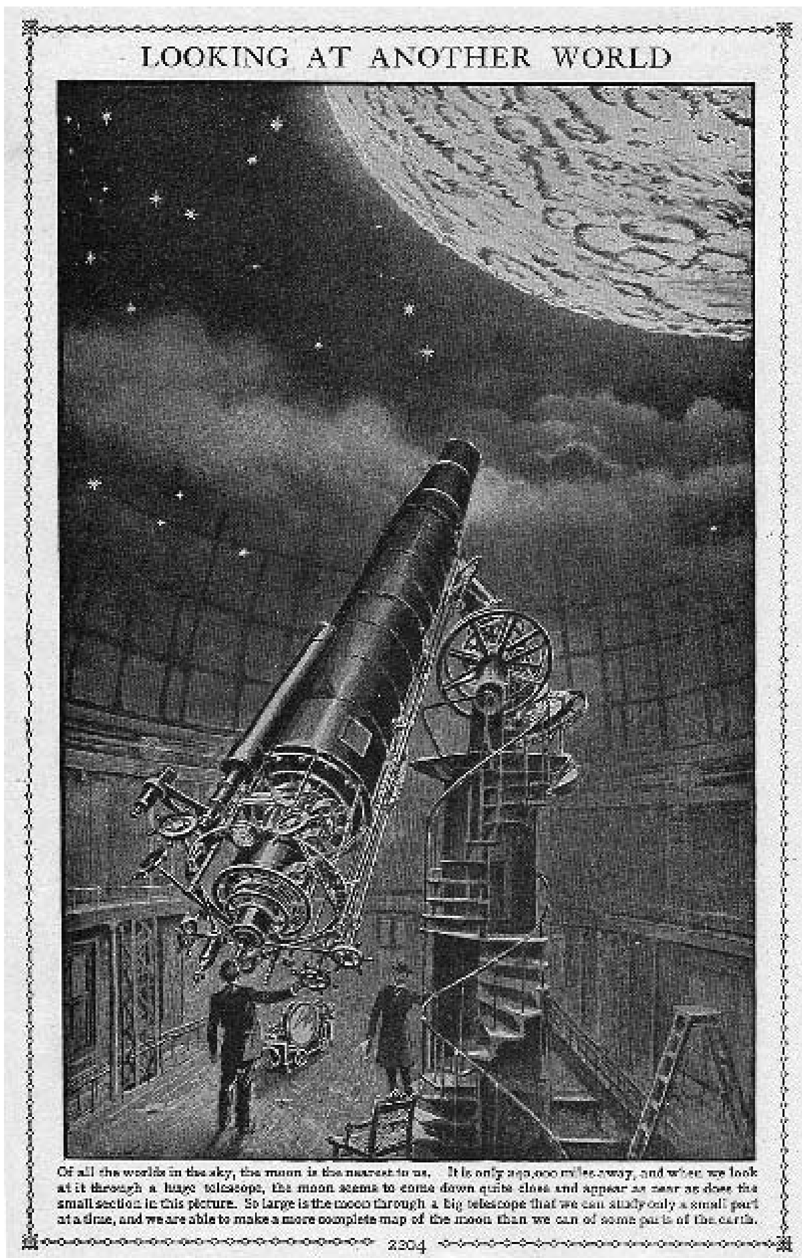
DEVOTED TO THE STUDY OF EARTH'S MOON
VOL. 25 NO. 4 WINTER 2006

SELENOLOGY

The Journal of The American Lunar Society



Selenology

Vol. 25 No. 4 - Winter 2006

The official journal of the American Lunar Society, an organization devoted to the observation and discovery of the earth's moon

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Illustration from an 1899 encyclopedia showing the Yerkes telescope aimed at the Moon.

Selenology, Vol. 25 No. 4, Winter 2006. A publication of the American Lunar Society.
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WHY THE LUNAR VOLCANIC EJECTA THEORY OF TEKTITES LIVES ON

By Hal Povenmire

Abstract

The origin of tektites has been controversial for about 160 years. In the early 1960's, an accepted theory was that they were the result of lunar volcanic ejecta. When astronauts landed on the moon in 1969, this theory lost popularity because although it was expected that large quantities of tektites would be found on the moon, they were not. As a result, the terrestrial impact theory became popular—not through new discoveries of physics or math but more by popular acclamation. This implied that a large asteroid or comet impacted the Earth and splashed melted surface materials into space, which reentered as tektites. While this is the simple and popular theory, it has severe flaws. First, Stokes's Law clearly states that ejecting tektites by terrestrial impact is highly improbable with our current knowledge of impact physics and glass making. Second, a crater for the Australasian tektite strewn field has not been found. Third, the velocity needed to produce the flanged Australites is much more compatible with a lunar origin than a terrestrial origin. Regardless of which theory is correct, there are approximately 50 points which must be answered if the lunar volcanic ejecta theory of tektite origin is to be rejected.

Now is the time for a complete reevaluation of the lunar volcanic ejecta theory.

Introduction

Tektites have been known since Cro-Magnon Man lived in the caves of Altimira and Lascaux approximately 30,000 years ago. Henry Faul described tektites as the most frustrating objects on the Earth essentially defying logic. Many theories have been devised to explain them and their origin. Most of these are now just a humorous note of history. All scientists are in agreement that tektites are a product of the Earth-Moon system but that is where the agreement ends. Harvey Nininger in the late 1930's stated that they probably came from the moon. Ernst Opik about the same time showed that approximately one meteorite in five hundred on the surface of the Earth probably came from the moon.

In the late 1950's, John A. O'Keefe, of NASA-Goddard, began his career-long research on the origin of tektites. Later, Edward Chao stated that he believed tektites were lunar impact ejecta. After astronauts went to the moon in 1969, the majority of planetary scientists abandoned the lunar origin of tektites for the terrestrial impact melt theory of origin. Charles Schnetzler made his famous statement that, "The lunar origin of tektites died on July 20, 1969 due to a massive overdose of lunar evidence." The terrestrial impact origin is today the most accepted theory by a factor of approximately 99 percent.

In the meantime, John O'Keefe revised his theory from having the origin of tektites in lunar meteorite impact ejecta to lunar volcanic ejecta.

The Russian astrogeologist, Emil P. Izokh, agreed that tektites are extraterrestrial but did not believe they came from either the Earth or the moon.

In summary, no one really knows exactly the origin of tektites. NASA geologist, Paul Lowman, summarized this when he wrote an abstract for the American Geophysical Union in 1997 stating, "If tektites didn't exist and the physicist were asked if they could exist much of our knowledge of impact physics and glass making would indicate that they would be impossible to form."

The purpose of this paper is to call attention to the unanswered points of the unpopular theory of the origin of tektites, the lunar volcanic ejecta theory. If these points can be answered, then this theory will die. If not, then it is time to reevaluate this theory and all of the other theories. It is not a matter of one theory winning or losing, the ultimate goal is to find the truth of the origin of these enigmatic objects. Today, we are a lot closer to the final answers. Each year, more papers and abstracts are written giving more physical knowledge about tektites. What are noticeably absent are papers addressing the problems of their origins. This researcher is convinced that much more research is needed to fully understand the physics of the origin of tektite formation.

Discussion Of Theories For Origin of Tektites

Tektites are small, glassy, natural, meteorite-like objects of uncertain origin found over the Earth and which have made at least one trip through the atmosphere. Tektites are found in groups, have similar characteristics, and the areas where they fell are called strewn fields.

All planetary scientists are in agreement that tektites originated within the Earth-Moon system. This is known because of the small amount of the cosmogenic isotope aluminum-26 present. There are two major theories as to the origin of tektites (1).

The most popular and widely accepted theory is that tektites are the result of terrestrial impact. More clearly stated, they are the result of a comet or asteroid impact on the Earth which threw material out into space, and the material reentered as tektites. However, this theory does not even state whether the impactor is a comet or asteroid. This is the simplest theory as it does not involve the moon. We know that impact features are normal phenomena on the Earth. This is the theory that is accepted by approximately 99 percent of the planetary scientists.

The second theory is that tektites are the result of lunar volcanic ejecta. Obsidian is volcanic glass which flows from terrestrial volcanoes. This means that volcanoes on the moon ejected “lunar obsidian,” which escaped the lunar gravity and fell onto the Earth as tektites. This theory was advocated by Dr.. John A. O’Keefe for about 40 years (2).

Both theories are unproven. Some of their problems are minor, but others are severe.

When there is a crater and a tektite strewn field which are close in proximity and of the same age, the crater is called a “connate crater.” However, they may or may not be related to each other.

The number of known terrestrial impact craters and astroblemes is about 200. This means that 98 percent of impact craters have no associated tektite strewn fields. The number of new tektite strewn fields has now more than doubled to about 13. However, the number of connate craters has remained about the same at 4. Perhaps the “connate” craters are just a coincidence unless made by large glassy bodies, probably from the moon.

When a large comet or asteroid impacts the Earth, large amounts of kinetic energy are released. Large impacts may cause biological mass extinctions. When the Chicxulub impact occurred 65 million years ago, the equivalent of approximately 100 million megatons of TNT energy was released. This caused the extermination of the dinosaurs, ammonites and about 65 percent of all life on the Earth. While the iridium debris layer covered the Earth, it did not produce a major tektite event. This created the Cretaceous-Tertiary or K-T Boundary.

Approximately 35 million years ago two impacts occurred. These were the 90 km Chesapeake Bay crater and the 100 km Popigai Crater in Siberia which nearly coincided with or was the cause of the Eocene-Oligocene Boundary.

The most massive tektite event occurred 0.78 million years ago, covering about 20 percent of the Earth’s surface. This Australasian tektite event apparently did not cause any mass extinction or even a crater. At approximately the same time and probably related to this event was the Brunhes-Matuyama geomagnetic reversal of the Earth’s magnetic field. We know from the skeletal remains of Java and Peking Man (Homo erectus) that humans were present and apparently doing well in China, Indochina and Indonesia when this event occurred. This represents a paradox which needs to be answered.

If tektites are formed by terrestrial impact, then there must be a massive crater for each of these falls. Craters have been found for the falls of 65 m.y., 35 m.y., 15 m.y. and 1.1 m.y. before present. The problem is that the most recent and largest fall, that of the Australasian fall which is only 0.78 million years before present, does not have any known crater. This crater should be found in the Indochina area and have a diameter of approximately 110 ± km.

All of the land expeditions to Southeast Asia to hunt for the Australasian Crater have come up empty. Lake Tonle Sap on the Mekong River is the right size and location. The problem is that it shows absolutely no evidence of impact origin.

Some scientists have believed that the crater may exist beneath the South China Sea. However, Robert Dietz has shown that even 9 meters of water

Tektite Types	**Age in M.Y.**
1. Early Precambrian macrokrystites	2,600.0
2. Upper Devonian microtektites	365.0
3. Libyan Desert Glass	28.5
4. Urengoites	23.6
5. High Na/K australites	10.2
6. ODPS 1169 South Tasman Sea GBMT, OPD189 12.1	4.6
7. South Ural Glass	6.2
8. Tikal, Guatemala tektites	0.8
9. Australasian tektites	0.78

Table 1: tabulation of tektite events and their ages.

would be sufficient to prevent the formation of tektites from a terrestrial impact (3). In spite of a great deal of field work, no crater has yet been found and that is a serious problem.

If tektites are formed by major impact crater events, where are the craters for the other tektite strewn fields, or the strewn fields for the larger known impact craters? There are at least nine tektite strewn fields where no crater is known. It is reasonable to assume that evidence of a major impact crater would survive longer than tektite glass, which is slightly soluble in fresh water. Shatter cones, breccia and coesite are stable and will last for millions of years undisturbed. Table 1 gives a tabulation of these other tektite events and their ages in millions of years.

The Libyan Desert Glass (LDG) has presented a situation which now may be resolved. This 6600 square km strewn field of homogenized, high silica, tektite-like glass has been included with the tektites. The problem is that it shows no splash form tektites and much more closely resembles the Muong Nong-type or layered tektites. The LDG composition is similar to the local Nubian Sandstone. There are other problems including evidence of being shocked and containing abnormally large amounts of iridium and osmium. No reasonable crater could be found. In March 2006, Farouk El Baz found images of a 31 km diameter complex crater 100 km west of the LDG strewn field. He has named it Kebira which means large. This is probably the parent crater. The meteoroid was probably a low density asteroid or comet which exploded above the Earth's surface. The crater age has been confirmed by fission track dating, so the LDG should be considered impact glass and not tektite glass.

The Darwin Glass is another cosmic related glass which should be reevaluated. South of Australia on the island of Tasmania, southeast of Queenstown is a kilometer-sized crater. This crater produced large amounts of gray-green glass which resembled layered tektite-like glass. Darwin Glass was classed with the tektites because it had an age very close to the 780,000 year BP age of the Australasian tektite event and was located within this strewn field. The most current thinking is that Darwin Glass is not related to the Australasian tektites and should therefore be regarded as an impact glass.

Let us look at this paradox of contending hypotheses conditions: if impact events produce tektites, why are tektites not found in or near most of the 200 known impact craters on the Earth? Using the same logic, then tektites should be found on the moon and Mars from impacts.

As an example, let us assume that the 35 million year old, 90 ± km Chesapeake Bay Crater is the source of the North American tektites and microtektites. Why are there no tektites found for the 100 km Popigai Crater in Siberia of the same age? (4).

The extremely well-preserved El'gygytgyn Crater, also in Siberia, is 18 km in diameter and 3.6 million years in age. This is comparable in size and age with the Ries Kessel in Germany and Bosumtwi in Ghana, Africa. The surface material is composed of rhyodacite tuff, ignimbrite, with rhyolite, andesite tuff and basalt. There is more than adequate SiO_2, if impacts do create tektites. There have been glassy bombs and shock metamorphosed rocks but no tektites. Is anyone looking for tektites from these craters?

It should be noted that the craters which are supposed to be the parent craters for some of the tektite events have geological compositional problems associated with them. The ages match fairly well; however, the geochemistry does not. The composition of the tektites and the basement rocks of the craters is a poor match for the Ries Crater in Germany and the associated moldavites and the Bosumtwi Crater in Ghana, and the associated Ivory Coast tektites. With the Ries Crater and the moldavites, even the isotopes do not match. It should be noted that tektites have not been found within 250 km of either of these craters (4).

Christian Koeberl believes that tektites can be formed from impact craters where the comet or asteroid impacted at an oblique angle to the surface of the Earth. This still does not address the Stokes's Law paradox.

The planetary scientist, Billy P. Glass, has shown that the basement geology of the Chesapeake Bay Crater is uniquely compatible with the chemistry of the North American tektites. No one seriously doubts that the Chesapeake Bay Crater is the result of a massive impact of a comet, asteroid or a large glass lunar volcanic ejection. In the Georgia tektite strewn field, shocked quartz has been found in the strata in which the tektites should be found. It is important to note that no tektite fragments or microtektites have been found associated with this shocked quartz. This still leaves us with the problem of Stokes's Law and that paradox.

Muong Nong-type or layered tektites are thought to be found near the source crater. Why have the few Muong Nong North American tektites been found in the georgiaite and bediasite strewn fields and none near the Chesapeake Bay Crater? The Muong Nong moldavites are found only in southern Bohemia, more than 250 km from the Ries Crater.

There are other minor problems. Why did the Chicxulub Crater produce only very small pieces of tektite-like glass? We have massive amounts of tektite glass spread over more than 20 percent of the Earth's surface from the Australasian tektite event and yet we have not found the crater. The Ries Crater is about 25 times older and 20 times smaller than the alleged Australasian Crater, and yet we have not found the latter crater. This simply does not make sense. The Zhamanshin Crater in Siberia is probably not even a source of tektite glass. Recently, the planetary scientist, Christian Koeberl, has declared that the four types of glass found at Zhamanshin are simply impact glass. They are not of tektite origin, water content or composition.

There are four small, recent impact craters which may be different than normal meteorite craters. These are Zhamanshin, Aouelloul, Darwin and Lonar. In each case there is glass associated with them which does not appear to be normal impact glass.

The Aouelloul Crater in Mauritania, Africa is approximately 300 meters in diameter and 36 meters deep. It is fairly recent and well preserved with an estimated age of 3.1-3.5 million years. On the east side, the well-preserved rim has large quantities of glass. This glass seems to be unlike typical impact glass in that it shows little terrestrial contamination and appears to be homogenized. The basement rock is Ordovician sandstone. The geochemistry of the glass and the sandstone do not match. There are no known meteorites found in the area nor does the glass match any meteorite contamination. It was proposed by J.A. O'Keefe that the impacting body was a large chunk of tektite-like glass. This might be an obsidian-like plug from a lunar volcano. The geochemistry does match that of a tektite-like glass.

When astronauts arrived at the moon on Apollo 11, it was expected they would find vast quantities of tektites. This did not happen. However, when the electron microprobe examined some of the small volcanic spherules which make up the regolith of the moon, a much different situation was found. These spherules were not only similar or nearly identical to the composition of tektites, they were indistinguishable.

Lechatelierite is a natural silica glass formed from quartz at high temperature and pressure. It is found in all tektites. By definition, a tektite must contain lechatelierite. Lachatelierite is also found in some volcanic glasses. This is not surprising if we consider tektites to be of volcanic origin.

Is Our Moon Volcanically Active?

One problem is that there is no established definition regarding what constitutes volcanism. No one would argue that Krakatoa with massive explosive gas, dust, and magma is not volcanic. But is a volcano which emits gases and dust but no magma still volcanic? What about a fissure which emits hot volcanic gases but with no volcano present?

On the North Island of New Zealand, there is a geothermal area called Rotorua. As one walks along the park trails, small fissures and fumaroles (often only minutes old) open and emit hot steam and gases. The composition of these gases are identical to confirmed volcanic gases. Are these fumaroles volcanic? From the Earth, a massive volcanic eruption on the moon could be easily confirmed. However, a lesser volcanic gas emission would be difficult to confirm.

What part of the moon contains areas that would be conducive to producing lunar volcanic ejecta? John O'Keefe thought that the craters around Mare Smythii were good candidates. Lunar volcanic craters look different from impact craters. Lunar volcanoes are generally low relief features like dome or shield volcanoes on Earth. Mauna Loa in Hawaii is a good example of a shield volcano. Some of the lunar volcanoes have a diameter of 60 km. There are lists available of lunar volcanic craters which are easily visible with amateur-sized telescopes (5). Shield volcanoes on both the moon and Earth have very fluid rather than viscous lava. Lava comes in two forms. Highly fluid lava is basaltic in composition. It is lower in silica and is associated with lava fountains and quiet volcanoes. The second type of lava is associated with explosive volcanoes. This lava is very viscous and high in silica. Obsidian volcanic bombs and pumice are associated with this type of lava. This silica-rich lava is most similar to tektite composition.

Two Apollo lunar samples must be mentioned from Apollos 12 and 14. The specimen (12013) weighed 82.0 g and had a vein of granitic composition of high silica content. An entire issue of *Earth and Planetary Science Letters* was devoted to its analysis (6).

The second specimen (14425), was a small sphere of volcanic glass about the size of a pea. When analyzed under the electron microprobe, it was essentially identical to some Australasian tektites but with a silica content of about 47%. This is very low for a tektite. However, this led John O'Keefe to state, "If this specimen had been found on the Antarctic ice shelf instead of Fra Mauro on the moon, it would be declared a tektite."

One of the problems for the lunar volcanic origin of tektites is that most of the moon's surface is composed of materials that are too low in SiO_2. Some of the Apollo 12 and 14 mission samples had SiO_2 content of approximately 64%, but these are not representative of the surface of the moon. However, this does bridge the SiO_2 gap as the lowest accepted SiO_2 values of tektites are about 62%. An important point is that tektites may come from deep in the moon's interior where the SiO_2 content is much higher (as with terrestrial obsidian).

An inherent difference in the Earth and the moon is that most seismic and volcanic events occur near the surface of the Earth. A typical depth of a terrestrial volcano or seismic event might be approximately 30 km. On the moon, seismic and volcanic events originate much deeper, perhaps 600 km. On both the Earth and the moon, when a volcanic or seismic event occurs, radon gas is given off. Apollos 15 and 16 had alpha particle spectrometers on them. Both missions recorded radon and polonium gas over the Aristarchus plateau and a few other sites. It is not known whether this was from a seismic or volcanic event. The fact that Aristarchus has been the source of many suspected pyroclastic and volcanic Lunar Transient Events (LTE) cannot be ignored.

The proponents of the terrestrial impact theory argue that it would take molecular hydrogen instead of steam to eject tektites from lunar volcanoes. We know that molecular hydrogen exists on the moon from two sources. The spectrum of the November 3-4, 1958 pyroclastic volcanic emission on the moon was recorded by N.A. Kozyrev and from the Lunar Prospector spacecraft of January 6, 1998. The Lunar Prospector mission clearly showed that there is significant hydrogen in the form of water ice at the

STOKES'S LAW AND ITS APPLICATION

About the time of the American Civil War, English physicist George Stokes attempted to quantify the activity of bubbles rising in a liquid. Glass is a liquid and therefore obeys this law. Stokes determined that three major factors were linked. One, the higher the temperature, the faster the bubble will rise. Two, the lower the atmospheric pressure, the faster the bubble will rise. Three, the greater the viscosity, the slower the bubble will rise. Thus, the general equation for Stokes's Law.

$V = (d-do)\ g\ r^2/3k$ where
1. v = velocity of bubble rise
2. d = density of the glass
3. do = density of the gas in the bubble
4. g = effective value of local gravity
5. r = radius of the bubble
6. k = viscosity

We use 1/3 rather than the familiar 2/9 because we have a gas bubble in a liquid rather than a solid sphere in a liquid.

When these three factors are applied to obsidian, a terrestrial volcanic glass, it explains why obsidian is essentially bubble free, and very homogeneous. If tektites are lunar volcanic obsidian ejected from the moon after forming in an anhydrous crucible, it would also explain their similar characteristics including their profound absence of water.

When a glass is heated slightly past the melting point but not past the temperature where the volatiles will boil off, this allows the bubbles to rise. If glass is held at that temperature, it will completely clear of bubbles in a period of time defined by Stokes's Law. (In practice, this is often 18 hours at approximately 1000 degrees C.) This only occurs in three situations. One, artificial glass. Two, obsidian in a terrestrial volcano. Three, in tektites. Glass which has undergone this process is called "fined."

It can quickly be observed, that an impact of a comet or asteroid on the surface of the Earth will quickly cause an intense spike of temperature which will quickly melt the surface material; but just as quickly, the temperature will drop and the impact glass will freeze, completely ruling out any fining and homogenization. This impact glass will also be completely contaminated by the surface material. An impact fails to produce a fined glass by a time factor of between 10,000 and 100,000. This provides very clear reason for rejecting the terrestrial impact theory for the origin of tektites.

lunar poles. The original source of this water was probably volcanic rather than the impact of comets.

On November 29, 1993 there was a total eclipse of the moon. During the eclipse it was discovered that the moon has a plasma sodium atmosphere and tail. The atmosphere was more than twice the diameter of the moon and the tail is 22,000 km long. This is likely the result of volcanic activity. It is believed that a similar situation exists on Jupiter's moon Io, and on Mercury.

In the early days, it was questioned as to whether lunar materials could reach the Earth by natural means. Ernst Opik had predicted in the 1930's that one out of every 500 meteorites found on the Earth should be of lunar origin. However, after extensive searches, none were found. About 1964, there was a NASA Project called Moon Harvest which was initiated and monitored by J.A. O'Keefe. Any rocks found in the rock-free areas of the Plains states were requested to be sent to NASA to see if they were of lunar origin. None were definitely confirmed and this was considered negative evidence of the lunar origin of tektites. During the Apollo era, 382 kg of lunar rocks were recovered and brought back to Houston, Texas for analysis. About 13 years later, a small meteorite found in Antarctica named Allan Hills 81005 was found to be of lunar origin. Since that time, more than 100 other lunar meteorites from about 44 sites and weighing approximately 31.0 kg have been recognized in Antarctica, Australia, the

Arabian Peninsula, and Africa. Most of the lunar meteorites weighed less than 1.0 kg. In 2005, a 13.5 kg specimen, (Kalahari 009), was announced in southern Africa. Currently the rate of find of new lunar meteorites is more than 2.0 kg per year. It should be noted that these are lunar meteorites, not tektites. The highest SiO_2 content of these lunar meteorites is approximately 46%. Two Apollo 15 specimens (15426 and 15427) had light green clasts of picritic (Mg-rich) basalt with a SiO_2 content of 46%. In 2005, a 115 g anorthositic highland breccia lunar meteorite was found in Oman on the Arabian Peninsula. This meteorite is known as Dhofar 1180. In it were found several one-cubic-millimeter green glass clasts or inclusions. These are too large for silica melt inclusions. They appear similar to bottle-green tektites. The electron microprobe analysis of these clasts may determine which theory of tektite origin is correct. The lowest SiO_2 content of a tektite is approximately 62% and the highest is more than 82%. It might also be noted that no glass meteorites have been found in Antarctica. These were the result of meteorite impacts on the lunar surface with the lunar meteorites being ejected into space and falling to the Earth. The lunar escape velocity is 2.37 km per second. It has been calculated that a one kg meteorite hitting the moon can eject 4 kg of lunar material into space and some of this would reach the Earth.

In 1992, a 300 meter diameter asteroid in a near circular orbit similar to the Earth's orbit was discovered by the Spacewatch Telescope. It was named 1992 JD. On March 13, 1994, Jim Scotti, using the same Spacewatch Telescope on Kitt Peak, found a fast moving asteroid that had passed only about 160,000 km from the Earth. This small asteroid had a diameter of only about 15 meters and was named 1994 ES1. It is now realized that about 60 near Earth asteroids (NEA's) have similar orbits. None of these asteroids have received a number or name at this time. This group of asteroids has been called the Arjuna or Apohele Class, but this is not an accepted name. This type of asteroid is exactly what we would expect from either a lunar asteroidal impact or lunar volcanic eruption. These are asteroids or meteorites which may eventually impact the Earth. We also know that if we have found some objects like these, there are many more which we haven't yet discovered. It is of the greatest importance to get a reflectance spectra of these objects so we can determine their composition and origin.

On the early evening of February 9, 1913, a remarkable procession of meteoritic fireballs started over northern Canada near Regina, Saskatchewan and proceeded to the southeast over the northeastern United States. They then crossed over water near Bermuda but were still visible past the eastern tip of South America, Cape Sao Rogue. This has been named the Cyrillid Meteor Procession. This distance is about one quarter of the way around the Earth. This type of path is not compatible with the entry of a typical small fireball but is entirely consistent with a captured small asteroid which is in a decaying orbit around the Earth.

This event was studied intensively by Dr. C. A. Chant of the University of Toronto who collected newspaper reports and did some analysis. This path became known as Chant's Trace. This work was picked up by Dr. John A. O'Keefe who did the orbital analysis. He was able to determine that this object had an inclination or azimuth of approximately 120° and the perigee was over New York and Pennsylvania. The perigee occurred at approximately 9:05 P.M. E.S.T. At perigee is where the breakup of the object occurs. The altitude over Pennsylvania was approximately 80 km and several minutes after the passage, low rumbling sonic booms were heard. From the low apparent velocity, O'Keefe concluded that it was a captured Near Earth Asteroid. The type of asteroid which could be captured is one which is in a similar orbit to that of the Earth and was most likely ejected from the moon.

These are the orbits from which lunar meteorites come. The Campo del Cielo iron meteorite strewn field in Argentine is also believed to have been from a captured earth satellite due to the long strewn field and evidence of a second orbital pass.

On the Earth, moon and moons of some other planets are long strings or chains of craters. These could be caused by an asteroid or comet impacting at a low angle of incidence or a satellite decaying out of orbit. One of the most outstanding of these is the 38th parallel Chain of Craters across the states of Kansas, Missouri and Illinois extending a distance of approximately 700 km. There are at least 8 astroblemes which may have resulted from a large decaying near earth asteroid or satellite in Earth orbit that fragmented as it entered the Earth's atmosphere. This near earth asteroid or satellite could have had a lunar origin. This chain of craters is under intense investigation at the present time.

When an earth satellite is launched into an eccentric orbit, the decay process starts due to dynamic pressures at perigee and the strewn field is long and narrow.

The area around Port Campbell, Australia is noted for the large number of flanged Australasian tektites. The late Prof. Dean R. Chapman did significant work with the wind tunnels of NASA-Ames to show that the entry velocity (about 11 km/s) of the flanged tektites was uniquely compatible with a lunar source and not compatible with a terrestrial source like Indochina. He also advocated that the lunar crater Tycho, an 86 km diameter impact crater with two central peaks having summit craters (likely from later volcanism) and Rosse Ray were the direct source of the Australasian tektites. This work was independently confirmed at NASA-Marshall. This work stood unchallenged for many years and was strong support for the lunar origin of tektites. On his deathbed, he revised his work and opinion, indicating that it was strongly supportive of the lunar origin and weakly supportive of a terrestrial origin. The important point is that it is most strongly supportive of a lunar origin.

Small meteorites high in SiO_2 have also shown the flange phenomena. In 1968, a small 4.617g, H chondrite with a fusion crust and shaped like a flanged tektite button was found in Australia. It is listed in the *Catalogue of Meteorites* as "Nallah." In 1991, a small H4 flanged button shaped chondrite was found at the Rio Curarto Meteorite Craters in Argentina. This shows that any high silica entry body can develop a flange during meteoritic velocity entry and is not limited to tektites.

One of the arguments that the proponents of the terrestrial impact theory give is that the ratio of beryllium-10 / aluminum-26 isotopes is not what we would expect from a lunar origin. Exposure to primary cosmic rays in meteorites and lunar samples in space produces a larger amount of aluminum-26 than beryllium-10. In the case of tektites, there seems to be a higher ratio of beryllium-10 to aluminum-26. The total beryllium-10 to aluminum-26 is dependent on the amount of cover while on the moon. If 5 to 10 meters of cover existed, this could account for the discrepancy. Part of this discrepancy may also be due to problems of accurate measurement. While this is an annoying problem and deserves attention, it is certainly not a fatal problem.

There is another reliable concept: that the age of a tektite can be determined by measuring the ratio of its isotopes of potassium and argon. When the tektite glass is in a thoroughly molten state, the argon gas is driven off. The age is determined by the fact that potassium-40 decays to argon-40 at a known rate. That we can determine consistent ages indicates that this process works. In a volcano, a tektite or obsidian is heated thoroughly so that it is cleared of argon. For a speedier result, it is necessary that the tektite be heated to 2000 degrees C. for 30 minutes. This would cause the tektite to marginally vaporize. But even this would still be far short of the time necessary for the tektite to be cleared of its argon. Consequently, an impact which would last for only a finite number of seconds, will not remove all the argon.

The strongest evidence comes from basic physics. Stokes's Law is usually presented at about sophomore college level physics. Stokes's Law deals with the way that a bubble rises in a liquid. The rate of rise is directly proportional to the heat and pressure and inversely proportional to the viscosity of the liquid. Glass is a liquid and follows these laws (See Appendix I). Glass forms in two ways. The first is like that of an impact or shock. When sand is subjected to an intense thermal shock, it forms a crude glass. This can occur when lightning, an artillery shell, or a meteorite impacts sand. The temperature rises very quickly, melting the sand, which then freezes very quickly. This does not allow any "fining," or homogenization to occur and is referred to as shock or impact glass.

A nuclear explosion has many similarities to a cosmic impact event. Nuclear explosions produce small glass spherules, but these more closely resemble impact glasses than tektites. Most of these spherules are very small (about 100 microns), have more water content than a tektite, and are about as homogeneous as the most primitive tektites. Tektites have about .001% water, the driest terrestrial volcanic glasses have about 1.0% water and originate from the silica-rich volcanoes.

The second form of glass is that of "fined" or homogenized glass. This requires careful heating in a crucible over an extended period of time to allow the bubbles to rise and for the glass to become homogenized. This type of glass is found in three situations: artificial glass, obsidian from a terrestrial volcano, and in tektites.

Professional glass makers like Corning make extremely high quality glass. This process must obey Stokes's Law and cannot be hurried. Quartz melts at 1470 degrees C. The sand is heated and held at a high but stable temperature (about 1750 degrees C) for about 20 hours. Temperatures of about 1800 degrees C must not be exceeded or the volatiles will be evaporated and good glass will not result. This same process occurs in volcanoes; when an eruption occurs, obsidian oozes as volcanic glass. We know that tektites have undergone a similar process, but we also know that this occurred outside of the Earth. The closest place where volcanic activity has occurred is the moon. If we heated silicon dioxide in an anhydrous crucible like a lunar volcano, what would we expect to get? The answer is a glass which is essentially devoid of water. Tektites are extremely dry glass—which is exactly what would be expected. Typically, most tektites contain approximately 40 parts per million of water, while terrestrial obsidian contains approximately 4000 parts per million of water.

In Colombia, Ecuador and Peru spherical obsidian glasses are found which resemble tektites. Their outer superficial surface contains tektite surface features. Because of a water content of 0.4% they are clearly obsidian. They are called Amerikanites or Macusanites. They appear to be the terrestrial version of tektites. The important point is this: These are terrestrial obsidian and not impact glass. They are similar to volcanic ejecta and not at all similar to impact glass.

The terrestrial impact theory states that the composition of tektites closely resembles the surface rocks of the differentiated Earth. It is true that tektites chemically resemble obsidian, dacite, granites, rhyolite, subgreywacke and loess. One notable difference is that lunar rocks are much lower in iron. However, if the moon originated from the Earth, as a result of a grazing collision from another large body and only the lithosphere was involved, it is not surprising that their composition would be similar.

Many planetary scientists have argued that the moon is geologically dead. This researcher does not agree. There is evidence that the moon is slightly geologically active today and perhaps getting more so, and that the moon was highly volcanically active as recently as 0.78 m.y. ago. For lunar volcanism there must be heat. There are at least four sources of heat. One is the radioactive decay of uranium, thorium and potassium. The second, is the gravitational tidal stresses from the Earth. The moon's gravity causes the tides on the Earth. The Earth's gravity also exerts tides on the moon which are more than fifty times greater than the moon's tidal effects on Earth. Every crack and fault on the moon is stressed by tidal heating each lunar month. The third source is the molten center of the moon which has existed since its formation. The fourth source is the heat of impacts. From the original impact which created the moon to all the impacts which followed. Impacts continue on the moon's surface. At 9:49 UT on May 13, 1972 a six meter diameter meteorite or small asteroid impacted the moon 142 km. due north of Frau Mauro. The energy of the impact was equivalent to 200 tons of TNT and was equivalent to a Richter 4 earthquake. Much of this heat has been retained below the regolith of the moon. All of these sources are cumulative and growing. The regolith of the moon is an excellent insulator. Only 50 cm below the surface of the moon, the temperature becomes stable. Most heat generated in the interior is retained and accumulated. In summary, there is more than adequate heat for volcanism. We know that Mercury, Venus, Earth, Mars, Io, Titan, Enceladus, Neptune and Triton have been volcanic in the past and are probably still active to some extent today. It is more logical that the moon would be volcanically active rather than geologically dead. From the Apollo ALSEP seismometers, we know the moon is seismically active with about 10,000 seismic quakes of Richter 1 or 2 each year. It is not as active as the Earth, but still significantly active. There is also strong evidence that the moon is volcanically active to some extent. W.S. Cameron of NASA-Goddard Space Flight Center published The Lunar Transient Phenomena Catalog (5). There are now more than 2250 recorded Lunar Transient Events. Several areas of the moon have been continual sources of suspected volcanic activity. Among these are Aristarchus, Alphonsus, Gassendi, Plato, Kepler, Ptolemaeus, the western part of Mare Crisium and the Cobra Head Region of Schroters Valley. Some of these events were possible observational mistakes, sunlit peaks near the terminator or meteoritic impacts, but most observations were made by highly competent astronomers. These observations were made over decades of time under all illumination aspects and photographed from Lick and Mt. Wilson Observatories.

Four of these observations cannot be ignored. They were made by PhD astronomers (with state of the art instrumentation) who were specialists in their fields. All had corroboration either by photographs, spectra, or other experienced observers.

First, on October 26, 1956, Dinsmore Alter photographed a brightening in Alphonsus using the 60-inch reflector at Mount Wilson, California. He obtained a remarkable series of photographs. His project was started when he found obscuration of half of Alphonsus in a photograph from the Lick 36" refractor.

Second, on November 3-4, 1958, Nikolai A. Kozyrev, using the 50 inch reflector at The Crimea Astrophysical Observatory, observed a brightening in the crater Alphonsus. He obtained a high dispersion spectrum of this event. This spectrum clearly showed emission bands of molecular sodium and other gases consistent with a gaseous volcanic emission (7). Eleven months later he obtained another spectrum in Alphonsus and, in 1962, three in Aristarchus within a week and identified N_2, H_2 and C_2 (diatomic carbon).

Third, on October 29, 1963, James A. Greenacre was using the 24 inch refractor at Lowell to complete some lunar charts for the U.S. Air Force. He and his experienced assistant Edward Barr observed an 18 km long reddish brightening of Aristarchus which lasted for 75 minutes. He alerted the U.S. Naval Observatory in Flagstaff, Arizona and they confirmed it with their 61" reflector. In summary, LTP's have been confirmed by photography, photometry, polarimetry, spectroscopically and photoelectrically.

Fourth, in December 1992 and January 1993, Audouin Dollfus was using a video-polarimeter designed at the Paris Observatory. He observed brightenings in the 150 km diameter crater Langrenus with the one meter Meudon Observatory in France. These events are best explained by dust and a volcanic gas emission. The events lasted from December 29, 1992 until January 2, 1993.

On the evening of June 25, 1178 A.D., five prominent monks from Canterbury, England observed a torch-like light from near the northern cusp of the thin waxing moon. They gave written and sworn statements. The light was a prominent naked eye phenomenon as the telescope had not been invented until 1609. This event can be more easily explained by a volcano than an impact. One possible interpretation is that this was a lunar volcanic eruption in the crater Giordano Bruno. If it were a volcanic eruption, there would still be massive evidence on the moon today. This would provide conclusive proof as to whether the moon is currently volcanically active (6).

The above four events are consistent with volcanic gas emissions and are only the best documented observations of many other apparent volcanic phenomena observed in these areas. All of these observations were published in refereed journals and also in popular astronomical magazines like Sky and Telescope along with the photographs and spectra.

This researcher believes that it is more likely that the moon is volcanically active than that all of the more than 2250 recorded Lunar Transient Events are false. The moon is believed to have a small iron core (about 600 km in diameter) which is probably in a liquid state at a temperature of about 1000 degrees Kelvin. This is shown by the inability of seismic secondary waves to pass through the deep interior, showing the center of the moon to be at least partially molten. It is believed that the Earth and moon had a common origin. The oxygen isotopes (170 and 180) are identical which support this theory. When all of this data is considered carefully, it is likely that the moon is somewhat volcanically active today.

Other Concepts

Another argument of the proponents of the terrestrial impact theory is that the impact of lunar tektites on the Earth should be a chaotic event instead of creating strewn fields. It was originally thought that the Australasian strewn field covered approximately 10 percent of the Earth. We now know that it is more than 20 percent. It is possible that the Earth, being a major gravitational source, acts as a focusing body.

In the 1960's, John O'Keefe and, recently, Jay Jayawardena have proposed that tektites fell onto the Earth as the result of their decaying out of orbit from a ring of tektite material in Earth orbit. It is an interesting theory and is supported by some evidence. A terrestrial impact or terrestrial volcano cannot inject material into Earth orbit. If the Earth ring theory is correct, then it follows that the best logical source would be lunar volcanic ejecta.

An area of research that may shed some answers is that of the layered or Muong Nong-type tektites. These seem to be similar to splash-form microtektites that have not been completely melted, fined and homogenized. In one interpretation, they appear to be melted microtektites which were hot welded and deposited in layers on the moon and then blown off during an eruption or lunar impacts ejecting lunar regolith. Some of them show ablative features indicating that they formed and then entered the atmosphere. It was not until 1993 that the first Georgia layered tektite was found. This 130 g tektite is the Rosetta Stone of all North American tektites (8). It is now one of the most studied specimens. Layered tektites are not homogenized and in one electron microprobe analysis, the SiO_2 values varied from 69 to 99 percent. In appearance and petrology, they seem similar to banded or layered obsidian. The researcher, Darryl Futrell, wrote a comprehensive paper explaining many of the details of the physical dynamics of these layered tektites (9). If Muong Nong tektites came from terrestrial impact, they should show terrestrial basement rock and impactor contamination. They do not. They also have not shown any inclusions that are lunar in origin. While much more research needs to be done on them, it appears that they can be more easily explained by a volcanic process than an impact event.

The plastic tektites are those which were molten and then the surface began to harden (10). Before the interior hardened, the tektite suffered some trauma which broke it open, exposing the molten interior to a second hardening. Currently, the interpretation of this phenomenon is difficult to explain. One explanation is that as the tektites were launched from the moon they started to cool and harden. Then by impact or collision, they were broken open and hardened again. This still seems to be more easily explained by a volcanic process than an impact event.

Conclusion

If planetary scientists reject the lunar volcanic ejecta theory of tektites, then they have to prove Stokes's Law to be incorrect. Stokes's Law has withstood the test of time for about 150 years. If it were wrong, it would have been discovered many years ago. These planetary scientists must also find a massive crater in the Indochina area. For thirty or more years, every land search has failed to discover this 110 ± km diameter crater. If this crater were to be found, it would not prove very much unless the impactor were a lunar volcanic ejectum. With what we know now of impact physics and glass making, forming tektites by impact is probably impossible. Stokes's Law shows that the terrestrial impact theory fails by a time factor of between 10,000 and 100,000 times. The glass making industry spends a lot of money and laboratory time on research. If there were a quick way to make bubble-free glass, they would have found it. To this date, the glass making time has not been reduced by even one percent. If Stokes's Law were incorrect, or the crater existed, or the formulas for glass making were incorrect, these would have been discovered many years ago. These are critical errors for the terrestrial impact theory. Until these questions are answered, the planetary scientists need to go back and reevaluate the terrestrial impact theory.

When all of the above data are carefully considered without prejudice, it seems that one of the safest assumptions in planetary science is that tektites simply cannot be produced by a terrestrial impact and that they can be produced in a volcanic crucible in a nearby body, the moon being the most reasonable source.

It is not expected that every planetary scientist will accept this theory. Planetary scientists like Stuart R. Taylor, Billy P. Glass and Christian Koeberl are adamant that the terrestrial impact theory is correct. Yet, to this researcher's knowledge, they do not have an explanation for the Stokes's paradox.

The terrestrial impact theory suggests that tektites are formed from the ascending jet or plume after impact. If so, it would be highly contaminated with basement rock and portions of the impacting body. Neither of these are found in tektites. Tektites are not shocked. This is hardly compatible with an impact. Where does the silica come from: the basement rocks or the impactor? Most planetary geologists believe that the silica comes from the basement rocks. Tektites are fairly homogeneous and show little cosmogenic contamination. Small spherules of nickel-iron have been found in some indochinites, philippinites and Aouelloul Glass but the rare earth elements suggest that they are not meteoritic. They seem to be condensed out from the silica in a reducing situation. There are no abnormal amounts of iridium found in tektites. This is not reasonable for a cometary or asteroidal impact.

A fair question to ask is: "Has this researcher ignored the evidence of the terrestrial impact theory group?" No. The evidence has been read and studied. In summary, "It is not convincing." This researcher maintains the evidence for the lunar volcanic ejecta theory is much stronger.

This paradox led NASA geologist Paul Lowman to declare, “If tektites did not exist, and the physicists were asked if they could exist, based on our current knowledge of glass making and impact physics they would say no.” (13)

Every point and argument introduced here should be debated in print in a refereed journal. Each point should be supported by referenced mathematics, geology, chemistry and not by hearsay or opinion. However, before the minor points are discussed, the major unresolved points of the terrestrial impact theory must be answered.

The origin of tektites is widely believed to have been settled: formation by meteoritic or cometary impacts on the Earth. Significant evidence, in fact, supports the terrestrial impact theory—most recently the finding that the age of the Chesapeake Bay impact Crater is essentially the same as that of the North American tektites. However, several problems remain unsolved. It was shown by Dean Chapman that the flanged australites had entered the Earth's atmosphere at 11 km/second (which is the Earth's escape velocity) as cold, solid bodies that ablated during atmospheric entry.

It is still not clear how high-quality glass (tektites) can be formed instantaneously from the heterogeneous material of the Earth's crust. The supposed 800 thousand year old source crater for the Australasian tektites, estimated in the billions of tons, has not been found despite several field expeditions and other studies. If the terrestrial impact origin should be correct, it implies that we have only the vaguest understanding of the violence and temperatures of catastrophic impact events.

The late Elbert King stated, “Since tektites are just terrestrial impact products, they are very much over studied.” This researcher disagrees and maintains we have a great deal more to learn about these enigmatic objects.

In early 2000, John O’Keefe stated, “I think I have done a better job of proving the lunar volcanic ejecta theory for tektites than convincing others.”

John O'Keefe died on September 8, 2000. In his funeral program it was stated in Latin, "Tektitae De Luna Sunt!" which translates to "Tektites are from the moon!" His legacy is going to live much longer.

Acknowledgements

I wish to thank Paul Lowman, Winifred S. Cameron, Billy P. Glass Paul Huddlestun, Michael Roden, Lou Varricchio, John Whatley, Scott Harris and Randy Korotev for their helpful comments.

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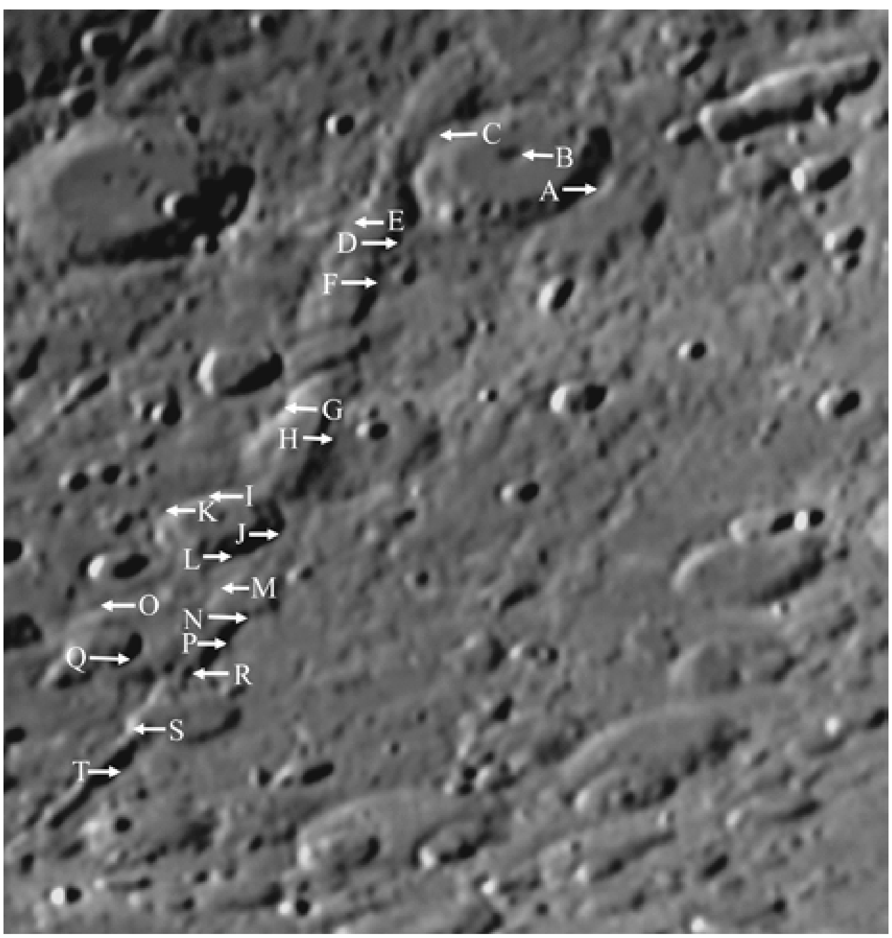
LTVT PART 2: continued from last issue

By Steve Boint

The beautiful Rheita Valley: what caused it, how deep is it, how wide is it, how long is it, what is the composition of its soil? With the power of LTVT, Google, and good atlases it should be possible to begin answering these questions. The accompanying chart gives the LAC-measured heights for specific points. I know of no other readily available values for vertical displacement in this valley. The mosaic (mine) shows the positions for the values of vertical displacement and position listed in Table 1. So, Google till your fingers hurt. Dig out those atlases. Dust off your old photos or take new photos and try out LTVT on the Rheita Valley. And, if you enjoy taking photos, but have no interest in measuring features [we'd still like to see your images], we might have reciprocal members who like to measure features, but have no access to photos. So, e-mail your photos to me, give permission for others to use them, and if people e-mail and ask for a "loaner" photo, I'll pass one along to them. For all photos, be sure to include the date and time the photo was taken and your location when you took it. In the case of a loaner photo, it is necessary to include the observer's latitude, longitude, and height above sea level. Send your results and photos to sboint0362@msn.com by May 31 and we'll publish the results of our group effort in an upcoming issue of Selenology.

The LAC map of the Rheita Valley can be found, courtesy of the Lunar and Planetary Institute, at: www.lpi.usra.edu/resources/mapcatalog/LAC/lac114/



	LAC Height (m)	Longitude	Latitude
A	3900	48.279	-36.370
B	3340	46.991	-36.870
C	4420	45.904	-36.942
D	2530	47.270	-38.609
E	2430	46.261	-38.682
F	none	48.587	-39.941
G	4120	49.351	-41.300
H	2010	50.024	-41.606
I	3530	50.954	-43.000
J	3460	52.600	-43.000
K	3300	50.686	-43.630
L	3440	52.767	-43.868
M	1810	53.235	-44.027
N	1760	54.393	-44.187
O	3000	52.677	-45.235
P	1490	55.264	-44.910
Q	2070	54.407	-45.890
R	2150	55.545	-45.398
S	1910	56.716	-46.635
T	2030	58.008	-47.223

CATENA DAVY

By Jack Kramer

Upon observing small lunar craters stretched out in a row, we may well wonder what might have been the cause. There are a variety of possibilities.

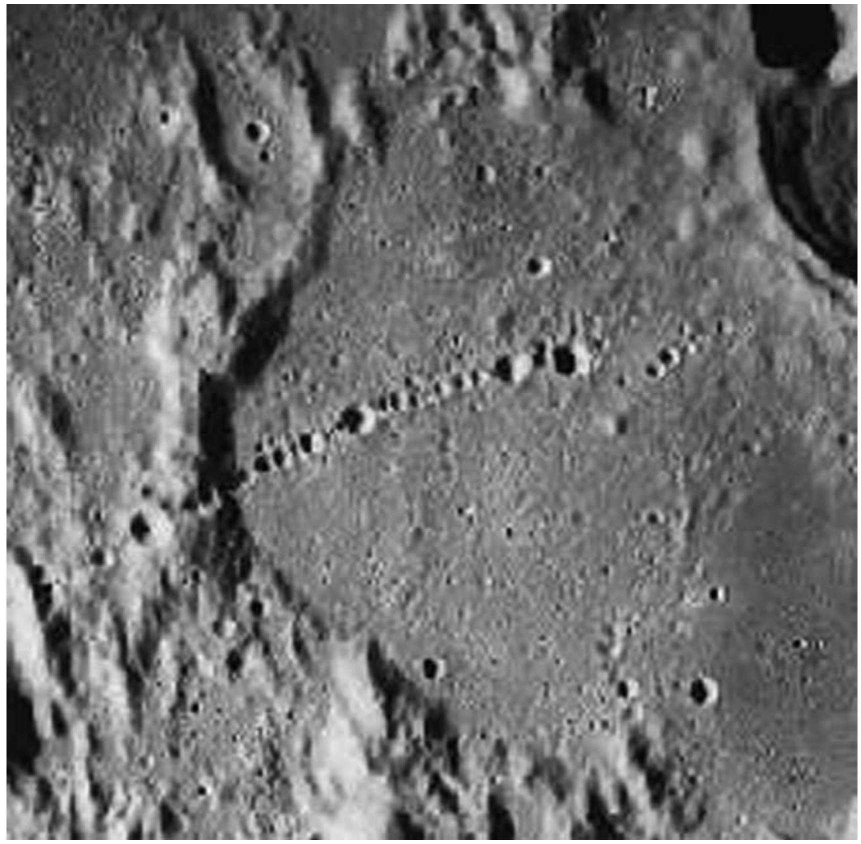
1) Some are endogenic, having originated from activity within the moon itself. Examples of this type include those that lie within rills, suggesting they were caused by subsidence or vulcanism.

2) Secondary crater chains on the moon are common and they usually occur in groups. Such chains are generally radial to a large crater and have raised rims with “chevron” imprints between craters that point back to the primary. Clearly, they were formed from debris thrown out of the large crater upon its formation. We also find craterlets distributed in haphazard lines around some large craters, such as Copernicus.

3) Several crater chains on the moon and elsewhere in the Solar System don’t seem to fit either of the two previous scenarios. The mystery was solved in 1993 with the discovery of Comet Shoemaker-Levy 9. As you recall, it was not a single comet, but a chain of twenty-one comet fragments created a year earlier when Jupiter’s gravity tore apart the original comet. SL-9 crashed into Jupiter in 1994, and we can visualize that if Jupiter had a solid surface, a chain of craters would probably have resulted from any particles of SL-9 that survived passage through the atmosphere. In fact, such crater chains have been found on Jupiter’s moons Callisto and Ganymede. We now know that fragmented comets are not unusual. The breakup of Comet Schwasmann-Wachmann 3 is a recent example. And there’s evidence that many asteroids are really aggregates of dust and rock barely held together by a slight bit of gravity. If they were to hit a terrestrial object, they’d likely make chains of craters. If you haven’t already guessed, the word “catena” is a Latin term adopted by the International Astronomical Union to signify a chain of small craters. In 1994, Jay Melosh and Ewen Whitaker announced their finding of two crater chains on the moon, neither of which appears endogenic or secondary to a larger impact. One fairly large chain is near the crater Abulfeda and the other lies near Davy. The Davy crater chain is particularly interesting because it’s an almost perfect line of twenty-three pockmarks each only a few miles in diameter. This gave credence to the notion that multiple-impact crater chains exist in the Earth-Moon system.

This chain of craterlets doesn’t actually lie within Davy, but in the larger, highly eroded crater basin with Davy at the (lunar) west edge. This basin is referred-to as “Davy Y”. The following image from the Lunar Orbiter clearly shows the chain stretching across Davy Y and up onto the walls of the basin (part of the crater Davy is seen at the upper right edge of the image).

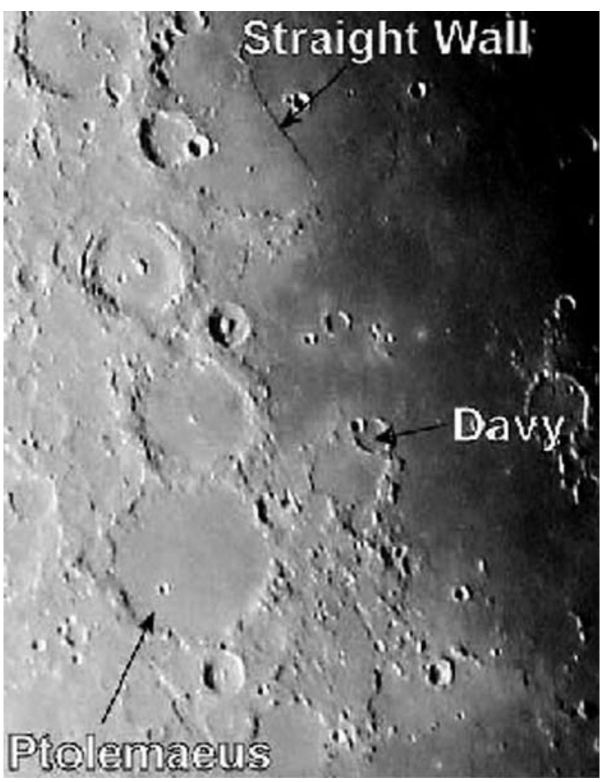
To help in locating the site, the image below is one that I took of the area through a 4-inch refractor. It shows Davy in relation to the large ruined crater



Ptolemaeus and the famous “Straight Wall”.

The crater chain doesn’t show up in the above picture, but you might be able to see a faint light-colored line stretching across Davy Y. This follows the line of craterlets, so at first I thought it might be lunar surface material scattered as pieces of space debris impacted the moon. Checking a number of lunar atlases, the light line shows up in wide-field images, but not close-ups. That suggests it’s more likely to be sunlight brightening the rims of the craterlets; an inability to resolve individual craters may cause the reflected points of light to knit together into what looks like a continuous line. This seems to be confirmed by close inspection of Clementine Mission imagery. In my 6-inch refractor, the smaller craters appeared to reflect a lot of sunlight, making them visible sometimes as mere points of light.

Observing the Davy crater chain will test the quality of your telescope optics. This is one of those features that calls for high magnification. Bear in mind that even the largest of these craterlets is only a few miles wide. The best time to view is when the moon is around 8 days old with strong shadows. The Straight Wall is a good indicator – if you can see it as a black line, then there is sufficient shadowing to see, at least, the largest craters of the Davy chain. Still, I’ve clearly seen the entire chain in the 6-inch refractor at 300x when the moon was nearly 11 days old. The larger craterlets in the chain appear relatively deep, so shadows linger for quite awhile. The resolution of a large telescope is helpful, but not required, so long as the optical quality is good. Many years ago, I tried with an 80mm refractor, but could only detect a light-colored line where the crater chain lies. More recently I caught sight of the three largest craterlets on the floor of Davy Y using the 4-inch refractor at a little over 200x. They were at the edge of resolution, becoming apparent off and on as seeing conditions fluctuated. The craters superimposed on the wall of Davy Y were visible in the 6-inch, but not in the 4-inch.



THE MOON AT YERKES OBSERVATORY

By Francis Graham

(Above left) Yerkes exterior. (Above) The lunar limb. (Below) Mare Crisium.

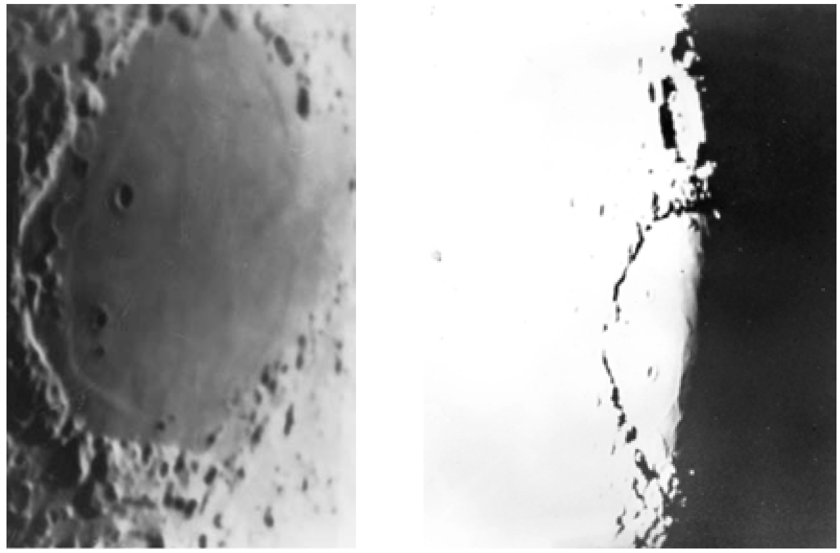
I was fortunate to observe the moon at Yerkes Observatory once, through the largest lens-telescope in the world. During the entire 20th century, Yerkes was a vital center of astrophysical research, especially under the directorship of Otto Struve. Of late, it is threatened with closure as long-focus refractors, even *the largest one on Earth,* are not in favor by astronomers for cutting edge research, but are relegated to parallax work and double star measurement. Yerkes, as big as a shopping mall and expensive to maintain, was not deemed valuable.

Before the wrecking ball comes in, I want to share with you some photos of the moon taken with the Yerkes refractor which I copied from old plates during a visit there, with permission of the director. They show the beauty and power of this fine old instrument.

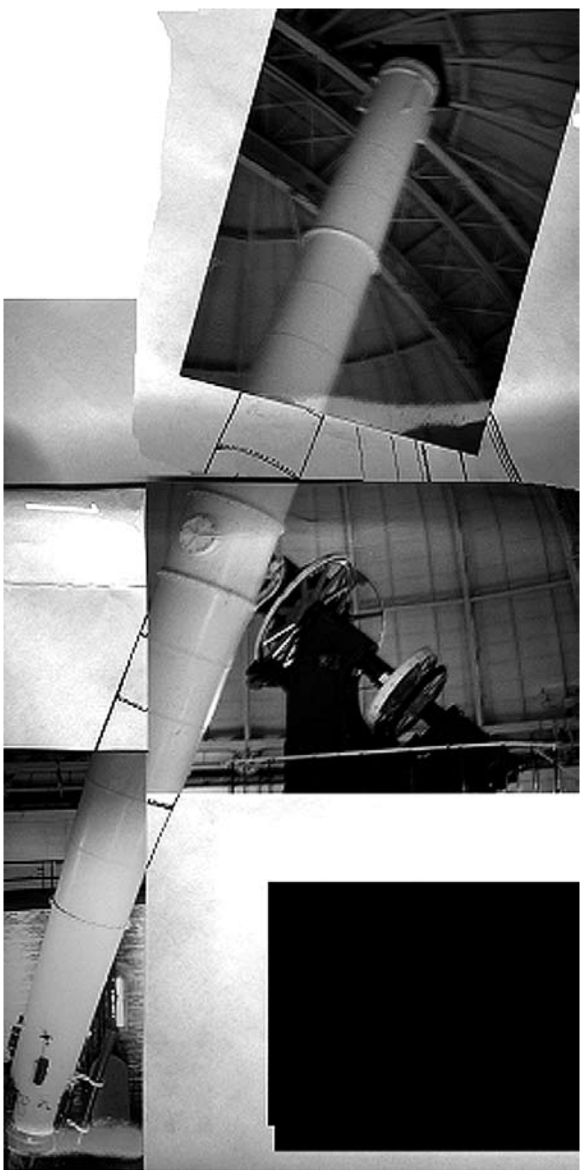
The observatory may have gained a reprieve. Word from Williams Bay, Wisconsin, the site of Yerkes Observatory, is that the Mirbeau Resort plan was rejected. This allows for possible takeover of the Yerkes Observatory by nearby Aurora College and Adler Planetarium. This may extend the use of the observatory, although not as a major research center. The Yerkes Observatory site is 79 acres

and Mirbeau hasn't completely ruled out the site as a resort, but the plan, without cooperation of the Williams Bay zoning board, is quite doomed.

The University of Chicago, which presently runs Yerkes, wants to unload the observatory and redirect its resources to cutting edge research at other sites with more modern telescopes. Present plans that have received support from the Williams Bay community involve using it as a center for science education, which would give it a new 50-year lease on life as one of the best observatories of the world, although its mission would change from research to science education.



Two more views of Mare Crisium



Above left: The crescent moon. Above: Mare Fecunditatis.
Left: Composite photo of the 40-inch refractor at Yerkes.