TEKTITES
MYSTERIOUS GLASSY PEBBLES

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My interest in tektites began in childhood, before the advent of the space age. As a boy, already interested in astronomy, I first became fascinated by them when I heard say of "mysterious little green rocks from the Moon." Since that time I have collected and studied these intriguing little glassy pebbles and have written and lectured innumerable times about them to equally fascinated audiences.

Splashform Tektites from Indochina (author's collection)

Introduction and Background

Tektites are small pieces of natural glassy-like material found in specific areas of the world. With some exceptions tektites resemble terrestrial obsidian. The name tektite is derived from the Greek word "tektos," which means *molten* or *melted,* a term selected because of unmistakable evidence that these glassy particles were shaped while in plastic condition. Their origin is one of the great mysteries of modern science, but it is certain they made at least one passage through Earth's atmosphere. Tektites have been known since ancient times, and in every region where they have been found, they have been collected because of their distinct difference from the surface materials in which they are found. In some cases primitive people made artifacts from tektites. The uniqueness of tektites also led to the early suspicion that they were extraterrestrial. Because of their evidence of an extraterrestrial origin, discussions of tektites are usually included as a separate chapter in most books about meteorites.

Even though tektites have been closely associated with stony and metallic meteorites, these "glassy meteorites" differ in some important respects. Their form, composition, surface markings, and distribution indicate they came from a source different from that of typical meteorites, and it is evident they encountered the Earth's atmosphere at speeds somewhat less than that of most meteorites. Unlike meteorites which continuously enter the Earth's atmosphere, a tektite fall has never been observed. The study or science of tektites, being a relatively recent development has, as yet, no well-known formal designation by name. Geo-tektites and astro-ceramics have been suggested, although a third, *tektitics*, is the term preferred by this writer.

The truly puzzling nature of these enigmatic objects is evidenced by the many theories that have been proposed to explain their origin. Early suggestions have included terrestrial lava bombs, glass worked by ancient artificers, gizzard stones of ancient birds or fossilized excreta, concretions in limestone, atmospheric or terrestrial dust fused by lightning (fulgurites), and, of course, glass meteorites. However, it has been only within the last 150 years or so that tektites have come under serious scientific scrutiny. Tektites have been subjected to nearly every conceivable kind of analysis and a considerable amount of data has been accumulated about them, but only a rough idea of the process of their formation has emerged. Discussions between scientists of differing opinions often continue to a spirited degree. Almost all the literature that has been published about tektites has been written with the assumption of uniformity with its great ages of Earth history.

Some Important Facts We Know about Tektites

There are a number of well-established and significant facts about tektites that have been gathered over the years. Hence, any finally-accepted hypothesis on their origin must be harmonized with all of these facts.

Tektites are found in about a dozen specific areas of the world called strewn fields. The more significant of these strewn fields includes Southeast Asia (Indo-China), Philippine Islands, Australia, Moldavia in Czechoslovakia, Libya in Africa, and areas within North America, including regions in Georgia and Texas. Respectively, specimens from these areas are called Indochinites, Philippinites, Australites, Moldavites, Libyan Desert Glass, Georgiaites, and Bedlasites from the area of Bedias, Texas.

Tektites range in size from tiny particles smaller than a grain of sand called micro-tektites, through intermediate sizes of curious shapes weighing up to several hundred grams, to, in rare cases, blocks the size of a football. A typical tektite found in a strewn field might be about the size of a fingertip or a small walnut. Tektites appear to be the same size as they were when they were created. In other words, they do not appear to be pieces broken from larger formations, and they seem to have rapidly cooled after being in a molten state for a short period of time, perhaps on the order of minutes.

The shape of tektites is one of their most outstanding characteristics and is indicative of a once semi-fluid state. Their surface markings are strongly suggestive of a high velocity flight through the atmosphere where they were ablated and sculptured aerodynamically. At the same time, their structures strongly evidence that their forms have been attained while spinning freely. Many of the intermediate-sized tektites are shaped like spheres, eggs, dumbbells, bowling pins, teardrops, bars, disks, lenses, buttons, and other nondescript forms. The kinetically-formed shapes of the Indochinites are called "splash form," a term originated by the late Virgil E. Barnes, director of tektite research at the University of Texas.

Overall, tektites occur in five distinct forms: 1. aerodynamic forms most noticeable in the small lenses and flanged button australites, 2. kinetically-shaped splash form Indochinites which are the most commonly-known type, 3. large homogenous moderately-rough glassy nondescript specimens without the characteristic splash form shapes, 4. the occasionally-larger rough and gritty layered Muong Nongs, and 5. the tiny micro-tektites which appear like glassy spheroids under a microscope.

Tektites are geographically specific. In other words, they are found in widespread groups limited to certain areas of the world, in the aforementioned strewn fields. Each group seems to have arrived as a separate fall with no individuals having fallen between or apart from such events. Along with this, tektites are geologically non-conforming, in that they occur as detached pieces bearing no physical relationship to the particular terrain in which they are found. They are distributed as if from somewhere else, namely from the sky. Furthermore, they are superficially deposited very high if not at the top of the geologic column, and never deep, which seems to indicate an arrival after most if not all the formative geological processes of the terrain in which they are found. In other words, tektites likely arrived shortly after the great Earth-changing convulsions of Noah's Flood.

Tektites exhibit a unique surface sculpturing which is often characterized by the presence of grooves, notches, bubbly-like pits, radial gouges, and alternating parallel straight or swirled glassy bands or wrinkles sometimes called flow lines, and smooth or "bald" areas. Internally they are swirly and slightly bubbly. Evidence strongly suggests that the surface sculpturing of tektites is the result of aerodynamic ablation during their rapid hot fall through the atmosphere. That their surface sculpturing was completed before they reached the ground seems confirmed by a few specimens which show what appears to be stretched breaks which must have occurred during flight while the piece was still in plastic condition. The lack of surface sculpturing at the break is indicative that the sculpturing was complete before the break occurred and before the tektite reached the ground.

When they are cleaned of soil residue, tektites are in such good condition that they usually appear fresh and unweathered, or in other words, new. This lack of solution etching is a strong indication that tektites have not been subjected to terrestrial weathering, even in situ, for more than a few thousand years. It is certain that tektites were cooled and hard by the time they reached the ground because none have been found with embedded material from their impact on the soil as would be the case with soft molten particles. A few sources have referred to ancient archaeological sites where tektite chips, which exhibited fresh breaks, were found as products of tool making. That these breaks were fresh is also consistent with the fact that the primitives lived only a few thousand years ago, not millions.

When the ages of tektites is considered in the context of radiometric dating methods, those specimens of a given strewn field appear to all have the same age. The same dating methods also seem to indicate age variations between the various strewn fields. However all strewn fields appear to be geologically recent.

Most tektites appear very much like dull black opaque glass, similar in appearance to obsidian. However, when they are broken or cut into thin slices and held up to a strong light source, they show an amber color and are translucent. In this respect Indochinites and Philippinites both show similar effects. Tektites from Moldavia in Czechoslovakia however are about the color of green bottle glass. Those from the Libyan desert in Africa appear yellowish. Moldavites and Libyanites both are relatively transparent when cut or faceted. Others appear smoky gray, light or dark green, olive or various hues of brown, some virtually colorless. Like the Indochinites and Philippinites, American tektites appear dark as a whole piece. However, the American pieces show a more or less translucent greenish-brown color in thin slices.

Tektites are relatively hard, being between 6-7 on Moh's scale of hardness, which makes them harder than artificial glass. Tektites are also relatively dense having a specific gravity of 2.4. Being a natural glass like obsidian, tektite glass appears to have formed initially by rapid cooling and has no crystal structure in the general sense of the term, hence cleavage is absent and fracture is conchoidal. Their refractive index is close to 1.5.

A distinguishing material characteristic of tektite glass is its unique chemical nature as revealed by geochemical analysis. Tektites are very high in silica content. They are a silicate glass containing anywhere between 58% to 85% silicon dioxide with some specimens of Libyan desert glass containing 98% SiO_2, which make them almost pure silica. The typical tektite contains about 70% silica, 11-15% aluminum oxide, small amounts of the oxides of iron, magnesium, calcium, potassium, sodium, titanium, manganese, and traces of other elements. There is practically the same chemical composition among all types of tektites, however, scientists are able to distinguish tektite specimens from different regions. The gas trapped in tektites is about as dense as that found in the Earth's atmosphere at an altitude of 30 miles, indicating their formation in a near vacuum.

Perhaps the most outstanding attribute of tektites is their exceedingly low water content. They are drier than terrestrial rocks by a factor of at least 100 or more. This difference has been demonstrated in the laboratory by taking two pieces of rock, both black and glassy: one a piece of obsidian and the other a tektite and subjecting the two to a hot blowtorch flame. The relatively soggy obsidian will bubble and froth as the water trapped inside is forced out, while the arid tektite will merely change into a molten lump.

The non-crystalline tektite glass is very pure and homogenous and if it was manufactured artificially, it would represent a very high grade of glass. It is a type of glass which cannot be produced quickly but requires very specific conditions in order to form. The only natural glasses that meet these criteria are terrestrial obsidian and tektites. A crude glass can be easily produced from sand by lightning, an artillery shell, a nuclear explosion, or cosmic impact. In this process there is a quick rise in temperature, a melting of the sand, and then a refreezing with the rapid drop in temperature. This does not allow for the production of glass of the quality that we see in tektites. This crude type of glass is referred to as shock or impact glass and is the kind of glass which is found at various impact sites around the world.

Another peculiarity of tektites is the fact that no tektite-strewn fields have been found further than 50 degrees latitude north or south of the equator. This represents another great anomaly about tektites, however this circumstance seems to suggest that tektites arrived as a shoal of particles from a source located at a relatively short cosmic distance. Otherwise, had these particles arrived from a much greater distance from Earth, they would have had more time to disperse so that they should be distributed uniformly over the Earth, like meteorites.

Although tektites are often associated with meteorites, an important difference between meteorites and tektites is the evidence that tektites never spent much time in space. An indication that a meteorite has been in space for any length of time is the presence of cosmic ray tracks in the meteorite specimen. When cosmic rays penetrate through a piece of material, they leave microscopic tracks. The number of cosmic ray tracks etched into the meteorite is taken as an indicator of how long the meteorite has been in space. However, no cosmic ray tracks are found in tektites. From this fact scientists conclude that tektites could not have existed in space for more than a few thousand years, neither could they have come from beyond the Earth-Moon system.

Tektite Theories of Origins

Of all the ideas that have been entertained in the past 150 years about the origins of tektites, four theories have prevailed and which have been given the most serious consideration by modern science. These theories are 1. terrestrial volcanism, 2. lunar impact, 3. terrestrial impact, and 4. lunar volcanism. These theories are described respectively in the following paragraphs.

Early on it was proposed that tektites had their origin in explosive terrestrial volcanic eruptions and that they are a type of volcanic bomb. However, tektites are found in regions where there is no volcanism. No volcanic regions are known to produce glass of the tektite type. Furthermore, a volcanic blast does not produce the velocity necessary to loft a pebble above the atmosphere let alone create the aerodynamic effects observed on tektites. Beyond that, air resistance would become an inhibiting effect. Besides, no volcano has ever been observed to expel projectiles to the velocity of incandescence as of a meteor.

Later on, in the 1940s Harvey H. Nininger, considered by many as the father of American meteoritics, proposed that tektites are the product of material blasted off the Moon as a result of gigantic meteorite impacts there. To an observer with only a modest portable telescope, it can be seen that the Moon is virtually covered with circular impact features, some of these clearly showing extensive deposits of debris conspicuously radiating out from the point of impact. In several cases these radiants can be seen extending more than half-way across the face of the Moon. These are most visible during full Moon. Because of the violent impact of a large meteorite on the Moon and the subsequent explosion, it is evident that some of these streams of lunite could have escaped the Moon entirely, and possibly in a direction which brings their material into the Earth's influence. When this material finally reached the Earth the individual pieces would have been sculptured by their passage through the atmosphere and deposited on the ground in the form of the strewn fields which we observe today.

In the 1960s this possibility was explored by a number of researchers, and in great detail, by leading astronomer and geophysicist John A. O'Keefe and aerodynamic engineer Dean R. Chapman, both NASA scientists who were involved with the Apollo program. Probably no one else in the world had accumulated so varied a collection of tektites nor has ever studied these strange objects so thoroughly and scientifically as these two men who concluded that tektites were from the Moon.

When tektites were not immediately found on the Moon by the Apollo astronauts, the lunar impact theory was abandoned by most scientists and the terrestrial impact theory became popular. However, this was not as the result of any evidence from new discoveries but by popular acclaim. Perhaps future missions to the Moon will be more discriminating in selecting locations for the search of tektites, or tektite material on the Moon. Little known is the fact that when the 843 pounds of lunar material retrieved by the astronauts were carefully examined, they contained pieces of glass which could not be distinguished from tektite material.

Nininger's early lunar impact theory for tektites has the advantage of being dynamically feasible, especially when it is considered that since the Apollo program a number of meteorites have been identified as having a lunar origin. Given that scientists have collected meteorites from Mars, it should be all the more likely by orders of magnitude that meteorites from the Moon have been collected on the Earth as well. Hence, if there are mechanisms and forces within our planetary system which have produced these results, then it should come as no surprise that the tektites found on the soils of the Earth should have come from the Moon.

Hence, this third idea, the terrestrial impact theory, states that a gigantic meteorite impacted the Earth causing an explosion and excavation of terrestrial material which was heated and launched upward through the atmosphere after which it passed back downward through the atmosphere as tektites, coming to rest in their arrangement as a strewn field. No other theory of terrestrial origin has been so seriously put forward.

Today most scientists involved in the study of tektite origins believe that this is how tektites were formed. However there are some serious questions about this theory that have not been answered.

One question which must be asked in respect to the launching of molten globules upward from a terrestrial meteorite blast is, how would the soft molten globules of tektite material survive the force and velocity of the upward thrust without being blown apart into fine droplets by the acceleration and air resistance during their flight up from the lower atmosphere? Suggestions such as a local vacuum in the atmosphere caused by the explosion which allowed the tektites to pass upward unimpeded are met with serious circumstantial problems.

It is evident that the flanged button Australites were initially cold glassy spheres. Carefully-conducted air jet experiments which exactly duplicated the formation of the flanged buttons leave no doubt that these objects were formed during a downward flight through the atmosphere, and at an entry velocity of approximately 6.5 miles per second. All of this suggests an extraterrestrial origin.

Another question which must be asked is, if tektites formed when a gigantic meteorite or a comet struck the Earth where are craters or remains of craters caused by these collisions in the areas where tektites are found? No consistent correlation between the locations of known terrestrial impact structures and the location of tektite fields has been realized. Almost all terrestrial impact features exhibit no associated tektite strewn fields. Furthermore, the great ages usually assigned to these features by conventional dating methods are conspicuously inconsistent with the evident recent deposition of the tektites. Unlike the Moon where meteorite impacts in the thousands appear to be the principal force forming the landscape, there are only about 200 known impact structures and astroblemes on the Earth. However, most of these are deeply covered in sediment or lie deep under the ocean, another sign that tektites arrived on the Earth after Noah’s Flood. The best-preserved impact features we see today are all relatively small, like Barringer Crater in Arizona, Chubb Crater in Northern Quebec, or Wolf Creek Crater in Western Australia. We do not see any very large impact features miles across that are fresh and well preserved, another indication that most of the terrestrial impacting siege occurred during the Flood epoch, the smaller well-preserved craters having resulted from late-comer, post-Flood meteorite impacts.

The difficulty of launching material out from the Earth is shared with the terrestrial volcanic theory in that atmospheric retardation of hyper-velocities is tremendous especially in the dense lower atmosphere and consequently restricts the flight range of small objects.

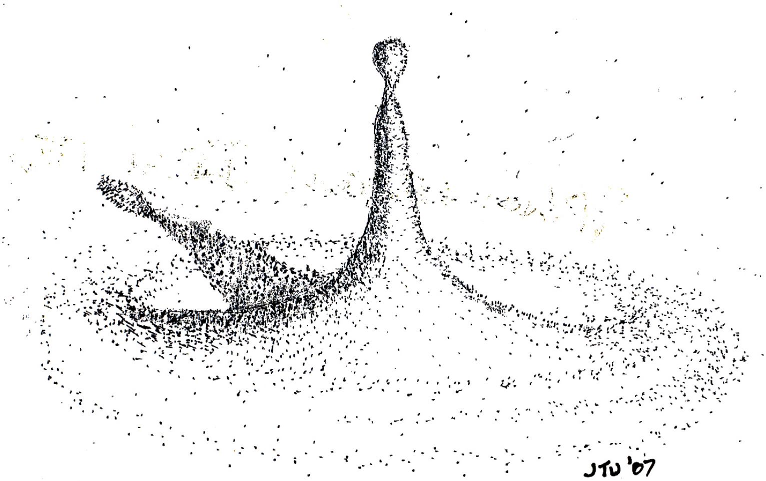
One of the most important discussions that must take place in regard to tektite origins has to do with the quality of the tektite glass itself. Tektites are essentially bubble free and very homogenous. In commercial glass making, fining is the process whereby homogenized glass is produced. To fine glass requires careful heating in a crucible at the right temperature for an extended period of time according to a formula called Stoke's Law. This is necessary in order to allow the bubbles to rise and clear out and for the glass to become homogenized, that is, internally consistent throughout. It is a process that is reminiscent of the homogenization of cows' milk. When we consider the homogenization of glass, such a glass product is found in only three known situations: 1. artificial glass, 2. obsidian from a terrestrial volcano, and, 3. in tektites.

Glass is formed in two ways, by a fining process as just described and by impact or shock. When sand, for instance, is subjected to an intense thermal shock, it forms a crude glass. As mentioned previously, this can occur as a result of a direct lightning strike, the explosion of an artillery shell, or a meteorite impact. During any of these events the temperature rises very quickly, melts the sand, then the temperature drops almost as quickly allowing whatever material that was melted in those few moments to freeze. Because this sequence occurs so briefly it does not allow any "fining" or homogenization to occur. The resultant product is not a glass which is chemically pure and consistent throughout but a product known as shock or impact glass which is a crude glass, materially contaminated by other surface material. Hence, it is impossible to produce fined glass like tektites naturally under these circumstances. In other words the sequence, as we understand it, of a giant meteorite impact on the Earth cannot produce tektite glass.

It is evident therefore that the fining of tektite glass had to have occurred somehow outside of the Earth. Furthermore, no known natural process on Earth can produce material as dry as tektite glass. The Earth is simply much too wet, and all terrestrial rocks are reflective of this hard fact. Finally, there is the limiting factor of the absence of cosmic ray tracks in tektites. Thus from these important facts it must be concluded that the nearest and only physical location where tektite glass could have formed is the Moon.

A fourth theory, referred to as the lunar volcanism theory, states that tektites are the products of explosive volcanic eruptions on the Moon. This theory has been considered by some as the most workable and viable model to date given all the known facts about tektites themselves. However, this theory is believed by only a small minority of the scientists studying the tektite problem today.

The lunar volcanism theory would provide an explanation for why the surface rocks on the Moon examined so far are, for the most part, different in composition from tektites. Terrestrial obsidian is formed under the surface of the Earth and is brought to the surface by volcanoes. Tektites may be dry lunar obsidian that, as the result of lunar volcanic eruptions, comes from deep within the Moon where the SiO_2 content is much higher. This deep location would also explain the absence of cosmic ray tracks in tektites. Under these circumstances the only conceivable mechanism for excavating this material would be a very large-scale volcanic explosion. However, a credible explanation on how a lunar volcano could expel material at such a force and velocity as to escape the Moon entirely without first disintegrating and scattering the body of the volcano itself widely over the lunar surface has not been forthcoming.



Liquid Drip Spike
(Illustration by Joseph T. Unruh)

Of interest is the fact that an observer with even a modest portable telescope can see spread, splash, and rebound impact features on the Moon, all betraying differences in the manner of which lunar material reacted to incoming projectiles in its excavation and launching as ejecta. Experiments conducted by this author involving the dropping or thrusting of objects into a mass of water, sand, or mud, show that the size, shape, mass, angle, and velocity of the falling body or projectile all contribute to a diversity of impact ejection results. The shape of the projectile seems to be particularly important in the nature of the splash result. While the dropping of a glass or steel marble into a swimming pool from waist height produced practically no splash whatsoever, an irregular stone of the same size produced a more significant and complex splash result. Occasionally the spherical objects produced a splash with a symmetrical rebound spire or spike. A recent article in *Nature* described an experiment involving the dropping of a heavy ball into aerated sand that produced a tall sharp spiked jet of grains immediately after being engulfed in the sand. Undoubtedly the shape of the object has something to do with the rebound spike effect. Particularly interesting is the fact that a small somewhat irregularly-shaped heavy iron object produced a splash rebound which traveled at a speed noticeably greater than the speed of the falling object initially dropped into the water, and at the same time the rebound liquid reached a considerably greater height than the height from which the metallic object was dropped into the water. This seems to be confirmed by others, including Ronald A. Oriti who in 1967 wrote that: "…experimental evidence indicates that it is possible to eject fragments with speeds exceeding that of the impacting missile. There can be no doubt that the Earth must be receiving matter from the Moon. It may be that some of this matter is so similar in appearance to terrestrial rocks that it has gone unnoticed."

Perhaps such experimental results will prove helpful in developing a working model on tektite origins when it is considered that a splash is merely a collision of particles under various conditions of surface tension and viscosity. We must remember that a large-scale meteorite impact on the Moon acting along with the fluid behavior of the lunar surface material under this circumstance should be seen as hardly different than any ordinary impact splash in water, sand, or mud on Earth, but simply on a much larger scale. If tektite glass is in fact lunar obsidian, this material must have been deeply excavated and launched to Earth by large cosmic impacts under a highly unusual and specific set of circumstances. This possibility is consistent with the observed rarity and restricted geography of tektite fields on Earth.

Thus we might suggest the possibility that under the right circumstances the concentrated force of impact of a very large heavy incoming projectile—an irregular yet roughly spherical metallic asteroid—could have discriminately launched material from deep under the lunar surface expelling it out as a plume of material that escapes the Moon's relatively weak gravity and sending it off toward an Earthbound trajectory. Furthermore, through some kind of ecliptic restricted gravitationally influenced effect, this shoal of particles might have followed a route close to the plane of the ecliptic in its relatively short drift to

Earth. Such a scenario would allow for its observed deposit in the lower latitudes. This scenario is similar to Nininger's original model with the primary distinction being in the nature of the lunar impact itself.

Conclusion

The evidence we have about tektites—that they formed as a result of a gigantic explosive impact, that their formation occurred in a near vacuum in a place where there is very little water, that they have not been exposed long to cosmic rays, that they underwent a very rapid hot flight down through the atmosphere, that they are geographically-specific, and that they are composed of highly-fined glass—seems to reinforce the conclusion of only one physical place of origin, namely the Moon. Since the Moon seems to be so overwhelmingly-implicated as the origin of tektites, it seems incumbent upon us to look for the mechanism which would launch and deliver this material to the Earth in the form of which we find it today. Furthermore, given the unanswered questions still residing with the four previously-reviewed theories, it is this writer's suggestion that perhaps a fifth, *the lunar impact rebound spike ejecta theory*, as implicated in the liquid drop experiments previously described, deserves further investigation and study as a viable explanation for the presence of tektites on Earth.

In spite of the great deal of research that has been brought to bear on the nature and origin of tektites, we must plead ignorance in our full understanding of these most enigmatic objects until that day when one of our theories is finally vindicated. Thus, it has been said by not only a few of our fellow scientists seeking to divine the true identity of these unique objects that tektites represent one of the most frustrating, illogical, and impossible objects on Earth.

Given the Earth's immobility and preferred place in the cosmos, and given that we reckon our everyday life in terms of Euclidean geometry, i.e., in terms of "breadth, and length, and depth, and height" (Ephesians 3:18), it should come as no surprise that we should occasionally find odd relics in the soils of the earth sent "down" from on high. There are a number of references in the Bible to stars falling to the Earth (Revelation 6:13), stones cast down from heaven (Joshua 10:11), fire and brimstone (Luke 17:29), all of which would indicate a fixed Earth Central as the recipient of heavenly meteoritic material. If the stars should fall to the Earth and make their mark from a distance so great, so then should tektites also from a distance much less.

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