123

A new branch of Space Science Research focusses on studies on Tektites, Meteorites and moon rocks, the trio with codename XTM (Extra Terrestrial Materials). Theory of Extra terrestrial origin of Tektite has been weighed against the hypothesis of terrestrial origin. Distribution of Tektites on earth, their composition and age have been discussed. The importance of studies on meteorites both in the field of cosmology and origin of life in space has been pointed out. Moon rocks reveal the internal constitution of moon and its age. How those studies help solve some basic questions about the nature of magnetism and life history of solar system etc have been pointed out.

Extra-Terrestrial Materials (XTM)

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In 1975, the Department of Space Science was reorganised at NASA Headquarters in Washington and a new branch was created for research on meteorites and lunar rock samples under the code name XTM (Extra Terrestrial Materials) with Bevan M French as its Programme Chief. Having carried out investigations on Terrestrial rock and mineral samples under a CSIR project 'Dating rocks', I became interested in the study of lunar rock samples. But there was an obvious big 'if' I get the samples. After preliminary enquiries from NASA HQ, I came to know the minimum requirements for obtaining these samples. Because of their high theft values. NASA people insist on heavy security arrangements. The samples are stored and processed in special containers of stainless steel under an atmosphere of dry nitrogen.

The XTM includes the following materials which are available for research–

(a) Tektites
(b) Meteorites and
(c) Moon rocks

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(a) Tektites

After remaining a source of puzzlement and esoteric debate in scientific literature for nearly 200 years, tektites have come into public notice over the past few years with the advent of space travel. One school of thought has maintained that they originate from the moon but the other still insist that they belong to earth. Judging from preliminary reports, there are, indeed, marked similarities between moon rocks and the tektites. Tektites (from Greek word tektos i.e., molten) are usually small, glassy objects, jet black in colour and found in certain restricted areas of the world called 'strewn fields'. Four such fields are generally recognised. They are: (1) Moldavites, found in the valley of river Moldau, in Western Czchecoslovakia, (2) Australites, which was the first to be collected and recorded in 1864 by Charles Darwin. He obtained them from the Australian aborigines, (3) Ivory coast tektites in Western Africa and (4) The North American bediasites from Texas (named after a local Indian tribe by the discoverer, V Barnes of Texas University in 1936). It is interesting to note that the Australian

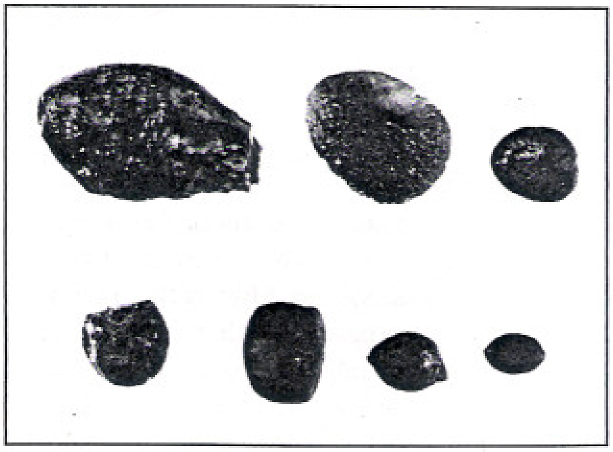

Fig.1 Tektites (Australites) of different shapes (lens, button, spherical) shaping ablation effect, collected from Australia.

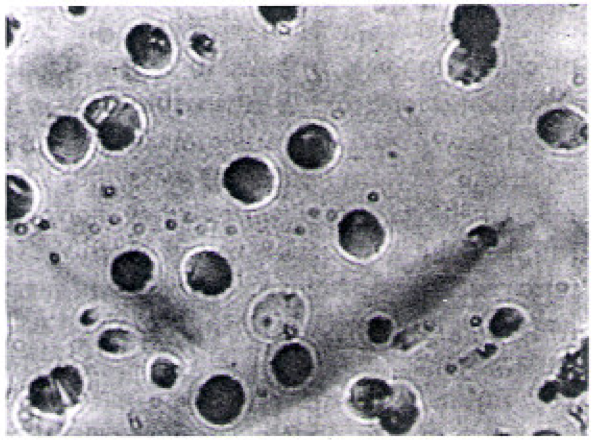

Fig.2 Induced fission trucks in tektite are indentical to those formed in glass (Etchant : HF acid)

aborigines, as well as the Ivory coast natives, have long regarded tektites as possessing supernatural, magical powers.

Now a question may be posed as to what makes these chips of 'glass' so interesting from a scientific point of view?

First, of course, is their distribution. Why are they found in only four places and nowhere else?

The second, their peculiar composition: they have distinct physical and chemical characteristics which set them apart from both volcanic glasses (obsidians) and impactites (glasses produced on the earth by the of meteorites). They have Sp gr 2.30-2.52 and refractive index n = (1.48 – 1.52). Their composition: silicon content 68 to 82 percent, high content of lime, alumina, magnesia and iron oxide, and the abnormally low water content (0.005 percent). Their special characteristics are some external and internal features. Most tektites have shapes which strongly suggest modelling by aerodynamic forces. It appears likely that they have traversed the Earth's atmosphere at great speeds, getting their exterior surface ablated in the process. The posterior surface shows swirls flow bands appearing like the wrinkles in a piece of cloth under a microscope. Australites are most frequently button-shaped or lensoid, but a number of other forms exist. The shapes have been modified by weatheing such as solution – etching, erosion and sand-blasting. The size varies from only a few grammes to the largest recorded weighing 3.2 kg. The total number of tektite samples collected over the past 200 years is some 3/4 of a million out of which half a million samples are in the possession of H O Bayer in Manila.

In America the black market price of tektites is upto 200 US $ per gram.

Origin and Age of Tektites

The origin of tektites is the most controversial subject. Here, two schools of thought have existed for a long time: (i) the terrestrial and (ii) the extra-terrestrial. The mystery of origin of tektites is yet unsolved. The theories most worthy of consideration are those proposing the formation of tektites by the impact of meteorites or comets, either on the Earth or on the Moon. L J Spencer of the British Museum was the first to propose splashed material coming down in a fine spray. There are several objections to this hypothesis: (i) The strewn fields are too large for tektites to achieve the requisite high velocities without complete destruction. (ii) If tektites have resulted from fused local rocks, they should reflect their composition whereas they often do not. (iii) The third objection raised by the 'extra-terrestrialists' is tantamount to asking, in police parlance, the question 'where is the body?' i.e., the impact craters.

There are two answers to these questions: The first is that of A J Cohen of University of Pittsburg who has argued that Ries Crater in South Germany and the Lake Bosumtwi crater in Ghana are responsible respectively for the Moldavites and the Ivory Coast tektites. Harold Urey has put forward the ingenious hypothesis of cometary impacts. Comets being so nebulous, consisting largely of heated gases and vapours, no concrete craters need be made!

H H Nininger was the first to propound in 1936, the theory that tektites originated from meteoritic impacts on the Moon. Recently D Chapman, of NASA's Ames Research Centre has pinpointed not only the crater on the moon (Viz Tycho) which is responsible for the Australasian tektites i.e. Australites but also the crater ray (Rosse ray) along which the ejected lunar material initially travelled. The lunar craters responsible for American and Central European fields – 14 m.y. and 34 m.y. respectively may well by now have been eroded by meteorite impacts.

On balance, however, the lunar hypothesis appears to me to be more plausible, as it widely explains the observed facts. The NASA report of the analysis of lunar materials lends powerful support to this hypothesis. Glass is found to constitute about half of the fine material.

Age of Tektites

By fission track technique, we have calculated the ages of Moldavites and Australites. Our results agree very well with the ages determined by other groups. The australites are the youngest with an age of 0.7 m.y. and the Moldavites give an age of 15 m.y.

(b) Meteorites

Meteorites appear to be among the oldest and, in some cases, the least chemically differentiated objects in the solar system. Most of the meteorites were apparently formed in a rather short time interval of several tens of millions of years at a time 4.6×10^9 years ago – that is at the time of separation and condensation of solar system materials from the rest of the Galaxy. Some authors predict their formation as a result of asteroid collisions in space.

Meteorites have been classified into various categories depending upon their contents: Irons, Carbonaceous chondirites, achondrites, siderophyre (Bronzite), Lodranite, mesosiderites and Pallasites. Recently carbonaceous chondrites have assumed added importance due to the presence of complex organic (carbon) compounds in them. It has been predicted from their analysis that life first began (evolved) in space and not on our earth. So we are related to a much advance civilization somehwere in remote space.

Although both meteorites and lunar rocks have been exposed to energetic particles in space for long times, there are some fundamental differences in the particle record preserved in them. First, the orbits are different, meteorites sample a different region of interplanetary space than do the lunar samples. Secondly, when meteorites enter the earth's atmosphere, there is a spectacular luminous display which burns the outer regions of a meteorite (ablation) thus destroying the record of low energy particles, such as those produced in solar flares. Lunar rocks carried to earth inside a spacecraft clearly do not suffer this limitation. Another important difference in the nature of meteorites and lunar rocks is the difference in their exposure ages. The cosmic ray exposure ages of meteorites are $10^7 - 10^8$ years. Thus they retain the complete record since the time of evolution of solar system. On the other hand, the lunar surface has been continuously churned by the impact of meteorites and meteroids due to the lack of atmosphere giving rise to craters on the moon surface. The size of lunar craters varies from a few mm to some 300 km in diameter.

Fossil Tracks in Meteorites

Meteorites can, in principle, contain tracks from the following:

(a) Spontaneous fission of U^{238},
(b) Spontaneous fission of Pu^{244},
(c) induced fission of heavy elements by high energy primary cosmic rays,
(d) induced fission by low energy secondaries,
(e) Spallation recoils from primary interactions,
(f) heavy primaries,
(g) meson jets, and
(h) magnetic monopoles.

Fossil tracks from these different sources can be distinguished from each other on the basis of measurable parameters such as the appearance, the density, the length distribution, and the angular distribution.

Extinct Isotope Pu^{244}

In addition to spontaneous fission tracks from U^{238}, meteorites may also contain tracks from extinct Pu^{244}. This isotope with an α-decay half-life 76×10^6 years, has a probability for spontaneous fission 4×10^5 times greater than that of U^{238}.

If we exclude all other sources of fossil tracks in meteorites except the spontaneous fission of U^{238} and Pu^{244}, Fleischer et al (1965) showed that the ratio of Pu^{244} spontaneous fission tracks to those from U^{238} is given by the following expression:

$$\frac{\rho_{Pu}}{\rho_U} = \frac{\lambda_{F\rho u}\lambda_{Du}}{\lambda_{D\rho u}\lambda_{Fu}}\left(\frac{\rho_u}{U}\right)_0 \frac{[1-\exp(-\lambda_{D\rho u}\Delta T_1)]}{[1-\exp(-\lambda_{Du}\Delta T_1)]}\exp[-(\lambda_{D\rho u}-\lambda_{Du})\Delta T_0]$$

At some point in time, Pu and U stopped being formed in our solar system. A time interval ΔT_0 later, the present meteoritic minerals were formed and cooled to a temperature where tracks were retained. $\left(\frac{\rho u}{U}\right)_0$ is the $\rho u^{244}/U^{238}$ ratio at the end of the nucleosynthesis, λ_F denotes spontaneous decay constant and λ_D, α-decay constant of elements. ΔT_1 is the time interval from the end of cooldown to the present. To a good approx $\Delta T_0 << \Delta T_1$ and $\Delta T_1 \approx 4.5 \times 10^9$ years. The density P_u of U^{238} spontaneous fission tracks can be determined by means of separate irradiation in a nuclear reactor.

$$T = \frac{1}{\lambda_D}[ln(1 + \frac{\lambda_D\rho_s}{\lambda_F\rho_i}\phi\sigma I)]$$

$T = 4.5 \times 10^9$ years
ρ_i = known (from expt.)
ρ_s = can be found out.

The difference between the observed track density and the calculated U^{238} density is then attributed to spontaneous fission of ρu^{244}. Values of ΔT_0 may then be inferred from above equation for several choices of $(\rho_u/U)_0$ taken from different models of nucleosynthesis. The only assumption is that provided no chemical separation between ρ_u and U took place during mineral formation. It was found that the ratio

$\frac{\rho_t-\rho_u}{\rho_u} = \frac{\rho_{Pu}}{\rho_u} \approx 200\text{-}500$ for Toluca and Patwar meteorites. This value is 1500 – 3900 for Kodaikanal meteorite.

The most important evidence in favour of $\rho_{U}{}^{244}$ excess tracks comes from the study of Kuroda (1960), Reynolds (1963) and Wasserburg et al (1969). They established experimentally the direct linkage between excess fission tracks and excess fission Xenon gas. Reynolds observed a large Xe^{129} anomaly in the Xenon isotope pattern in the Richardton meteorite and Wasserburg measured a xenon fission component in witlockite crystals from the meteorite St. S'everin. The excess track density due to $\rho_{U}{}^{244}$ in a meteorite varies with the nature of the mineral further proving that the tracks are sensitive to thermal events.

Cosmic ray Exposure Age

As the meteorites are exposed to the galactic cosmic rays (in addition to solar flares etc) their cosmic ray exposure age can be calculated to know the time for which they remain travelling:

$$TcR = \rho_{\mu} / \phi v$$

where ϕ is the flux of cosmic ray protons and heavier nuclei in space and v is the production rate of observable V–tracks found from an accelerator irradiation experiment (7.6×10^{-12} V's / proton).

(c) Moon Rocks

It was Galileo who provided the first topographic description of the Moon using his telescope. He observed the great dark smooth areas that he called maria or seas bordered by high range of mountains which he called terrae or highlands. Thus the myth of a 'Man in the Moon' or a 'Woman with the spinning wheel' was exploded for ever.

In less than a decade the Russian Lunas and the American Apollos have changed our Moon from an Unknown and unreachable object into a familiar world. On February 2, 1966 the Russian Luna-9 made a soft landing on the lunar surface and transmitted photographs back to Earth.

Twelve men have walked on the Moon's surface. Moon rocks have been collected from eight places on the Moon: 382 kgms from six Apollo landings, and a small return of about 130 grams collected by two Russian spacecraft called Luna-16 and Luna-20.

Instruments placed on the moon as long as six years are still measuring moonquakes, meteorite impacts, magnetism, and the heat flowing out of the Moon.

Before the landing of Apollo II on July 20, 1969, the nature and origin of the Moon were still mysteries. Now, as a result of the Apollo program, we can answer questions that remained unsolved during centuries of speculation and scientific study: obviously the first question is, what is moon made of?

(1) Mineralogy of Moon

The Moon is made of rocks. Its rocks contain the same chemical elements as those in the Earth, although the amounts are different. The moon rocks are so much like Earth rocks that we can use same terms to describe them both. The moon rocks are all igneous and formed by cooling of molten lava. The dark regions (called maria) are covered with basalt lava, a rock similar to terrestrial basalts. The high regions of the moon (highlands) are made up of several kinds of rocks that cooled slowly deep within the moon. We call these rocks gabbro, norite and anorthosite. Mineral composition of Moon rocks has been given by B Mason as below:

Major group	:	Plagioclase, pyroxene, ilmenite (>10 percent)
Minor group	:	Olivine, cristobalite, tridymite (1-10 percent)
Accessory minerals	:	Copper, Iron, nickel, troilite Quartz, Zircon, Apatite (<1 percent)

Moon rocks and Earth rocks are also different, the biggest difference is that Moon rocks have no water at all, while almost all the terrestrial rocks contain at least a percent or two of water. Because Moon rocks have never been in contact with water or oxygen, therefore they are very fresh and well preserved. Light coloured highlands are rich in calcium and aluminium, while the dark-colored maria contain less of these elements and more of titanium, iron and magnesium.

(2) How old is the Moon?

Meteorite studies indicate that the sun and all the other bodies in the solar system formed about 4.6 b.y. (billion years) ago from a collapsing cloud of hot gas and dust called solar Nebula. However, the oldest known rocks on Earth are 3.7 b.y. old as the much older rocks have been destroyed by Earth's volcanism, mountain building, and erosion. The moon rocks fill in some of this gap in time between Earth's oldest rocks and the formation of the solar system. Dark maria consist of youngest rocks (3.3 – 3.7 b.y.) on the moon, while highlands consist of even older rocks (4.0 – 4.3 b.y.).

(3) Internal constitution of Moon

Moon is almost 'dead' as there is no volcanic activity or lava eruptions. However, there are about 3000 moonquakes each year, average moonquake releases the same energy as a firecracker. The moon does not have a magnetic field like the Earth's, and so the most baffling and unexpected result of the Apollo program was the discovery of preserved magnetism in many of the old lunar rocks. Moon had an ancient magnetic field that somehow disappeared after the formation of older rocks.

(4) Is there life on the Moon?

The lunar rocks were so barren of life that the quarantine period for returned astronauts was dropped after the third Apollo landing. Neither living organisms not fossil life have been found in any lunar samples. The lunar rocks contain no water, and it is therefore unlikely that life could ever have originated on the Moon. On the other hand, meteorites contain the basic ingredients necessary for the evolution of life. It has been reported that carbonaceous chondrites (Type I meteorite) contain the germs of life.

(5) Lunar Soils

The lunar surface is covered by a layer of fine broken up powder and nebula about 1-20 metres deep. This layer is usually called the lunar soil, although it contains no water or organic material, hence unfit for agriculture. There is continuous stirring and mixing of lunar soil as a result of meteorite impacts. Lunar soil *traps* the solar *wind* as well as cosmic rays. It is also called lunar regolith.

(6) What can the Moon tell us : The Moon has become an important key to solving several basic scientific questions, for example:

(a) What is the nature of magnetism?
(b) How do planets develop magnetic fields?
(c) What is the early history of the Earth and other planets?
(d) What is the life history of our sun and the solar system?
(e) How did life originate?

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