When Was the Lunar Surface Last Molten?

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I appreciate the challenge concerning the last time the lunar surface was heated and became also partly molten. I intend to show that of the three possibilities in Professor Derek York's discourse, the evidence is for (c)-- "there is something wrong with the radioactive clocks or our reading of them."

First, I will cite the impression the physical appearance of the lunar rocks made on qualified observers.

The Lunar Sample Preliminary Examination Team ("Preliminary Examination of Lunar Samples from Apollo 11") recorded "the extremely fresh appearance of the interior of all crystalline rocks, in spite of their microfractures and high potassium-argon age."

As to the exterior of the lunar material, T. Gold, writing in *Science,* discussed "Apollo 11 Observations of a Remarkable Glazing Phenomenon on the Lunar Surface." Gold, looking for a cause of the glazing assumed "a giant solar outburst in geologically recent times" that sprayed the surface of all lunar rocks with metallic glaze. How recent? "The glazing occurred less than 30,000 years ago: otherwise the glaze would have been eroded and dusted over by slow bombardment of the moon by cosmic dust. On the other hand, the event must have taken place some thousands of years ago, not only because it was not observed historically, but also to allow enough time for the metal-plating process to coat the glass."

The event was observed historically; however, it was not due to the sun becoming a nova for a second or so, but to the repeated disturbance in the moon's motion and the near-encounters in the celestial sphere described in *Worlds in Collision,* part II, "Mars."

With the knowledge attained in attempting to reconstruct the cosmic events of the eighth century and the beginning of the seventh before the present era (in which the earth, but mainly the moon and the planet Mars, were involved at 15-year intervals), I made the following claims concerning the moon:

a. The lunar surface rocks must show the effects of their melting and bubbling. Actually the rocks were found of igneous nature, containing pyrogenic mineral assemblages and cavities, created by bubbles of gas.

b. There must exist a steep thermal gradient under the surface: "Since the moon was heated and its surface became molten only a few thousand years ago, the temperature gradient under the surface crust will show, to some depth, a mounting curve." (My communiqué to Prof. H.H. Hess, Guyot Hall, Princeton University, dated July 2, 1969). Such a gradient was detected over two years later by the Apollo 15 team and startled the theorists--the outflow of heat was almost three times more than expected by those who hold to the hot origin of the moon; those who hold to the cold origin of the moon are baffled even more.

c. The hydrocarbons that have been deposited on the moon in an earlier cosmic event (*Worlds in Collision*, part I, "Venus") must have "in a subsequent melting of the ground" converted "into carbides or carbonates."

Small quantities of hydrocarbons and organic carbon were found in lunar material (and surprised the researchers); and substantial quantities of carbides have been found too, and created a problem.

d. Radioactivity of the lunar material and especially localized areas of excessive radioactivity (where interplanetary bolts, have fallen or emerged) would be found. Radioactive elements were first found in the rocks and fines brought by the Apollo 11 team. Localized thermal spots of high radioactivity were detected by the circling Apollo 15 craft, and large areas of highly radioactive KREEP were discovered in samples brought by the astronauts.

e. Excessive quantities of argon and neon would be found captured in the lunar rocks, having originated in an external source (Martian atmosphere); further, the abundance in which these noble gases would be found would lead to wrong, even bizarre, conclusions about the age of the lunar rocks.

Actually rich inclusions of both argon and neon were found in lunar material. Ages of seven billion and even 20 billion years were deduced, estimates that exceed the accepted age of the universe. Then it was claimed that much of the argon-40 arrived in the solar wind, though previously only atoms of hydrogen and helium were thought to be present in the wind (plasma). It was retorted that the solar wind *cannot* possibly contain argon-40; and it was found that the smaller the lunar grains are, the larger is the proportion of argon (and neon) to the grain's mass--it means that much of the argon must have come from the outside--therefore its presence is proportional to the surface, not to the volume of a rock or a fine.

Since argon-40 could not have arrived from the sun and most of it could not have been formed *in situ* by the decay of potassium-40 (because such an origin would have required a moon several times older than the accepted age of the universe), a rather far-fetched theory was offered and, in the absence of anything better, also accepted: namely, argon-40 was formed at the usual rate from the decay of potassium-40, and accumulated in the deeper strata of the moon; then, because of heating from some unidentified origin, the argon succeeded to come to the outside and form a lunar atmosphere but then it was *pushed* back into the surface rocks and grains by the solar wind acting purely mechanically. This, furthermore, requires that the rocks and grains opened themselves to permit an inclusion of argon and neon.

Is this not a most artificial explanation, especially in view of my advance claim of rich invasions of *argon and neon* of extra-lunar origin?

The conclusion is inescapable that the potassium-argon method of measuring the age of the lunar rocks needs to be discounted. And Professor York concedes this in the present short paper (and also conceded this to me following my lectures at the University of Toronto in October, 1971).

Before we proceed, I wish to make it clear that the question is not *when* the rocks have *been formed* or for the *first* time crystallized, but when they were heated and partly molten for the last time. The *age* of the *rocks* is not in dispute, only the time of the "carving" of the lunar surface. The rocks could be billions of years old. And let me repeat Professor York's words: the transformation rate of radioactive elements cannot be altered by "heating" or "hitting" or "exposure in vacuum." Since heating by itself cannot influence the radioactive' decay, a melting in the past cannot be detected by the resulting ratio between the quantities of the radioactive element found and the element product of the decay. However, one of the two may escape because of volatility in the process of heating. This is the case with lead--the end product of radioactive uranium or thorium.

It was found (and it caused one of the surprises of which the lunar exploration was rich) that the lunar rocks are greatly depleted of all volatile elements: lead, bismuth, cadmium, thallium, indium and others.

Actually, the lunar rocks contain only 10 percent, and down to as little as one percent, as much of these elements as corresponding terrestrial rocks. Thus, the uranium-lead and thorium-lead methods for estimating the age of lunar rocks are as inapplicable as the potassium-argon method. One method is undermined by the bountiful addition of the final product and the other method by the depletion of the final product.

Then how good is the third method for measuring the age of lunar rocks, by rubidium decaying to strontium (with a half of the rubidium-87 converting into strontium-87 in 50 billion years)?

I have asked Robert C. Wright, Senior Development Engineer with Princeton Applied Research Corporation, to tackle this method for its validity in measuring the time since the lunar rocks were last molten. His remarks follow my discourse.

At the Third Lunar Conference held at Houston in January, 1972, Leon T. Silver of the Division of Geological and Planetary Sciences, California Institute of Technology, challenged the age estimates of the lunar rocks. Lead and rubidium can become heated sufficiently to move freely over the moon as gases. Silver gave no estimate of how much the lunar "boil off" might have affected the estimates of the moon's age and by how much the "ages" need to be revised.

Already at the First Lunar Conference (1970) Silver drew attention to the volatile transfer of lead "as a major lunar geological process" and referred to "an early high temperature episode in lunar history" which "produced an apparent depletion in volatile elements, including lead, as indicated by the extraordinarily high uranium-238 to lead-204 ratios of lunar material from Tranquillity Base, compared to terrestrial and chondritic materials." This and other observations made him conclude his paper with these words: "Continuous examination of basic assumptions provides some of the greatest harvests in Science."

Upon observation and detection of more "parentless lead" in subsequently obtained lunar material, Silver, reporting to the 1972 Lunar Conference, gave the figures arrived at in laboratory experiments. He concluded that at some time in the past the lunar surface became heated to volatilize the lead; at 475 to 600 C a major release of lead would take place; and at 1000 C from 70 to 80 percent of the total lead would be volatilized. The heating of the surface is reflected in vitrification: some "drastic" lunar event converted at least half of the lunar soil (sample 14163) to various glasses. "One can reasonably expect some moon-wide volatile transfer effects from very large surface thermal events on the moon." This has "major implications and remarkable potential for understanding and explaining lunar surface history."

Thermal events must have enveloped the lunar surface to affect the transfer of lead. In such events the rock needed to be heated to something like 800 C, but did not need to be molten and recrystallized.

Rubidium evaporates at much lower temperatures than lead. As Wright shows in his paper, the heat of one long lunar day is amply sufficient for the transfer of rubidium. Thus the third method is most unreliable for dating even at normal conditions prevailing on the moon. Now we can ask how it is that it is claimed that concordant results have been obtained by the three methods unless a preconceived idea of the age of lunar rocks guides the researchers. In the meantime, we learned once more that the lunar surface was subjected to heating or several hearings after it was already cooled off.

In my article in the *New York Times*, written at the invitation of the editors for the "Man Walks on Moon" issue, I suggested that the thermoluminescence level of the rocks and glasses is the proper criterion for establishing the time when the last melting of the surface took place. This method is applied on inorganic material like pottery, glass, lava, rocks; the longer the time that has passed since the last heating to above ca. 150 C, the more luminescence must be stored for another heating or firing which is then done in a laboratory. To exclude the effect of the solar heat during the two week long lunar day, I suggested the extraction of a core from a three foot depth.

The thermoluminescence study by R. Walker and his collaborators at Washington University, St. Louis, was made on Apollo 12 cores. They reported tersely: "The TL (thermoluminescence) emitted above 225 C by samples between 4 and 13 cm show *anomalies resulting from disturbances 10,000 years ago."* The "disturbances" referred to were of a thermal nature.

Upon more consideration, I think that the increased radioactivity in lunar material must increase the thermoluminescence effect and thus let it appear that the last heating occurred earlier than historically true. Therefore it is necessary to extract material from sites which are the least radioactive.

The "extremely fresh" appearance of the interior of all crystalline lunar rocks; the vitrification of a large proportion of the lunar soil; the volatilization and transfer of lead; the glazing of the rocks that must be of recent date; the thermoluminescence studies indicating thermal disturbances in historical times; and the steep thermal gradient that bewilders the researchers; all point to the fact that the thermal history of the moon is not what it was thought to be only a few years ago.

Concluding, I wish to raise a fundamental question. When we measure the age of the universe, why do we assume that at creation the heavy elements like uranium predominated and not the simplest ones, hydrogen and helium?

It is philosophically simpler to assume that all started--if there ever was a start--with the most elementary elements. A catastrophic event or many such events were necessary to build uranium from hydrogen. Although the radioactive clock cannot be disturbed by heating or hitting, it can be disturbed by discharges of interplanetary potentials. This is what made me also claim localized areas of high radioactivity on the moon and Mars alike.

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