# Reports

## Lunar Eclipse: Infrared Images and an Anomaly of Possible Internal Origin

Abstract. *Infrared images of the lunar eclipse of 13 April 1968 were obtained and compared with infrared images of the 19 December 1964 eclipse. A similarity of apparent strength and distribution of most thermal anomalies on the maria is evident from inspection of these images, indicating that these features are not ephemeral. One new linear thermal anomaly was discovered, which is thermally enhanced during the lunar afternoon. Its close relation to a lunar crustal fracture line and other features of probable internal origin suggests that this anomaly may be of internal origin.*

Measurements of thermal radiation emitted by the lunar surface during an eclipse have been made for many years (*1*). Although these measurements were limited in spatial resolution and (or) area covered, they elucidated the general thermal characteristics of the lunar surface, and identified the anomalous cooling behavior of several lunar craters.

During the lunar eclipse of 19 December 1964, Saari and Shorthill (*2, 3*) performed the first infrared raster scan of the entire lunar disk, by the use of the 74-inch (188-cm) Kottamia telescope of the Helwan Observatory in Egypt. These observations showed that there are hundreds of "hot spots" on the lunar surface that cool more slowly than their surroundings, as well as large areas that remain thermally elevated over their environs during the eclipse. The raster-scan data that Saari and Shorthill recorded on magnetic tape can conveniently be displayed as an infrared image (Fig. 1).

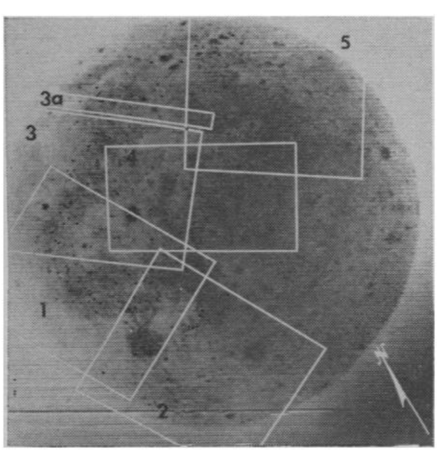


**Fig. 1. Infrared image of the eclipsed moon reconstructed from 200 line scans recorded during the eclipse of 19 December 1964. Black areas are warm. The areas scanned during the 13 April 1968 eclipse are outlined. (Infrared image from Shorthill and Saari, 1965.)**

The origin of these thermal anomalies has been a question of major importance in the field of lunar research. If all or some of the anomalies were of internal origin, it would be highly significant in terms of lunar thermal history. Likewise, if all or part of the anomalous behavior associated with lunar craters resulted from internal heat, this would have a strong bearing on the controversy concerning the process which formed these craters.

The origin first suggested for thermal anomalies (specifically Tycho) was that they are the result of the exposure of low-thermal inertia material on the surface (*4*). Salisbury and Hunt (*5*) showed that the nighttime cooling behavior of Tycho is, in fact, fully consistent with such an explanation, because the pattern of heat release for at least the first 48 hours during the night mirrors the pattern of solar illumination before sunset.

It has been suggested that reradiation from a rough surface can play a part in the thermal behavior of anomalies that are not as long-lived as Tycho (*6*). Still other possible mechanisms (including internal heat) have been explored (*7*). However, the thermal inertia mechanism for Tycho is the only one for which unambiguous supporting evidence has been found.

We now demonstrate that the hundreds of eclipse anomalies discovered by Saari and Shorthill have remained relatively unchanged for over 3½ years, and we point out one anomaly that we believe may have an internal origin.

We obtained new infrared images of the eclipsed moon on 13 April 1968. The images were constructed with a focal-plane raster-scanning device (*8*), by the use of a liquid helium-cooled, copper-doped germanium detector at the *f*16 cassegrain focus of a Boller and Chivens 24-inch (60-cm) telescope, located at Concord, Massachusetts. Our images have slightly better resolution than those of Saari and Shorthill. Our wider bandpass (8- to 14-$\mu$ atmospheric window plus a small contribution from the 17- to 24-$\mu$ window) resulted in at least a comparable signal-to-noise, because effects of atmospheric emission were reduced through the use of a thermal enhancement technique (*9*). This technique was designed to produce images on which the contrast between thermal anomalies and their surroundings is increased and broad areal temperature differences are suppressed. Our data record consists of photographic images produced in real time by focusing the output of a glowtube on Polaroid P/N film. The glowtube was mechanically linked to the scanner, and its brightness was controlled by the output signal of the infrared detector.

Figure 2 shows the location of our infrared images on the lunar surface. Saari and Shorthill's instrument, when mounted on a 74-inch (188-cm) telescope, scanned the entire moon with 200 lines in 17 minutes. Our scanner constructed a 136-line raster in 20 minutes. When this scanner was mounted on a 24-inch (61-cm) telescope, it produced an image covering about 20 percent of the lunar disk. Allowing for

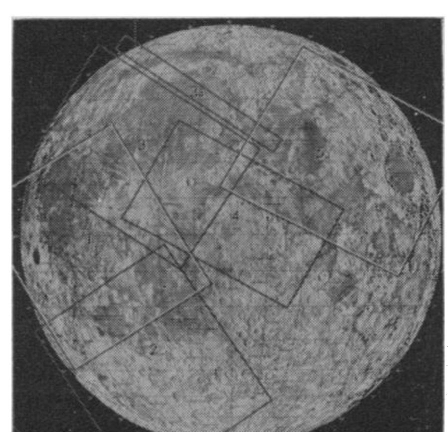

**Fig. 2. Lunar reference mosaic (USAF) on which are outlined the areas covered by the infrared images obtained during 13 April 1968 eclipse.**

overlap of our images and repeated scans of interesting areas, we could not cover the entire lunar surface during the umbral phase. We concentrated our efforts on the maria (Fig. 2), because they not only display the vast majority of thermal anomalies, but also seem to be the most likely locations in which to find evidence for the presence of internal heat sources (*10*). By following this line of attack, we obtained infrared images of more than 70 percent of the disk during the umbral phase of the lunar eclipse. A comparison of our images with the infrared images of the entire disk constructed by Saari and Shorthill showed that we detected all of the prominent thermal anomalies that they detected, with the exception of the anomaly discussed below. In addition, a great many of their questionable (faint) anomalies are seen on our images. A few anomalies that we detected, such as the ones to the northwest and southwest of Aristarchus, are not displayed in the Saari and Shorthill image (Fig. 1). These anomalies are, however, displayed on some of their other images. In view of the fact that we used a different scanning system, different image production system, different detector, smaller telescope, and were not in a favorable location for good atmospheric infrared transmission, the close similarity of distribution and apparent strength of the anomalies is quite striking. Thus, one result of our eclipse observations is that they provide the first confirmation of the only other detailed eclipse measurement (*2*). Because the hundreds of anomalies have remained relatively unchanged over the 3½ years, we know that they are not the result of ephemeral activity on the lunar surface.

The item of major importance is the linear feature (Figs. 3, 4) tending southward from Gassendi A. It coincides with the western margin of Mare Humorum, which is bordered here by a step fault. This step fault has east-facing escarpments along most of its length. Saari and Shorthill found that all of Mare Humorum was thermally anomalous during an eclipse, as we did also. Their unpublished data show that the thermal gradient at the western margin of the mare is quite steep, which could make it appear as a linear anomaly after being processed by our thermal enhancement technique. Thus, we might have detected the steep edge of a thermal "plateau" during the eclipse, rather than a linear anomaly as such. This does not appear to be the case during the lunar afternoon, however, because Saari and Shorthill (*11*) do not detect an elevated temperature for Mare Humorum at that time. In addition, the gray levels for the flat terrain on either side of our linear anomaly in Fig. 4 are the same, indicating an equal temperature for these areas. Consequently, we have apparently detected a linear anomaly during the lunar afternoon. We also believe that the western margin of Mare Humorum is warmer than its surroundings, both to the east and to the west, during an eclipse. Saari and Shorthill may have failed to detect this anomaly during the eclipse and during the lunar afternoon because of their poorer resolution. The most important aspect of this anomaly is that it is warmer than its surroundings before sunset, behavior not found for the prominent crater anomalies like Tycho (*11*).

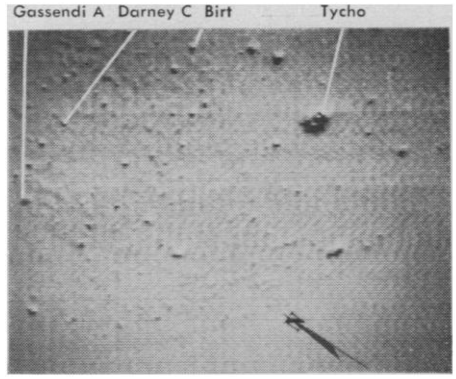


Fig. 3. Infrared image of area 2 outlined on Figs. 1 and 2. Scan lines run from astronautical NNW to SSE. Image construction began at 0410 U.T. and ended at 0430 U.T.

This linear anomaly cannot be caused by reradiation from a rough surface, because a rough surface would tend to be cooler than its surroundings during the afternoon. It could be caused by the presence of low thermal inertia material at the surface, or by an internal heat source.

We have no reason to believe that coarse debris of low thermal inertia is scattered along the western margin of Mare Humorum, as we would expect in the vicinity of a recent impact crater like Tycho. The Orbiter IV photography of Humorum, which has a ground resolution of about 59 m, also shows no unusual surface structures. The escarpment of the step fault, which would be expected to contain high-density rocks, is not continuous, and faces in the wrong direction (east) to provide excess heat during the afternoon. Finally, as mentioned above, other thermal anomalies, such as Tycho, that have an obvious contribution from stored solar heat, are not warmer than their surroundings during the afternoon.

By contrast, an internal origin is a more probable explanation for the Humorum anomaly for the following reasons. (i) The flow of heat to the surface from an internal source would tend to make an area warmer than its surroundings during the afternoon, as is the case with this anomaly. (ii) There is its geological setting. The location of the anomaly along a line of crustal fracture suggests a natural access to an internal heat source. Rock of low thermal inertia exposed in the fault zone could conduct the heat to the surface. Slow leakage of hot gases to the surface along the fault zone could provide an even more

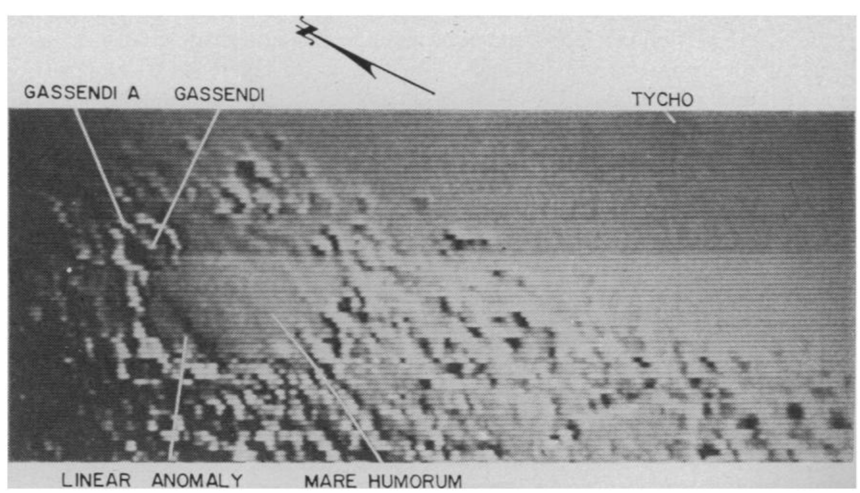


Fig. 4. Infrared image of Mare Humorum during "late afternoon" of the **lunar day.** East of the terminator, Tycho is barely discernible as a nighttime thermal **anomaly** at the low gain setting necessary to display the linear thermal anomaly on **the surface** of Humorum. Image was obtained on 9 October 1966 between **0601 U.T. and** 0610 U.T.

efficient heat transport mechanism. It may be significant in this respect that there are at least four dark-haloed craters along the fault line, and these features are generally considered to be gas explosion craters of internal origin (*10*). In addition, no fewer than 12 transient events, usually in the form of reddish flashes or patches, were reported for Gassendi during 1966 and 1967 (*12*).

The geological evidence, like the thermal behavior of the anomaly during the afternoon is, however, more suggestive than conclusive. Further high-resolution thermal measurements throughout a lunation are urgently needed in order to determine the origin of this thermal anomaly.

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13. We thank Captain S. R. Balsamo for discussions of the data; Lt. W. E. Alexander for assistance with the infrared scanner electronics during the eclipse; J. M. Saari and R. W. Shorthill for unpublished data and criticism.

1 May 1968; revised 5 August 1968

## Earliest Known Marsupials

Abstract. *The infraclass Metatheria has not been reported from deposits predating the mid-Cretaceous. Fossil material just recovered from Albian deposits in northcentral Texas has definite characteristics of the family Didelphidae and is submitted as being from the oldest known marsupials. The same locality has also produced remains referable to Eutheria, demonstrating a somewhat earlier divergence of these two important groups than was known before.*

In 1956 Patterson (*1*) described isolated teeth representing more than one species of metatherian-eutherian grade from middle Cretaceous (Albian) deposits near Forestburg, Texas. Since then "Forestburg Therians" appeared at the base of phylogenies for both marsupials (*2*) and placentals (*3*). Additional fossil material of the same age from another locality near Decatur, Texas, was reported (*4*), and the family Pappotheriidae was proposed. This locality also produced (*5*) submolariform premolars unknown among Metatheria and almost universal in Eutheria, and these were offered as evidence that eutherians are present in the assemblage. Although these premolars are too large to belong to *Pappotherium pattersoni,* Romer (*6*) and Van Valen (*3*) referred Pappotheriidae to the order Insectivora. I now believe that fossil material has been found which, although fragmentary, can be referred with some confidence to Metatheria.

There is no assurance that at a point so close to divergence, Metatheria and Eutheria were the only lineages of this grade. Even so, without evidence of nonmarsupial or nonplacental mammals of metatherian-eutherian grade, it seems best to make reference on the basis of characters known to be, or at least suspected to be, diagnostic.

Subclass Theria, Parker and Haswell
Order Marsupialia, Illiger
Family Didelphidae, Gray
*Clemensia*, new genus

Diagnosis: Parastyle hookshaped and larger than stylocone; metacone relatively larger than that of *Pappotherium*, nearly size of paracone. Stylar cusp C (*7*) large and adjacent to notch between paracone and metacone.

*Clemensia texana,* new species

Etymology: Generic designation is made in honor of Dr. William A. Clemens for his encouragement and in recognition of his work on Mesozoic mammals.

Holotype: SMP-SMU 61997 (Fig. 1, B and G). Upper molar with protocone missing.

Paratype: SMP-SMU 62009 (Fig. 1, A, E, and F). Ultimate upper molar.

Referred specimen: SMP-SMU 62131 (Fig. 1, C and D). Lower molar.

Type locality: Butler Farm locality about 30 m below the top of the Antlers formation; 5 km northwest of Decatur, Texas; 230 m northeast of U.S. Highway 81; on the property of Mr. Lee Butler.

Diagnosis: Same as for genus plus characters of paratype; stylar cusp C well developed on last molar; distinct conules present, but without wings.

Description: Parastyle (stylar cusp A) of holotype hookshaped, rounded labially and faceted lingually. Stylocone is somewhat smaller, conical, and connected to parastyle by a ridge. Stylar cusp C is extremely large, conical, and not connected to stylocone or metastylar area by ridges. At the posterolabial corner of the tooth there is a conical cusp about the size of the stylocone and a much smaller one (stylar cusp D) between this and stylar cusp C. An anterior cingulum is connected to the parastyle and extends to the protoconal basin but is not so well developed as in *Pappotherium*. Paracone is connected to the stylocone by a ridge. Although paracone and metacone are well worn, evidently the paracone was the larger of the two. Unlike *Pappotherium,* the base of the metacone extends almost as far lingually as the paracone.

Morphology and relative size of paracone, stylocone, and stylar cusp C of the ultimate upper molar (paratype) are about as that of the holotype. Metastylar area is greatly reduced, and metacone is much smaller relative to paracone. Paracrista fades before reaching the stylar cusps and is directed more toward the parastyle. Simple distinct conules are present but lack the wings of most later therians and are closer to the apex of the protocone than the bases of paracone and metacone.

Lower molars referred to *Clemensia texana* are of type 5 of the Trinity molars (*4*). They are referred on the basis of size and ease of occlusion. These teeth are very similar to others in the collection which are of quite different taxonomic affinity, but which probably reflect proximity to the point of divergence. All of the lower molars in the collection, representing eutherians, metatherians, and possibly even pantotherians, share one character: more extreme anteroposterior compression of the trigonid than in most later therians. This could suggest the ancestral condition. The single mammal of metatherian-eutherian grade known to be older than the Texas material is *Aegealodon* from the Neocomian of England (*8*). This form is based on a lower molariform tooth which does not have a particularly compressed trigonid, but considering the forward pitch of the