(density, about 8 g/cm^3) (Fig. 3). This great difference in density would normally have produced a complete physical separation of olivine and metal (*11*); such a separation is, with the possible exception of portions of Brenham and Glorieta Mountain, unobserved within the pallasites. Within the center of a parent body [model (iv)], gravitational separation would be minimized; moreover, according to model (iv) we would expect uniform and consistently low cooling rates as well as uniform olivine compositions; such features are in fact observed. Thus we feel that, despite unresolved problems connected with the energetics of core formation, our data indicate that the pallasites came from the central part of their parent body (or bodies) (*12*).

It is not known with certainty which if any of the iron meteorites formed in the same parent body as did the pallasites. If some of the irons formed within this body we can place some boundary conditions on their former locations: Iron meteorites having cooling rates as low as those of the pallasites could have occurred within or near the core; thus it is possible that a few iron meteorites occurred centrally to the pallasites. However, the bulk of the iron meteorites, having much faster cooling rates, must have been situated closer to the surface than were the pallasites. Furthermore, the faster cooling rates of many irons that may have formed in the same parent body as did the pallasites can best be explained if iron bodies were "suspended" in the mantle. Thus they would have been physically and thermally insulated from the pallasitic core by appreciable thicknesses of intervening silicates.

PETER R. BUSECK
Departments of Geology and Chemistry, Arizona State University, Tempe 85281

JOSEPH I. GOLDSTEIN
Planetology Branch, Goddard Space Flight Center, Greenbelt, Maryland

References and Notes

1. E. Anders, *Space Sci. Rev.* **3**, 616 (1964).
2. B. Mason, *Geochim. Cosmochim. Acta* **27**, 1011 (1963); W. R. Van Schmus and J. A. Wood, *ibid.* **31**, 747 (1967); K. Keil and K. Fredriksson, *J. Geophys. Res.* **69**, 3487 (1964).
3. P. R. Buseck and J. I. Goldstein, *Trans. Amer. Geophys. Union* **48**, 165 (1967); "Olivine compositions and cooling rates of pallasitic meteorites," in preparation.
4. Forty-three pallasites are recognized in the listing of M. H. Hey, *Catalogue of Meteorites* (British Museum, 1966); in addition we include two new pallasites [P. R. Buseck, C. B. Moore, J. I. Goldstein, *Geochim. Cosmochim. Acta* **31**, 1589 (1967); in preparation].
5. The symbol Fa represents the mole percentage of fayalite, Fe_2SiO_4, in solid solution with forsterite, Mg_2SiO_4.
6. B. Mason, *Amer. Museum Novitates 2163* (1963).
7. ———, *Geochim. Cosmochim. Acta* **27**, 1011 (1963).
8. T. Simkin and J. V. Smith, in *Abstr. Ann. Meeting Geol. Soc. Amer. 1966*, p. 203; C. S. Ross, M. D. Foster, A. T. Myers, *Amer. Mineralogist* **39**, 693 (1954).
9. J. Short and J. I. Goldstein, *Science* **156**, 59 (1967).
10. J. I. Goldstein and J. Short, *Geochim. Cosmochim. Acta* **31**, 1733 (1967).
11. R. A. Fish, G. G. Goles, E. Anders, *Astrophys. J.* **132**, 243 (1960).
12. It is indeed risky to draw an analogy with Earth. However, it occurs to us, as an interesting speculation, that a central pallasitic core surrounded by molten metal might explain the observed transmission of shear waves within Earth's inner core and not through the outer core, as well as the predicted discrepancy in density within the core.
13. Aided by grants from Research Corporation and the Arizona State University Grants Committee. We thank Kurt Fredriksson for assistance and advice. Charles Lewis and Paul Soules assisted with sample preparations, and Frank Wood helped with the microprobe measurements. Meteorites have kindly been made available by C. B. Moore (Nininger Meteorite Collection, Arizona State Univ.), K. Fredriksson and R. Clarke (U.S. Nat. Museum), V. Mansen (Amer. Museum Nat. Hist.), E. Olsen (Chicago Field Museum), C. Frondel (Harvard Univ.), G. Kurat (Vienna Museum), O. R. van Eeden (Geol. Surv. of South Africa), H. H. Nininger (Sedona, Ariz.), and L. O. Giacomelli (Buenos Aires). Contribution 28 from the Center for Meteorite Studies, Arizona State Univ.

13 November 1967

Utah Jet: A Vitrinite with Aberrant Properties

Abstract. *The gem-grade jet found in Upper Cretaceous rocks of the Jet Basin, Wayne County, Utah, has been shown to be a vitrinitic, high-volatile B bituminous coal with aberrant chemical constitution. The residual structure is entirely that of taxodiaceous conifer wood. The abnormally high volatile content (62 percent) and low reflectance (0.25 percent) of Utah jet compared with other vitrinites of similar rank is produced by the unusual derivatives of cellulose and lignin of which the woody structure is composed.*

Jet is a lustrous, tough, firmly compact variety of coal that breaks with a glassy, conchoidal fracture, takes a high polish, and, compared with other coals, is rather free of shrinkage cracks (Fig. 1A). It is also remarkably stable on exposure to air—that is, it checks and weathers very little even on prolonged exposure. From prehistoric times it has been cut, polished, and used as a gemstone for both decorative and magical purposes. The classic locality is Whitby, Yorkshire, England, and vicinity, where jetified logs and smaller pieces of jet occur in lower Lias (Jurassic) carbonaceous shales (*1*). Toward the end of the past century, over a thousand persons were employed in the production of jet jewelry in Whitby, but the vogue passed, and the industry is practically extinct today. Gem-grade jet is known also from other parts of the world—Spain, for example (*2*). Although there are numerous references to jet in the literature, its petrologic nature has never been satisfactorily explained.

A variety of coal material similar in properties to Whitby jet occurs in Upper Cretaceous rocks of the Jet Basin, Wayne County, Utah. It was mined commercially for gem jet from 1919 to 1925. One of us (R.W.K.) did reconnaissance field work for the Utah Geological and Mineralogical Survey in the Jet Basin in 1964 and collected samples for analysis. The samples were collected in the SE ¼ of Sec. 22, T30S, R10E, Wayne County.

Jet Basin is a steep-walled valley located nearly on the Wayne-Garfield county line, southeastern central Utah. The basin lies on the northeast flank of Table Mountain, one of the laccolithic bodies of the Henry Mountains. Jet Basin is the breached nose of an anticlinal fold that plunges to the north (*3*). The steep southern walls of this basin are composed of gray to black, montmorillonitic marine shales of the Tununk shale member of the Mancos formation of late Cretaceous age. These shales overlie pinkish-gray sandstone and conglomerate of the Dakota sandstone.

Jet occurs discontinously in an irregular layer of carbonaceous shale, 6 to 10 feet (20 to 32 m) thick, that crops out about 15 feet stratigraphically above the Tununk-Dakota contact. The layer becomes discontinuous on the southwest and west sides of Jet Basin; in this area petrified wood occurs instead of jet. The carbonaceous shale in which the jet occurs is subjacent to a thin, dark gray limestone containing numerous fossil mollusks (*Gryphaea newberryi*).

The external morphology of large pieces of jet that have been eroded from the shale resembles that of weathered logs. Jet occurs, *in situ*, in irregu-

lar masses, but local residents report that these can sometimes be traced into masses that resemble tree branches or roots. The masses of jet show some cracks, and the most prominent of these are apparently parallel to the bedding planes of the surrounding shale. Structure identifiable as that of wood can be observed on occasional hand specimens with a hand lens, but lustrous areas of conchoidal fracture seen in some specimens do not show any obvious relation to such structure.

Spheroidal masses composed of clusters of acicular, white to yellowish-white mineral matter occur in some samples of the jet. This material was identified by x-ray diffraction as a mixture of gypsum and epsomite. A yellowish earthy mineral that is common on the surface of the samples where they contact the associated carbonaceous shale was identified by the same method as hydronium jarosite.

Utah jet itself is black in hand specimen and lustrous black on fracture surfaces, with a hardness of about 2.25 and density of about 1.2. This jet would be classed petrographically as a mixture of vitrinitic and resinitic material, with macerals of the vitrinite series predominating. It is essentially 100 percent woody in structure. This jet, in common with other low-rank coals, shows little evidence of crystallographic order. X-ray diffraction examination of the jet revealed only a broad amorphous band, centered at about 4.7 Å, and a weak line at 3.37 Å. Infrared absorption spectrum analysis (Fig. 2) showed some conspicuous differences between jet and "normal" macerals of bituminous coals such as sporonite, resinite, or vitrinite. The general shape of the spectrum is somewhat different and jet deviates radically from normal coal macerals in the types of oxygen substitution. It is substituted in a different way from that of ordinary coal macerals (*4*). Analysis of the jet in a laser mass spectrometer showed that while jet grossly resembles other vitrinites in being mostly aromatic, the aliphatic groups are much more olefinic than is true of normal vitrinite.

Twenty-five readings of maximum reflectance were taken of a polished surface of jet, using standard coal petrographic methods. The mean reflectance value in oil was 0.25 percent. When reflectance data for vitrinites are plotted (Fig. 3), a rather smooth curve is obtained. Jet lies well off the curve—for its rank (approximately, carbon content), its reflectance is abnormally low (*5*).

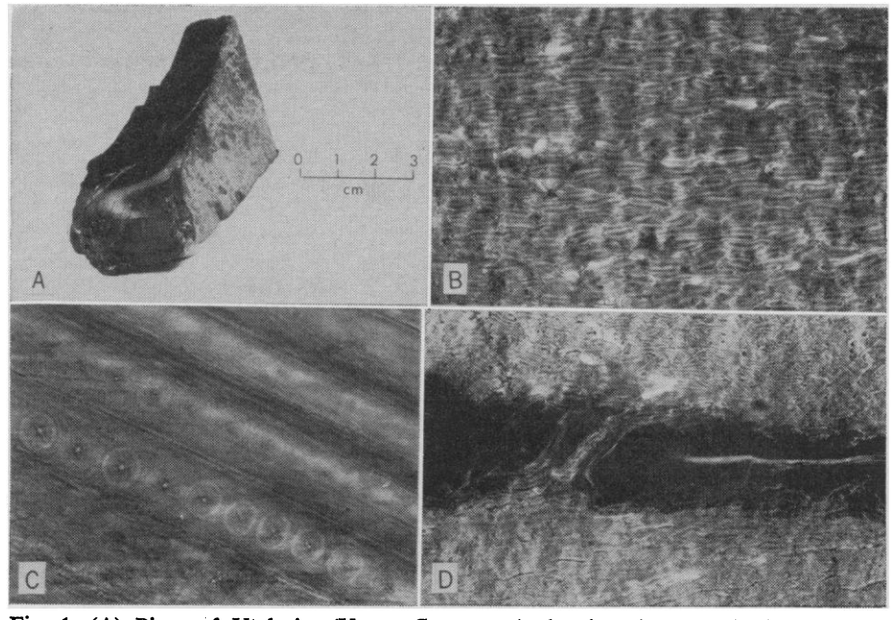

Fig. 1. (A) Piece of Utah jet (Upper Cretaceous) showing the smooth, lustrous appearance of broken surfaces. The mottled grayish surface on the right is the bedding-plane contact with the containing shale. (B to D) Photomicrographs of thin sections of Utah jet. Sections prepared by conventional polishing techniques, photographed by transmitted light. Fields shown are about 200 by 330 μ for B and D; 130 by 170 μ for C. (B) Transverse section showing the compressed tracheids and the dark (brown) fillings of the cell lumina. (C) Radial section showing circular bordered uniseriate pits. (D) Transverse section showing traumatic resin canal filled with amorphous (dark red) resinous matter.

Conventional chemical analysis of the jet (Table 1) by the methods usually employed for coals shows that Utah jet could be classified a high-volatile B bituminous coal. Chemical analysis supports other studies, particularly the reflectance data, in showing that Utah jet is a very peculiar coal. The volatile matter content of approximately 62 percent on the moisture-free basis is exceedingly high for coal material with such a high heating value, just as its low reflectance is abnormal for coal material with such a high carbon content.

From looking only at the chemical analyses, some persons have guessed that jet must be resinitic, sporonitic, or cutinitic. Yet the microstructure of Utah jet is that of highly altered coniferous wood, not that of spores and cuticles. The material that yields 62 percent volatile matter is evidently a highly modified derivative of lignin and

Table 1. Proximate and ultimate chemical analyses of Utah jet and of some other coals for comparison.

Content	Utah jet	Ohio high volatile B bituminous (*8*)	Wyoming subbituminous B (*8*)	Kentucky bituminous cannel coal (*9*)
Proximate analysis (moisture on as-received basis; all others on moisture-free basis)				
Moisture (%)	5.79	5.9	22.2	2.36
Ash (%)	1.85	4.1	5.6	10.7
Volatile matter (%)	61.82	46.5	41.9	49.6
Fixed carbon (%)	36.33	49.4	52.5	39.7
B.T.U.	14,308	13,980	12,510	13,770
Ultimate analysis (moisture-free basis)				
Carbon	76.21	76.7	69.3	71.98
Hydrogen	6.33	5.4	5.7	6.47
Nitrogen	0.63	1.4	1.3	1.16
Chlorine	0.04			
Sulfur	3.10	3.3	0.6	1.20
Oxygen	11.84	9.2	17.6	8.70

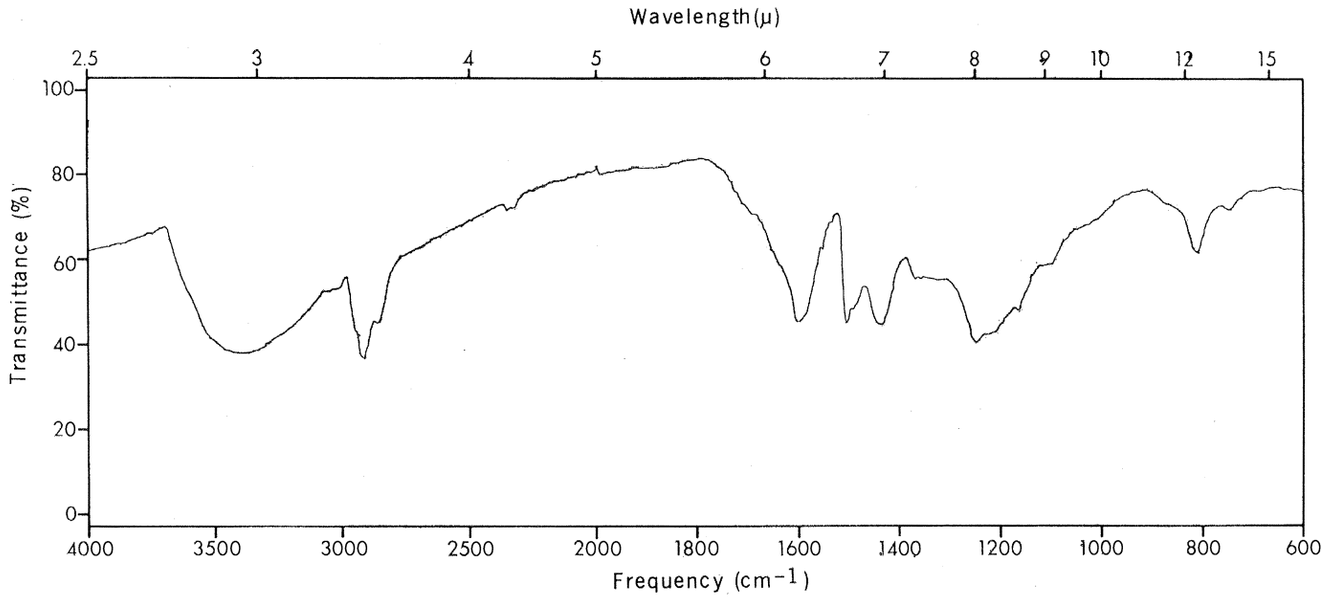

Fig. 2. Infrared absorption spectrum for Utah jet.

cellulose, differing from that present in normal coal.

In transverse sections (Fig. 1B), collapsed tracheid cell walls can be seen, along with scattered yellow bodies, presumably resin, that fill some ray parenchyma cells, certain tracheids, and occasionally bark cells. The cell structure is so collapsed that in many parts of a section it is difficult to observe the structure unless the light is very critically adjusted. The tracheids are filled with reddish brown amorphous organic matter, which rarely also fills larger cavities in the wood. In radial sections (Fig. 1C), coniferous side-wall pitting is displayed very clearly on some tracheids. Ray cells are clearly observable, and some of them indistinctly show side-wall pitting. There is no doubt that the Utah jet was derived from coniferous wood. The wood most closely resembles that of *Brachyoxylon*, a form genus of Cretaceous wood originally referred to the Araucariaceae, mostly on the basis of lack of crassulae. However, it has been pointed out (*6*) that the features of *Brachyoxylon* are really compatible with other coniferous families, and we feel that Utah jet wood is most probably taxodiaceous—the tracheary pitting and prominent wound resin canals (Fig. 1D) being especially persuasive.

The problem of the origin of Utah jet is significant for studies of the origin and diagenesis of coal. It is difficult to understand how a comparatively young coal of woody constitution—almost a pure vitrinite in conventional petrologic terms—can contain more volatile matter than cannel coal (Table 1). Samples of lignite consisting mostly of vitrinitic macerals sometimes have a volatile matter comparable to that of Utah jet, but only a fraction of its heating value. Bituminous cannel coals with high proportions of sporonite may approach jet in volatile content and heating value, but they are composed to a large extent of coalified spore coats, not of macerals in the vitrinite series.

In the origin and diagenesis of this jet, taxodiaceous wood was deposited allocthonously in clays. The wood subsequently became quite plastic as a

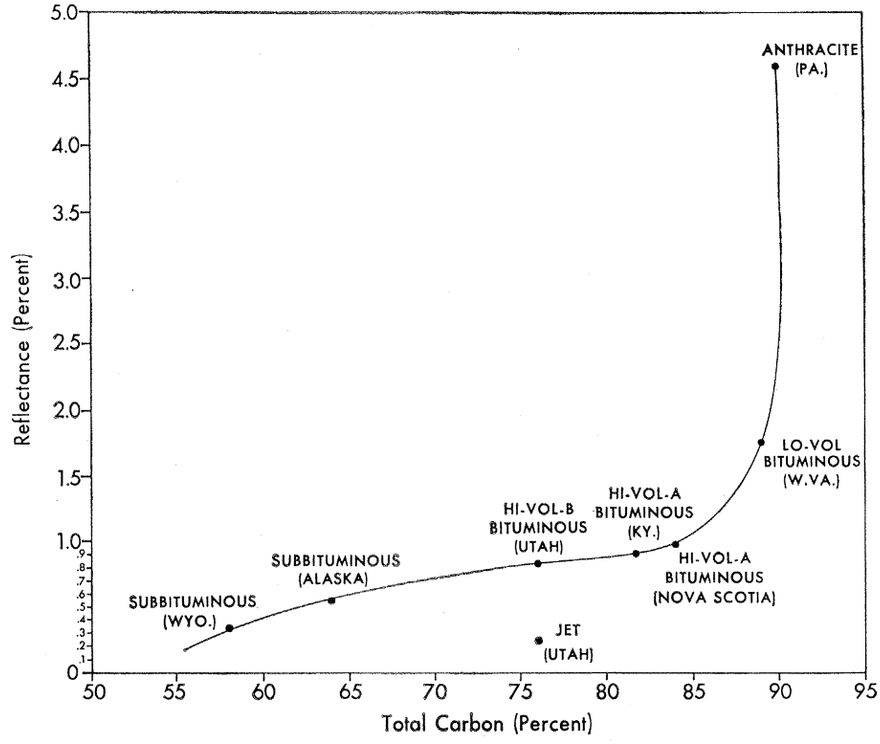

Fig. 3. Reflectance value and carbon content of Utah jet compared with mean values for vitrinites of coals of various ranks.

result of lithification in a marine environment and, perhaps, hydrothermal activity during subsequent diagenesis, with production of lignin-cellulose derivatives which are volatile, yet of comparatively high rank (*1*). The process altered the chemical nature of the coal in a direction quite different from that taken by normal vitrinite, and yet left the vitrinitic microstructure mostly intact. Although some apparently resinitic material is identifiable in thin sections, there is by no means enough to account for the high volatile content of the jet; this must depend on the properties of the amorphous organic matter that makes up the tracheids and fills other spaces in the woody structure. This provides a striking example of the proposition that ". . . from a single plant tissue various dissimilar materials may result as products of coalification" (see *7*).

ALFRED TRAVERSE
Department of Geology and Geophysics, Pennsylvania State University, University Park 16802
ROGER W. KOLVOORD
Department of Geology, University of Texas, Austin 78712

References and Notes

1. A. C. Seward, "The Jurassic Flora II," in *Catalogue of the Mesozoic Plants* (British Museum of Natural History, 1904), pp. 62–72. Seward noted similarities in the structure of English jet to araucarian wood. He observed that English jet sometimes has marine fossils embedded in it and suggested that the fossils were pressed into the wood when it was soft.
2. W. Gothan, *Kohle* (Ferdinand Enke, Stuttgart, 1937), p. 315.
3. C. B. Hunt, *U.S. Geol. Surv. Prof. Paper 228* (1953).
4. Infrared absorption spectrum made from a finely ground sample dispersed in a pressed KBr disk, analyzed with a Perkin-Elmer Model 21 instrument. For the general shape of infrared spectra of normal vitrinites; see R. A. Friedel, *Brennstoff-Chemie* 44, 24 (1963).
5. Analyses other than that of jet are values provided by R. R. Dutcher, personal communication, based on his unpublished thesis, Pennsylvania State Univ. (1960).
6. I. W. Bailey, *Ann. Bot.* 47, 153 (1933).
7. W. Spackman and E. S. Barghoorn, in *Coal Science*, P. H. Given, Ed. (Advances in Chemistry, series 55) (American Chemical Society, Washington, D.C., 1966), p. 706.
8. Recalculated from Bureau of Mines Staff, *U.S. Bur. Mines Inform. Circ. 7691*, 45 (1954).
9. Recalculated from E. S. Moore, *Coal* (Wiley, New York, ed. 2, 1940), p. 100.
10. We acknowledge the assistance of R. R. Dutcher and J. C. Crelling with reflectance measurements, P. H. Given with infrared absorption spectrum analysis and interpretation, F. J. Vastola with laser mass spectrometer data and interpretation, as well as the advice of J. M. Schopf and the late J. A. Harrison. G. B. Baetcke identified *G. newberryi*, and J. R. Odekirk made preliminary microscopic examinations of samples of the jet.
11. Publication authorized by the director, Utah Geological and Mineralogical Survey.

23 October 1967

Venus: Uniformity of Clouds, and Photography

Abstract. *Photographs of Earth at a resolution of about 600 kilometers were compared to pictures of Venus taken from Earth at about the same resolution. Under these conditions Earth appears very heavily covered by clouds. Since details on the surface of Earth can be recorded from Earth orbit, it may be possible to photograph portions of the surface of Venus, through openings in the clouds, from an orbiting satellite.*

Photography of the surface of Venus from an orbiting spacecraft may be more rewarding than appears from study of our current pictures of Venus. This possibility is suggested by pictures of Earth taken from Moon by Lunar Orbiters I and V; these views show Earth at a surface resolution of about 7 km and with a cloud cover of at least 50 percent. In a picture taken by Lunar Orbiter I on 23 August 1966, gaps in the clouds appear small and widely scattered except for one area, 700 km in diameter, in the South Atlantic Ocean near the African coast. It seemed possible that, if this view of Earth were photographed in a manner similar to that used to record Venus from Earth, the reduced surface resolution (500 to 700 km) might produce a nearly featureless image of our planet.

This idea was explored by photographing a back-illuminated, positive transparency of the LOP-I picture of Earth. The contrast of this transparency was adjusted to a maximum of 6.3:1, measured between clouds and the darkest ocean surface; of course, most adjacent details were usually of much lower contrast. The laboratory photograph was made on Kodak Plus-X film with a lens of 135-mm focal length, stopped to *f*/70 by means of a 1.93-mm aperture. A flame from a cigarette lighter, held in front of this aperture, simulated the terrestrial air turbulence during the 0.5-second exposure. This optical system formed an image of Earth, 4.36 mm in diameter, that showed a limiting resolution of about 600 km. The size, resolution, and effect of film grain in this image are similar to those in an image of Venus made with an Earth-based telescope of 304-mm (12-inch) aperture at a focal ratio of *f*/70.

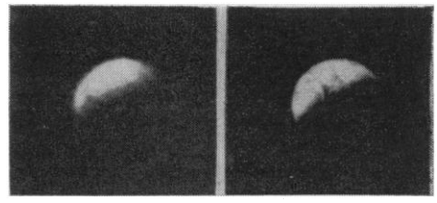

Fig. 1. (Left) Venus photographed in ultraviolet light with 304-cm reflector at Lick Observatory. (Right) Earth pictured by Lunar Orbiter I and rephotographed on Kodak Plus-X film at *f*/70 to obtain an image size of 4.36 mm.

An enlargement of this image was compared (Fig. 1) with a photograph of Venus taken in ultraviolet light with the 304-cm (120-inch) reflector at Lick Observatory. Details on Venus are very faint, even in a high-contrast print made from an ultraviolet record; normal white-light photographs of Venus show on details.

While the low-resolution view of Earth does reveal a few dark areas, it is sufficiently like the picture of Venus to rather firmly discourage an inhabitant of Mars, for example, from ever expecting to record many surface details on either planet.

Furthermore, this same comparison illustrates the need for careful study of orbital photography of Venus before conclusion that such a mission would be useless. Photographs of Earth taken by astronauts and by weather satellites show considerable surface detail through what are essentially holes in a fairly uniform cloud cover. Surface details may also be found in images of Venus taken from orbit by use of a selection of filters in the visible and ultraviolet spectrum with a camera capable of resolution of 1 to 3 km.

Venus would in fact appear quite featureless from Earth even if there were substantial gaps in the clouds. The high surface temperature on Venus eliminates the presence of oceans, which appear very dark in photographs of Earth. Most of the details in low-resolution pictures of Earth, taken from space, are caused by the contrast between oceans and clouds. On Venus, dry land areas would be of low contrast relative to the clouds and would be difficult to record in Earth-based photography.

GEORGE T. KEENE
Apparatus Division, Eastman Kodak Company, Rochester, New York

15 November 1967