sorptions at 3 μ observed over the polar cap edge (3) and dark limb absorptions near 12 μ. The possible relations among these observations are under study.

KENNETH C. HERR
GEORGE C. PIMENTEL
Department of Chemistry and Space Sciences Laboratory, University of California, Berkeley

References and Notes

1. Mariner 6 and 7 were NASA missions managed by the Jet Propulsion Laboratory (JPL) and directed by Project Manager H. M. Schurmeier.
2. The spectrometers were designed and constructed by the authors in the chemistry department and Space Sciences Laboratory at the University of California, at Berkeley.
3. The manner of illumination and rate of deposition have been described [K. C. Herr and G. C. Pimentel, *Science* **166**, 496 (1969)].
4. Analogous transmission spikes are observed in transmission spectra of molecular solids. They have been observed, for example, for solid carbon monoxide by G. E. Ewing and G. C. Pimentel [*J. Chem. Phys.* **35**, 925 (1961)]; see also G. E. Ewing, thesis, University of California, Berkeley (1960).
5. These trajectory calculations are based on JPL Pegasis calculations made for Mariner 6 after encounter and for Mariner 7 on 8 August 1969. Because the Mariner 7 spacecraft experienced a pre-encounter orbit anomaly, altitudes were inferred from the spectra themselves. All times are Greenwich mean times at the moment of observation of Mars.

10 October 1969

Lunar Igneous Intrusions

Abstract. *Photographs taken from Apollo 10 and 11 reveal a number of probable igneous intrusions, including three probable dikes that crosscut the wall and floor of an unnamed 75-kilometer crater on the lunar farside. These intrusions are distinguished by their setting, textures, structures, and brightness relative to the surrounding materials. Recognition of these probable igneous intrusions in the lunar highlands supports the indications of the heterogeneity of lunar materials and the plausibility of intrusive igneous activity, in addition to extrusive volcanism, on the moon.*

On the Apollo 10 and 11 missions, a number of regions on the lunar farside were photographed. Previous photographic coverage of these regions was provided by the unmanned Luna and Lunar Orbiter spacecraft. However, the resolution, sun angle, and viewing direction of Apollo photography helped delineate features and structures not evident in previous photography.

One of these regions includes an unnamed (1), generally round, partly crenulated, relatively young, large crater, about 75 km in diameter (Fig. 1). The crater, whose center is at approximately 4°N, 120°E on the Lunar Farside Chart (LFC-1), is situated in as yet undivided highland materials in the general area previously known as the "Soviet Mountains" (2). It exhibits a raised, wavy, and sculptured rim and terraced interior walls which suggest, although not unequivocally, an impact origin. It is not clear from the photographs whether the crater is rayed; the presence of an extensive ray system is held by most as a strong criterion for the impact origin of the younger lunar craters.

The crater is a few kilometers deep, and the depth of its floor in relation to the rim crest varies with the amount of fill. The crater wall is terraced, up to six levels, and the highest terrace is steeper than most, a feature common to craters of similar size. The floor of the crater displays a prominent central peak that is forked. It forms a unique Y-shape (Figs. 1 and 2), with the right arm trending nearly due north.

Apollo 10 and 11 photographs of this crater are oblique views, taken at high sun illumination with a hand-held Hasselblad camera from an altitude of about 110 km above the lunar surface. On Apollo 10, both the 80-mm lens (frames 4470 to 4474) and the 250-mm lens (frames 4349 to 4364) were used. Similarly, on the Apollo 11 mission the crater was photographed in medium resolution (frames 5419 to 5422, 6540 to 6543, and 6271) and in high resolution (frames 6448 and 6449). Both missions provided stereoscopic coverage of the crater and its environs.

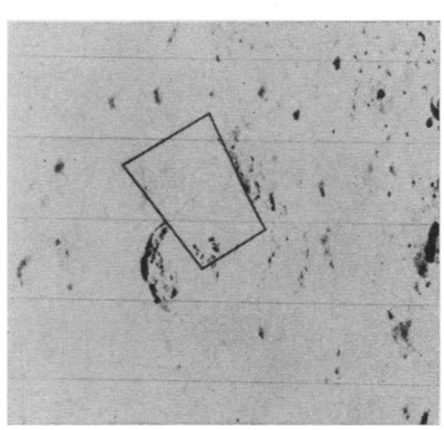

Fig. 1. Part of Lunar Orbiter I frame M-136 showing crater 211 (1) nearly in the center. Note the Y-shaped central peaks. A detail of the marked area is shown in Fig. 2.

Distinct layering is displayed along the crater walls, where rock ledges protrude at several levels within the wall terraces. At the rim crest, the first ledge of rock is in evidence along the crenulations, as in the middle of the right hand edge of Fig. 2 (Apollo 10, frame 4350). At lower levels on the wall, discontinuous rock ledges could be traced for distances of 10 km or more. These ledges are indicative of horizontal bedding and are different in their setting and textural characteristics from material produced by slumping and mass wasting along the walls.

In the northern segment of the crater wall there are at least four different rock types (Fig. 2). These are distinguished by their setting, textures, structures, and relative brightness. The first rock type is shown in area *A*, Fig. 2. It represents a mantle of relatively young material of low albedo. This material appears identical to that which can be seen in a pool-like depression beyond the rim crest of the crater (*A'*). The latter is part of an extensive unit that covers a region of more than several thousand square kilometers, as seen in the photographs from Apollo 8 (3). The textures and structures displayed by this unit are reminiscent of those exhibited by terrestrial lava flows. Wrinkles on its surface are common, especially at the lower parts of a given topographic level. The flow fronts are convex downslope and appear to be the result of a gentle or slow flow of molten material that has moved from higher to lower ground. There is also evidence of collapsed pool surfaces, as in the upper left edge of Fig. 2. An alternative interpretation of this mantling material would be that it is a debris flow or rock glacier. However, the aforementioned criteria signify an extrusive volcanic origin, that is, a lava flow.

The second rock type (area *B*, Fig. 2) is characterized by a very high albedo. Its texture is clearly different from that displayed by the rest of the crater wall. The latter represents a third rock type, a typical segment of which is marked *C* in the same figure. The brightest segment of the wall (area *B*) is characterized by a great number of massive domical hills. These are separated by shallow furrows filled by darker, probably fine-grained, debris material. These features indicate that this segment of the crater wall is made of a rock type which is dissimilar to that exposed elsewhere along the crater wall. The bright material may represent an exposure of intrusive, probably batholithic, rock mass (*4*).

It must be stated that the unusually high albedo of this intrusive material is not due to a mantle of bright material. Bright rays from the crater Giordano Bruno (located at 37.7°N, 102.5°E on LFC-1: barely seen on Lunar Orbiter V frame M-181 and best seen on Apollo 8 frame 2209), which were erroneously interpreted from Luna III photographs as the "Soviet Mountains" (*2*), are evident in the vicinity of the crater. The characteristics of these bright rays are easily distinguishable from those of what is here interpreted as an intrusive rock mass.

Two major zones of extremely dark rocks within the bright segment of the northern wall of the crater represent the fourth rock type. The one to the left (area *D*, Fig. 2) displays fine, closely spaced, discontinuous, linear outcrops of dark rock, which crosscut the wall material. The outcrops are localized in a zone 2 km long, with an average width of about 0.5 km. This zone, which trends in a northwesterly direction, is texturally different and is much darker than the enclosing wall materials. By earth analogy this zone most probably represents a dike (*5*) and is here so interpreted. An alternative explanation would be that it is a segment of the layered wall material which has rotated through slumping to stand on edge. However, the appearance of this rock and its setting support the interpretation as a dike.

Farther east, to the right of this dike, is another zone of the crater wall which displays a similar dark color. In this case, the first ledge below the top is nearly black. A dark zone about 2 km wide extends for a short distance beyond the rim crest of the crater. This zone includes a linear structure that may also represent a dike (*D'*, Fig. 2). Also in this area are dark layers overlying the lower wall terraces. The latter occurrence, however, probably represents a shedding from the upper rock mass.

A slightly arcuate and discontinuous line of rock that outcrops within the crater floor represents a third probable dike (*D''*). The outcrops are similar to the exposed rocks of the aforementioned probable intrusions. Here again, the rocks are texturally different from the enclosing material. The discontinuous outcrops stand above the surrounding terrain and appear much darker than it.

Outcrops of dark rock are also evident on top of the central peaks, especially along the sides of the right arm of the Y-shaped chain of mountains. These occurrences of dark material on the central peaks may be related to the intrusive rock material. They represent either extensions of the same material or a similar rock type that was brought to the surface by the cratering event (*6*).

The Flamsteed P ring in Oceanus Procellarum has been interpreted as a ring dike (*7*). A prominent zone within one of the central peaks of the crater Copernicus has also been interpreted as a possible lunar dike (*8*). The recognition of this new locality of probable igneous intrusions in the farside highlands is strong evidence for the heterogeneity of lunar materials. It lends additional support to the plausibility of intrusive igneous activity, in addition to extrusive volcanism, on the moon.

Fig. 2. Apollo 10 frame 4350 showing four different types of materials. *A*, Mantling material which may represent lava flows of the same material in the pool-like depression *A'*. *B*, High albedo material forming domical hills that may represent part of a batholithic intrusion. *C*, A segment of the crater wall typifying the character of the wall material exposed beyond the coverage of this photograph. *D*, *D'*, and *D''*, Dark wall-like zones (marked with dashed lines) which may represent the outcrops of dikes.

FAROUK EL-BAZ

Lunar Exploration Department, Bellcomm, Inc., Washington, D.C. 20024

References and Notes

1. The crater is given the number 211 on the (G) Lunar Farside Chart (LFC-1), 1967 edition.
2. E. A. Whitaker, "Comparison with Luna III photographs," in *Analysis of Apollo 8 Photography and Visual Observations* (U.S. Government Printing Office, Washington, D.C.), in press.
3. H. G. Wilshire and F. El-Baz, "Possible volcanic features—landforms," in *ibid.*; D. E. Wilhelms, D. E. Stuart-Alexander, K. A. Howard, "Lunar farside," in *ibid.*
4. Batholithic, meaning that it may be part of a mass of igneous intrusive rock that crystallized beneath the crust and whose diameter and depth are unknown. The fact that this bright mass of rock displays steep contacts supports this interpretation. The exposed portion of the rock mass appears to dip outward from the crater wall.
5. A dike is a wall-like tabular body of igneous rock that cuts across the structure of adjacent materials.
6. Additional photographs at higher resolutions are planned on future Apollo missions; these will help delineate these relations.
7. J. A. O'Keefe, P. D. Lowman, Jr., W. S. Cameron, *Science* **155**, 77 (1967).
8. F. El-Baz, *Geologic Characteristics of the Nine Lunar Landing Mission Sites Recommended by the Group for Lunar Exploration Planning*, Bellcomm TR-68-340-1, Washington, D.C. (1968).

9 September 1969