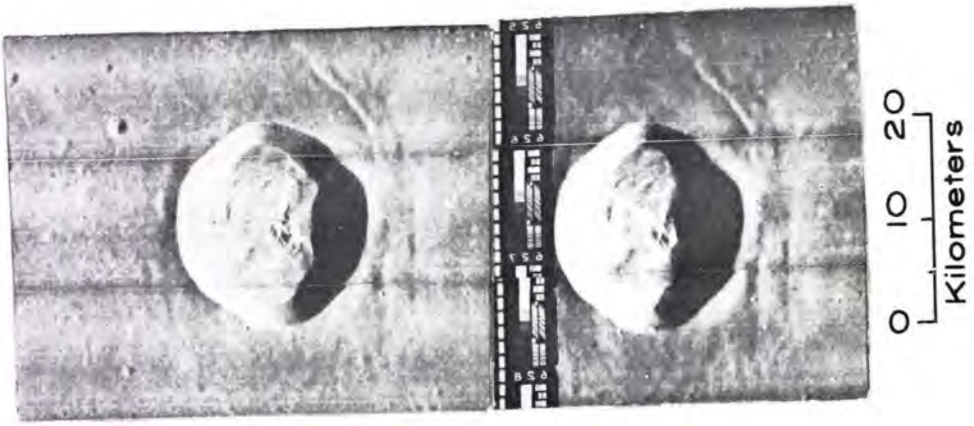

FRONTISPIECE.

FRONTISPIECE. High resolution stereo pair of Dawes, photographed by Lunar Orbiter IV in May 1967. The right photographs is from the 15th orbit (Frame no. 78) and the left photograph from the 16th orbit (Frame no. 85), taken about 12 hours later.

J. R. DONALDSON
Autometric Operation, Raytheon Co.
Houston, Texas 77058

The Lunar Crater Dawes

. . . one of the most significant features which could provide an insight to lunar volcanism.

(*Abstract on page 240*)

INTRODUCTION

THE INTENT OF THIS paper is to call attention to photogeological evidences of lunar volcanism as manifested by the lunar crater Dawes and present this interpretation for consideration. Dawes, isolated at the juncture of Mare Serenitatis and Mare Tranquillitatis (Figure 1), possesses distinctive features that are postulated to relate to its origin. These features consist of an exposure of strata on the crater walls near the rim, its lava-like floor surface, an irregular rim fracture pattern, the absence of ejecta materials or a ray pattern associated with impact or eruptive forces, as well as its overall relationship to the surrounding mare basins. The crater resembles a collapse caldera or volcanic sink which in essence was formed by the collapse of the overlying mare materials as the underlying magma withdrew from the fracture zone. Very little has been reported concerning the crater Dawes and it is the author's opinion that Dawes is one of the most significant lunar craters which could provide an insight to lunar volcanism.

Many lunar craters have been observed from Earth and studied from earth-based photographs but only a few of the larger rayed craters have been subjected to detailed analysis using the recently acquired Lunar Orbiter photography. The Orbiter spacecraft photographic system carries a dual framing camera with a high-resolution (24 inch $f/5.6$) lens and a medium (80 mm. $f/5.6$) lens (Kosofsky 1966). Lunar Orbiter IV photographed Dawes in part of its overall mission of covering almost all of the lunar frontside and backside. Previous observations of the crater were from earthbased study. The Frontispiece is a stereo pair of high resolution photographs of Dawes taken by Lunar Orbiter IV in May, 1967. The photography, although lacking in metric qualities (as do all line-scan systems), pro-

ABSTRACT: *Many of the lunar craters probably were formed by meteoritic impact and many may have been stimulated by such an action. In addition, there are those such as Dawes that appear to be volcanic in origin, although this is not to say that a meteoritic impact possibly could have started the chain of events leading to its present state of existence. But in the absence of features associated with an impact, the crater Dawes is an outstanding example of endogenous origin. This hypothesis, however, is not compatible with the contemporary geologic interpretation; that lends itself more to an impact theory. Based on a geologic analysis of the area on a detailed basis relative to origins, a geologic map of the crater is suggested. Although this approach to the presentation of Dawes has its implicit ambiguities, it nevertheless stresses a map relating more to origin rather than to a fixed system correlating all craters with one theoretical approach.*

vides better resolution than that obtainable on earth-based photography.

The right photograph was acquired on orbit 15 and the left photograph on orbit 16 approximately 12 hours later which accounts for the shadow positional differences on the crater floor. When viewing the stereo pair, the reader can readily see that the line-scan devices introduce distortions. The scale of the photographs is approximately 1:619,000.

Dawes was selected by the Lunar Orbiter Program Office as one of several lunar sites of potential scientific interest and it was included in the planning for Lunar Orbiter Mission V. In August, 1967, the last of the highly successful Lunar Orbiters photo-

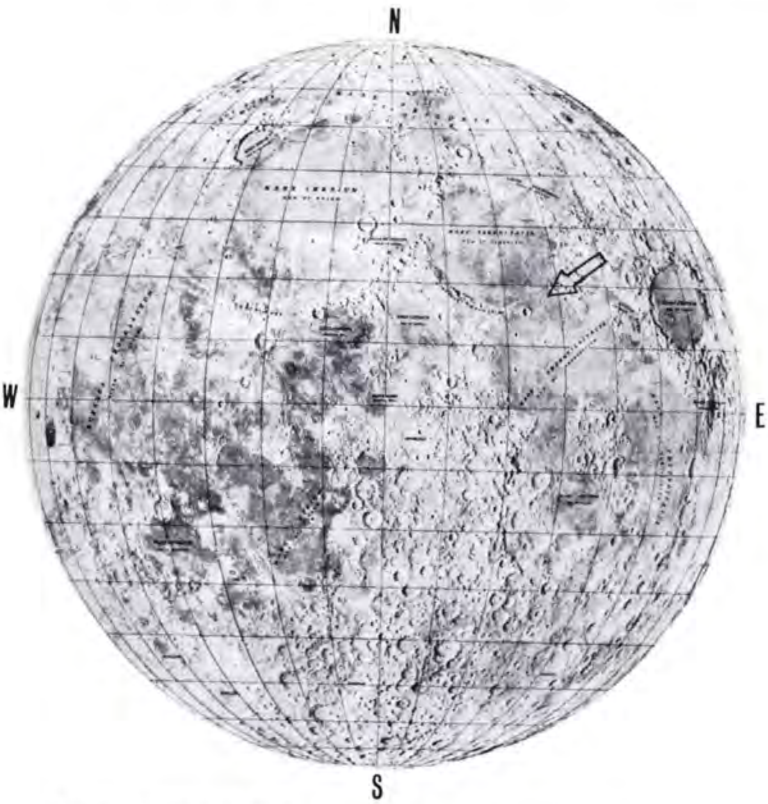

FIG. 1. Location of the lunar crater Dawes (17°12′N, 26°20′)E as indicated by arrow

FIG. 2. Medium resolution photograph taken by Lunar Orbiter V in August 1967. Area outlined is high resolution coverage shown in Figure 4.

graphed Dawes with the dual camera system producing high-resolution images of 2.4 meters, and on the moderate-resolution photographs provided 19.3 meters ground resolution as well as wide area coverage. Each of these systems was affected by a malfunction in the on-board processing unit which resulted in streaks and spots. Although these imperfections are distracting, they obscure but little of the excellent detail. Figure 2 presents a medium-resolution photograph of Dawes taken by Lunar Orbiter V in August, 1967. Clearly, the photograph defines Dawes' distinctive features. From the photograph a detailed description of Dawes and its formation can be ascertained. Figure 3, a high resolution section of the same frame (no. 70) of photography, also from Orbiter V, greatly assists in the establishment of a hypothesis on Dawes' origin as well as creating awe.

Description

Dawes, named after an English amateur astronomer, is located at 17°12′N and 26°20′E. It could be classed as a small-size crater measuring 17.8 km in diameter north-south and 15.9 km. east-west. Its rim pattern is polygonal or more precisely an irregular tridecagon. Such an irregular rim pattern is common to an earth caldera as opposed to a circular pattern of impact features such as a meteoritic crater, or volcanic cones and vents.

The crater is located in mare terrain that is primarily rolling and dissected with small craters and rilles (see Frontispiece). Most of the small craters in the surrounding terrain are shallow, generally with a circular rim pattern, and some are distorted due to roughness of the terrain on which they are superimposed. The rilles are straight, with a northeast-southwest alinement or trend, and appear to be filled with the same type of materials making up the mare surface. These rilles probably are faults which have developed in alinement with a belt or zone of structural weakness extending into the highland masses to the east and west and form a structural division of the two mare basins. These topographic features are indicated on Aeronautical Chart and Information Center LAC 42 (Figure 4).

In addition, as indicated by LAC 42, the slope of the surrounding terrain is away from the rim of the crater Dawes which is 300 meters higher than the mare surface.* This

---

* As noted on the LAC, the probable error of the localized relative elevations is from 100 meters near the lunar center to 300 meters at 70° departure from the center.

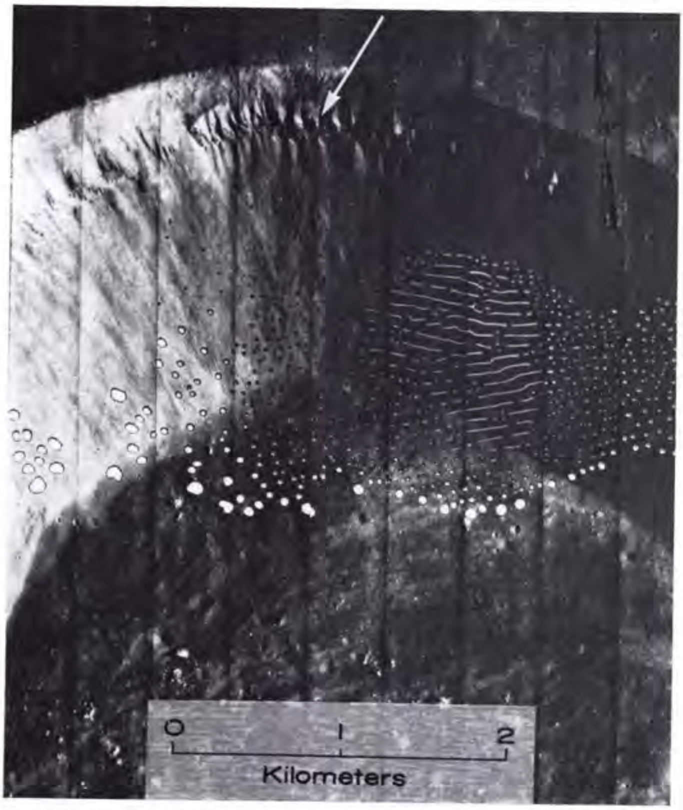

FIG. 3. A section of high resolution photography from Lunar Orbiter V. Arrow indicates rock outcrop believed to be igneous sill.

would tend to indicate the presence of a small anticlinal structure with the apex in the proximity of Dawes and the limbs sloping outward from the crater. To the east of Dawes are large ridges which almost circle one-half the crater (see Figure 2). These ridges probably are remnants of dikes associated with the early stages of the formation of the crater and the associated troughs next to the ridges are related to fracturing in the surrounding mare terrain. Surrounding most of the crater are wrinkle-like patterns which could have been formed by pyroclastics during the development of Dawes.

From the USGS geologic map (Carr 1966) covering the same area as LAC 42, the surrounding mare terrain is denoted as volcanic materials probably including both ash and lava flows belonging to the Procellarum Group of the Imbrian System. The rim materials are considered to be poorly sorted impact ejecta with some volcanic materials belonging to the Eratosthenian System as is the floor material of shock-crushed breccia or volcanics. The walls have been interpreted as freshly generated talus or exposed bedrock belonging to Copernican Age. To the east of the crater, near the rim and in the positions occupied by the previously mentioned ridges, two small faults are indicated. Several larger faults are delineated farther to the north of the crater. This geologic interpretation uses earth-based photography and observations as principal sources of information.

The outlined area on Figure 2 shows the position and extent of the crater segment shown as the high resolution image of Dawes (Figure 3). Approximately 250 meters down from the rim on the crater wall is an outcrop of more resistant strata which is indicated by an arrow on Figure 3. Once this feature is resolved on a photograph of this scale (1:25,300) it is also easily recognizable on the medium resolution photograph (Figure 2) which has a scale of 1:192,500. This outcrop could be a zone of stratification or compaction, although it is the author's opinion that it is an igneous intrusion such as a sill.

The floor of the crater resembles many relatively recent earth-type lava flows known

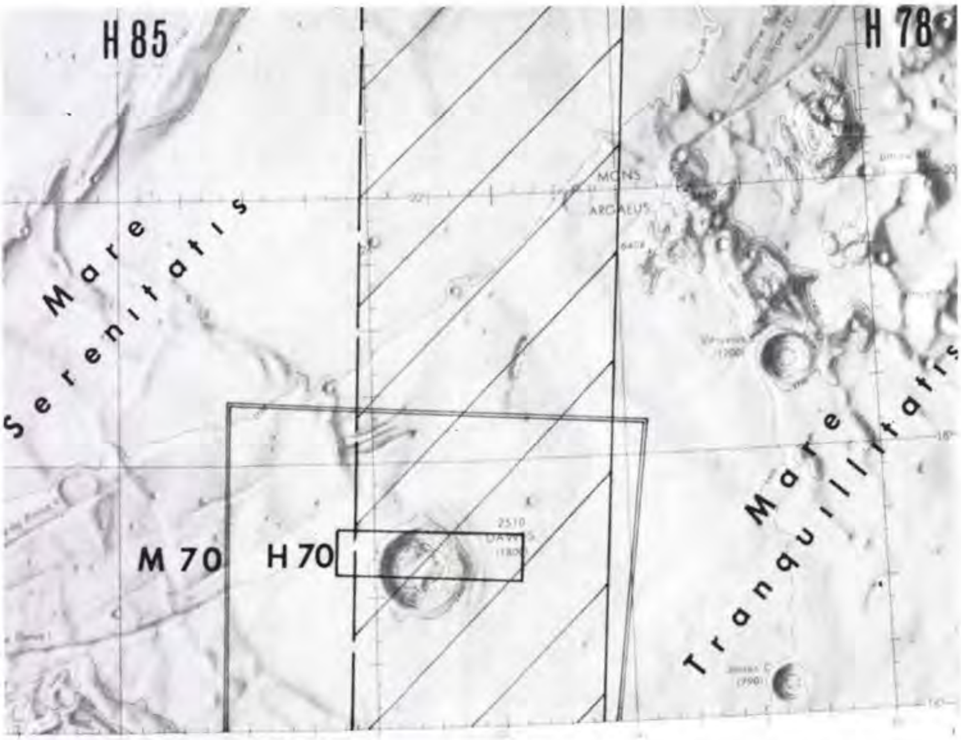

FIG. 4. LAC 41 (Mare Serenitatis) showing relation of crater Dawes to surrounding terrain and coverage of Lunar Orbiter. Double line indicates area covered by Orbiter V medium resolution photograph (M70). Rectangular outline is area of Orbiter V high resolution photograph (H70). Area covered by Orbiter IV covers entire section of the LAC and frame coverage is indicated by H 85 and H 78. Diagonal lines indicate stereo overlap of the Orbiter IV frames.

as pahoehoe. There are a few large blocks or boulders on the floor that probably were derived from the outcrop near the rim, although there are no tracks or trails leading to them. Other types of debris or talus from the crater walls and rim edge are present on the floor and could have filled and covered the boulder avenues, or the hardness of the floor materials in many places may be such that it would preclude evidence of rolling rocks and debris. There are several prominences on the crater floor that do not appear to be extraneous but rather a part of the overall floor mass. Furthermore, these prominences do not resemble the central peaks of many of the lunar craters; these are more in the form of spines from a central intrusive igneous body.

The intersection of the floor with the crater walls is sharp and forms five visible facies. The pattern formed by the floor-wall junctions seem to present a decagon although part of the area is obscured by shadow. As mentioned previously, the rim fracture pattern forms 13 sides. If the rim pattern is projected to the 10 on the floor there would be a loss of at least three facies of the crater walls. This would tend to indicate a triangular arrangment with principal bases at the rim and apexes toward the floor, which in the author's opinion is evidence of a downward displacement of the center mass relative to the walls. Vertical striations on the crater wall tend to enhance this evidence of gravitational movement although these striations could have been formed by the movement of talus type materials down the walls. Figure 5 helps to illustrate this point. Considering all of the aforementioned distinctive features of the crater Dawes, the following theory is postulated on its origin.

ANALYSIS

After the two principal mare basins (Mare Serenitatis and Tranquillitatis) were formed, as a consequence of the earlier stages of lunar geologic history, a large magmatic body developed and intruded near the present site of Dawes (Figure 6a). This intrusive body as it moved upward created a deformation of the

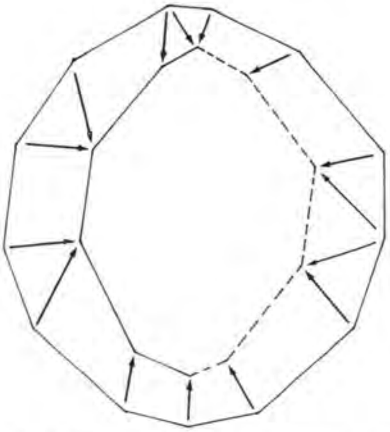

FIG. 5. Schematic showing polyagonal rim and floor fracture pattern. Rim forms a tridecagon and floor a decagon. Movement of floor mass relative to walls is downward as indicated by arrows.

country materials and an updoming of the roof or mare surface material. This would assist in explaining the presence of the small anticlinal structure centered at Dawes. Ruptures developing in the mare surface materials were probably more or less synchronus with the overall structural deformation and magmatic intrusion but to illustrate the point properly Figure 6b presents a second stage in the evolution of Dawes. The ruptures were formed both vertically and horizontally with the largest being near the apex of the central mass.

Two zones of interaction were created in the initial stages of development: a zone of structure and a zone of flowage. In the zone of structure, principal fractures were probably created vertically while secondary ones were developing horizontally near the surface. In the zone of flowage, the invading magma developed apophyses which intersected and filled the fractures as it moved upward. As the two zones combined, sills were formed in the horizontal fractures whereas the dikes were formed in the vertical ones. Sequentially as the intruding mass neared the lunar surface, the overlying mare materials collapsed due to the interaction of the two zones (Figure 6c).

With the overlying materials slumping or breaking off as a large fault block into the magmatic intrusion, it probably reached a point of subsidence as the materials were dissolved. Prior to the subsidence of the event there was possibly some eruptive type action which could account for some of the wrinkle-like patterns surrounding most of the crater. The ultimate event was total subsidence and cooling of the magma with sills and dikes cut off from the parent intrusive body (Figure 6d). The evidence of a sill is the outcrop of the more resistant strata on the upper crater wall and dikes probably are present to the east of the crater rim in the form of the ridges. The magma probably cooled rapidly, churning as the materials dissolved into it, which would account for the ropey-like structure of the crater floor. Due to the slow processes of weathering on the lunar surface most of the evidence of the origin of the crater Dawes remains prima facie.

CONCLUSIONS

It is important to note that all of the above analysis follows a volcanic school of thought. However, it is not the purpose of this paper to divorce itself entirely from an impact theory recognition. Many of the lunar craters probably were formed by meteoritic impact and many may have been stimulated by such an action. In addition, there are those such as Dawes that appear to be volcanic in origin, although there is nothing to say that a meteoritic impact possibly could have started the chain of events leading to its present state of existence. But in the absence of features associated with an impact, the author will continue to stress that the crater Dawes is an outstanding example of endogenous origin.

This hypothesis, however, is not compatible

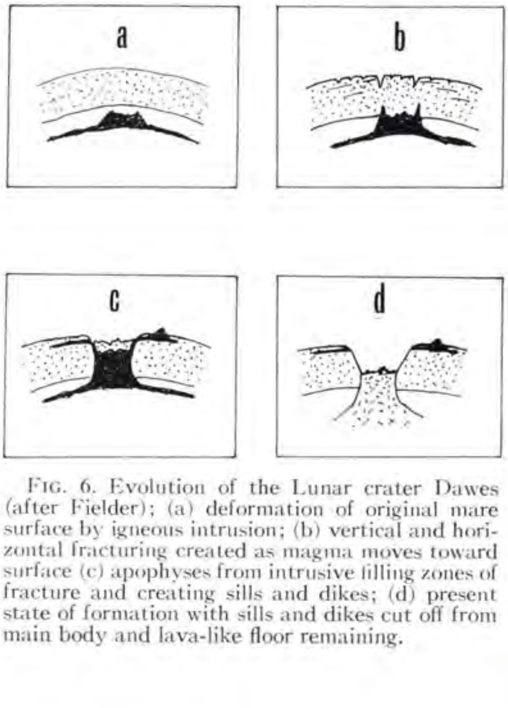

FIG. 6. Evolution of the Lunar crater Dawes (after Fielder); (a) deformation of original mare surface by igneous intrusion; (b) vertical and horizontal fracturing created as magma moves toward surface (c) apophyses from intrusive filling zones of fracture and creating sills and dikes; (d) present state of formation with sills and dikes cut off from main body and lava-like floor remaining.

with the contemporary geologic interpretation. The aforementioned geology lends itself more to an impact theory. If a geologic analysis of the area were to be undertaken on a detailed basis, the terms maria, premaria, and post-maria (terminology used by Mason, Hackman) would be more befitting to denote relative age and stratigraphic superposition. Once the relative age was assigned to the lunar feature an additional subdivision could be based on a macroscopic classification of the rocks and surface materials. Such a system of classification could use the terms: phanerites, aphanites, and pyroclastic for rocks of primary origin; psephites, phsummites and pelites for those of secondary origin; metamorphic for tertiary origin; and meteorolites for those believed to be of quaternary origin.

All of these terms would denote rock type in a very broad sense, and texture as related to origin and morphology. The terminology although not unique is certainly classic in geologic literature. Figure 7 presents a geologic map of the crater Dawes using this approach to a detailed lunar photogeologic interpretation. Although this approach to the presentation of Dawes has its implicit ambiguities, it nevertheless stresses a map relating more to origin rather than of a fixed system correlating all craters with one theoretical approach.

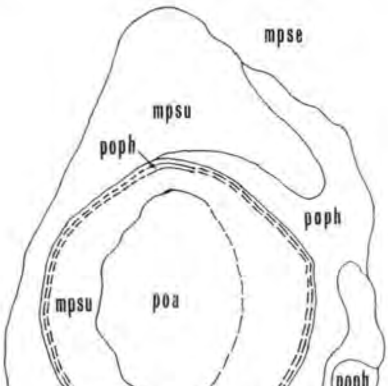

FIG. 7. Photogeology map of the lunar crater Dawes. Scale is approximately 1:192, 500.

ACKNOWLEDGMENTS

I am indebted to Frank Beatty, Chief of the Raytheon Image Group at MSC, for reviewing the manuscript and offering helpful suggestions and comments. Special thanks are due my colleagues at Raytheon, Messrs Fred Solomon, Richard Powers and Art Anderson for reading the manuscript and offering their comments.

REFERENCES

Carr, M. H., *Geology of the Moon*, Mare Serenitatis Region 1-489 (LAC 42) USGS Washington, D. C., 1966.

Fielder, G., *Lunar Geology*, Lutterworth Press, London, 1965.

Kosofsky, L. J., "Topography from Lunar Orbiter Photos," PHOTOGRAMMETRIC ENGINEERING, March 1966, pgs, 277–285.

Mason, A. C., and Hackman, Photogeologic Study of the Moon in *The Moon*, edited by Z. Kopal and A. K. Mikhailov, Academic Press, New York, 1962.

Pirsson, L. V., *Rocks and Rock Minerals*. 3rd Edition revised by Adolf Knopf, John Wiley and Sons Inc., New York, 1955.

USAF, Lunar Chart Mare Serenitatis LAC 42, Aeronautical Chart and Information Center, St. Louis, 1965.

Map Units

Post-Maria—*po*	Phanerites—*ph:*	Course grain rocks of primary origin; mostly intrusive igneous type masses, or individual bodies such as sills or dikes exposed by weathering processes and/or meteorite impact.
	Aphanites—*a:*	Fine grain rocks of primary origin; mostly extrusive igneous masses such as those resembling lava flows from fissures, joints, cracks, and surface rupture.
Maria—*m*	Psephites—*pse:*	Course grain materials of secondary origin; mostly detritals resembling rubble created by weathering processes or meteoritic impact. Some may resemble pyroclastic types.
	Psummites—*psu:*	Fine grain materials of secondary origin; mostly detritals resembling sands from weathered rock or rock materials. Some may resemble pyroclastic types.