Chapter 8

CRATER FORMS IN THE UWEINAT REGION

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ABSTRACT

The Uweinat area contains three different varieties of crater forms, namely: 1) two multi-ringed impact structures in southeast Libya, including the Oasis astrobleme and the BP structure, and two other craters of possible impact origin; 2) simple, breached, and complex volcanic craters northeast of Gebel Uweinat, some of which may be maars and other cryptoexplosion structures; and 3) a complex of large circular, shallow depressions east of Gebel Kissu in northwest Sudan. Because the number and variety of crater forms in the Uweinat area is unique, additional photogeologic interpretations are required based on computer-enhanced Landsat images or high resolution photographs from the Shuttle. These interpretations will allow detailed correlations of crater forms in this region with similar features on planetary bodies such as the Moon, Mars and Mercury.

INTRODUCTION

The eastern part of the Sahara where the borders of Egypt, Libya and Sudan meet is underlain by a Precambrian complex of metamorphic and intrusive rocks (Sandford, 1935c; Said, 1962; and Pesce, 1968). This complex is one of many that cropout in the middle of the Sahara, separating it into northern and southern parts. This "Oweinat series" (Hume, 1934, p. 55) of metamorphics is intruded by granites with subordinate rhyolites, which are believed to be of post-Carboniferous age (Pesce, 1968, p. 62). Four major intrusions average approximately 20 km in diameter including the mountains known as Gebel Babein, El-Bahri, Arkenu, and Uweinat (Fig. 8.1).

The Precambrian rocks are surrounded by hard quartzitic sandstones with highly consolidated conglomerate and syenite porphyry sheets, which are interbedded with sandstones, phonolites and trachyte sills, all of Paleozoic age (Issawi, 1980). In these Precambrian and Paleozoic rocks, Upper Cretaceous - Lower Oligocene (Meneisy and Kreuzer, 1974) basaltic and doleritic extrusions form isolated cones. Farther from the Uweinat region, only the continental Nubia Sandstone of late Mesozoic age abounds. This sandstone unit is partially

Figure 8.1 Apollo-Soyuz photograph (AST-2-127) of the Uweinat area in the eastern Sahara. Numbers identify the mountains of Babein (1), El-Bahri (2), Arkenu (3), and Uweinat (4).

covered by sand dunes and sand sheets of Quaternary age.

This area of the eastern Sahara exhibits an unusually large number of circular features, which resemble craters photographed on other planetary surfaces. In this paper features observed in Earth orbital photographs of this region will be discussed with emphasis on planetary analogies, including:

1. Multi-ringed impact structures in southeast Libya, including the "BP structure" and the "Oasis astrobleme."

2. Numerous vents including cryptoexplosion structures northeast of Gebel Uweinat in southwestern Egypt.

3. A complex of circular structures in northwest Sudan, located east-southeast of Uweinat and east of Gebel Kissu.

IMPACT STRUCTURES IN SOUTHEAST LIBYA

A stereo strip of color photographs was taken of southeastern Libya and southwestern Egypt by the Apollo-Soyuz Test Project (ASTP) mission of July 1975 (El-Baz and Mitchell, 1976). This strip included a photograph of the region of Kufra Oasis. Approximately 119 km north-northeast of Kufra, the photograph depicted a distinct, multi-ringed astrobleme (Fig. 8.2). The term "astrobleme" refers to an ancient circular feature of impact origin (Dietz, 1961, p. 51). These

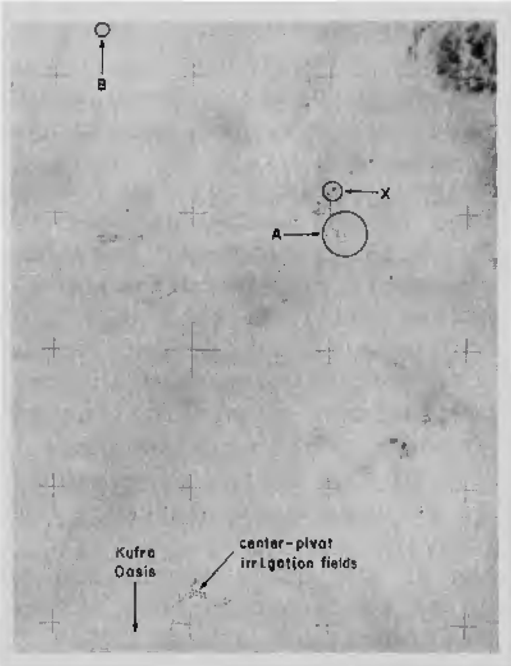

Figure 8.2 The region of Kufra Oasis in southeast Libya as photographed by the Apollo-Soyuz mission (AST-15-1244). Marked are the Oasis astrobleme (A), the BP structure (B), and a circular feature of unknown origin (X).

terrestrial features are of significant interest in comparative planetology because they constitute analogs to impact craters on planetary bodies such as the Moon, Mars and Mercury.

This circular feature was named "Oasis structure", because it was called to the attention of J. R. Underwood by geologists from the Oasis Oil Company of Libya. French and others (1974) estimated its diameter to be 11.5 km. However, study of Landsat images and Apollo-Soyuz photographs by Dietz and McHone (1979, p. 185) revealed an overall diameter of 17 km. Dietz and McHone renamed the structure the "Oasis astrobleme", further establishing its extraterrestrial origin.

The ASTP photograph of the Oasis astrobleme clearly shows a prominent central dome, about 5 km in diameter. The dome is outlined by resistant beds that form a series of discontinuous hills. There is also a faint indication of a 1 km diameter central ring, which may be a collapse structure. Thus, the multiple rings of the Oasis astrobleme (1, 5 and 17 km in diameter) make it appear similar in gross morphology to experimental explosion craters, for example the craters produced in alluvium by detonation of TNT charges.

Jones (1977) discussed several complex craters produced by detonation of TNT charges at the Defense Research Establishment, Suffield, Canada. Both the Snowball Crater and the Prairie Flat Crater particularly resemble the Oasis astrobleme. The Prairie Flat Crater was made on unconsolidated alluvial sands, in silts and clays with the water table at 6.7 m below the surface, and the sandstone bedrock at approximately 60 m depth. The resulting crater had an average rim crest diameter of 85.5 m with four inward sloping ridges measuring 43 m, 37 m, 32 m, and 17 m (Roddy, 1977, p. 227).

Multi-ringed craters abound on the Moon and the terrestrial planets, as exemplified by the well-preserved Orientale basin on the lunar west limb (Fig. 8.3). The inner part of the Orientale basin that is filled with basaltic mare material is 300 km across, and the basin exhibits four rings that are 320, 480, 620, and 920 km across. A fundamental concern in studying Orientale and similar basins on planetary bodies is the need to correctly interpret the apparent crater diameter and the structural meaning of the rings (Roddy, 1977, p. 230). Although the Orientale basin is 54 times larger than the Oasis feature, detailed study of the latter may shed more light on the formation of multi-ringed structures on planetary bodies.

The impact origin of the Oasis astrobleme has already been well established by studies of shock metamorphic effects, especially planar structures in quartz (French and others, 1974). The structure can only be dated as post-Early Cretaceous, which is the age of the Nubia Sandstone that is affected by the event (Dietz and McHone, 1979). It has been speculated that the Oasis astrobleme could possibly be the site of origin of the highly siliceous "Libyan Glass", which is also believed to have been produced by meteorite impact (Underwood, 1979).

Approximately 10 km north-northeast of the Oasis astrobleme is another circular structure (Fig. 8.2). To our knowledge, no one has explored this feature in the field, although it is rather close to the Oasis astrobleme. It shows a partial ring that is approximately 2.5 km

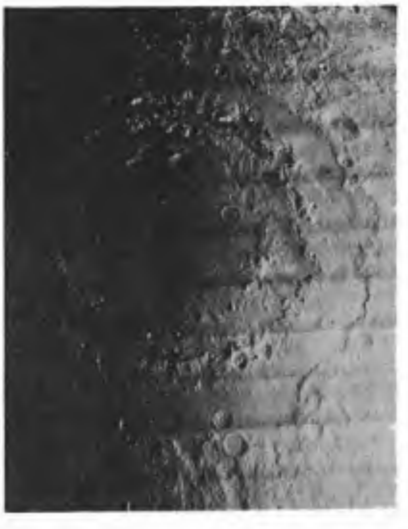

Figure 8.3 The Orientale basin on the western limb of the Moon as photographed by Lunar Orbiter IV (Frame M-187). The central part of the basin is filled with basaltic mare material; only patches of this mare material occur within the middle and outer rings of the basin.

in diameter and is visible on both Landsat images and Apollo-Soyuz photographs. It was labeled "twin site" by El-Baz and Mitchell (1976, p. 54). Based on photogeologic interpretations of the Apollo-Soyuz photographs, it is probable that this smaller circular feature is also an impact crater. However, the resolution of the orbital photographs does not allow recognition of internal structure or rings.

Some 80 km north of the Oasis astrobleme is another multi-ringed crater, approximately 2.8 km in diameter. It is known as the "BP structure", because it was first discovered by British Petroleum geologists working in southeastern Libya (Martin, 1969). The name was used incorrectly to identify the Oasis astrobleme by El-Baz and Mitchell (1975, p. 54).

The BP structure, which is 165 km northeast of Kufra Oasis, shows a distinct central peak and two rings (Fig. 8.4). The outer ring of hills, 2.8 km in diameter, has a maximum relief of about 20 m and is composed of sandstone beds that dip inward at angles ranging from 3° to 15°. The inner ring of hills, 2 km in diameter, is more structurally deformed than the outer ring with inward dip angles of 20° to 40° (French and others, 1974).

Because of its 600 m diameter, central peak, and the double ring, the BP structure may be considered an analog to many craters on the Moon and the terrestrial planets. For example, the ratio of the central peak to crater size (1:4.6) is similar to that of lunar craters such as Icarus and Theophilus (see, for example Masursky and others, 1978, p. 163). Also the same ratio of the two rings of the BP structure (2:2.8 km) is similar to that of the two rings of the crater Shroedinger (210:300 km; see Kosofsky and El-Baz, 1970, p. 106).

Figure 8.4 Aerial view of the "BP structure", a meteorite impact crater in southeastern Libya. The outer rim is 2.8 km in diameter; it encloses an inner ring and a large central peak (Courtesy of J. R. Underwood).

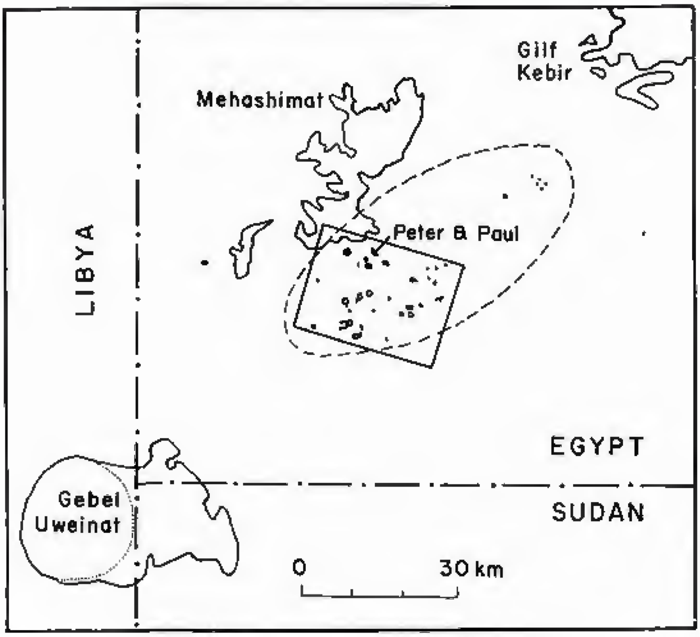

Figure 8.5 Sketch map of the fields of volcanic craters between the Gilf Kebir plateau and Gebel Uweinat in southwest Egypt. Compare with map by Peel (1939b, p. 300).

In addition to the craters discussed above, French and others (1974, p. 1425) mention another structure 160 km east-northeast of the Kufra Oasis that is elliptical, with a 3.5 km long axis trending north and a 1.8 km short axis trending east. In spite of the unique abundance of impact craters in this region, the resolution of ortital photographs is not sufficient to make more complete morphologic interpretations of these features. Using computer enhanced Landsat images or higher resolution photographs, the morphology of these crater forms could be more precisely compared to craters of impact origin on other planetary surfaces.

VOLCANIC CRATERS IN SOUTHWEST EGYPT

The vast plain between Gebel Uweinat and the Gilf Kebir plateau is marked by many crater-like features. Several of these craters were discovered by P. A. Clayton in 1931 and studied in detail by Sandford (1933c; 1935b). Later, Peel (1939b) discovered other groups of craters during the journey to the Gilf and Uweinat with R. A. Bagnold in 1938. Photographs and images taken from space provide a better perspective of their distribution (Fig. 8.5) compared to the detailed map of Peel (1939b, p. 300). These images also show the variety of crater forms in the region (Fig. 8.6).

Craters in this region cover areas varying from 100 km^2 to a few tens of square meters. In plan view, they are nearly circular, and some rise 200 m above the encompassing flat surface. The outer parts of the circles are made of Paleozoic sandstone, whereas volcanic rocks are piled inside, sometimes rising higher than the sandstone walls. A

Figure 8.6 Enlargement of Landsat image (E-1131-08141) of area marked in Figure 8.5. The image shows the variety of volcanic features.

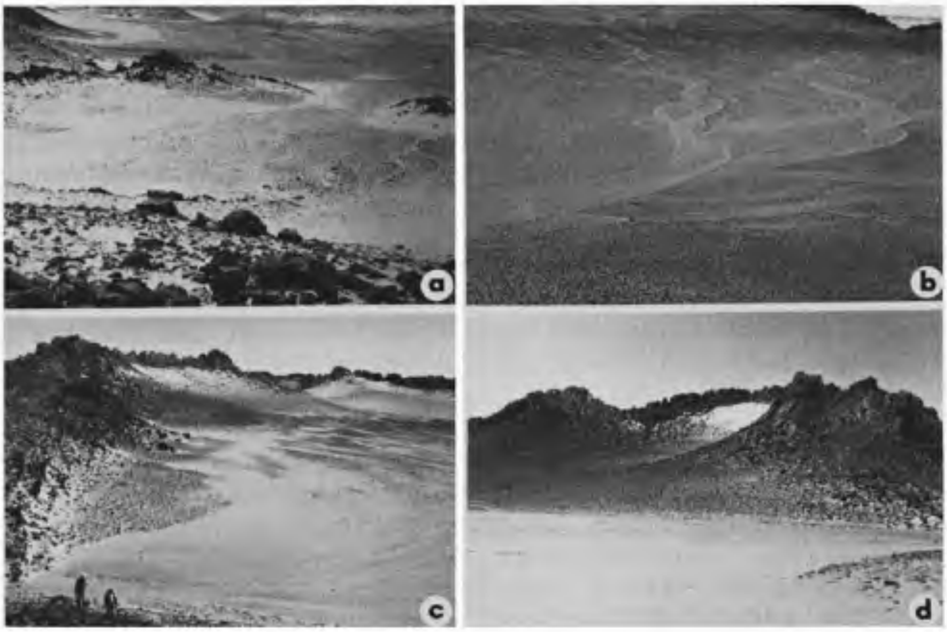

Figure 8.7 Photographs of crater forms in southwestern Egypt; a small crater within a larger feature showing multiple maar-like eruptions (a); crater floor with a drainage pattern from occasional rains in the area (b); and nearly vertical strata at rims of craters (c and d).

narrow gully may be found between the sediments and the volcanics. However, in some craters the volcanics are plastered on the sandstone leaving no gap in between, and filling the whole area inside the ring-like structure. In some of these craters the interior volcanics stand nearly vertical without any sandstone around, e.g. Peter and Paul (Fig. 8.7). The lack of sandstone rims results from the outer sandstones wearing away by wind erosion faster than the volcanics inside. In some cases, the erosion is incomplete, leaving low hummocks of sandstone at the foot of the vertical volcanics.

The sandstone "ring" may be completely closed, or may be breached by a wadi that drains the structure. The volcanic debris is thus distributed long distances away from the main mass. A few blocks lie at the foot of the rims, probably produced by gravity (mass wasting) and wind erosion.

The volcanics generally consist of trachytes and olivine basalts. The trachytes cross-cut and are interbedded in the Paleozoic sandstone together with phonolites, rhyolites and microsyenites. Only the trachytes form piles of considerable thickness, protruding 80 m above the sandstones, e.g., in the Ras El-Abd area; basalt has never been observed to form such features. The complex trachytes, phonolites, microsyenites and rhyolites are believed to be associated with the Hercynian orogeny which affected the area during the late Paleozoic.

The eruption of the volcanic bodies greatly affected the nearby sediments in a number of ways. The sandstone was baked, metamorphosed, and hardened. Dull glass-like quartz occurs within the sandstone of a crater east of Gebel Uweinat, along the Egypt-Sudan border. Chalcedony is also usually associated with the basaltic extrusions. The bedding is usually disturbed, and vertical to overturned beds are not uncommon (Fig. 8.7). Sandstones near the volcanic masses typically exhibit columnar jointing, especially near the basalts on the top of the Gilf Kebir. Ferruginous and manganiferous pockets and lenses were recorded from near the basalts of the Black Hill, the top of the Gilf Kebir, and the Uweinat area.

Our observations during the 1978 reconnaissance indicate that there are several craters that may best be described as cryptoexplosion structures. In such cases, the sandstone layers at the rim are nearly vertical (Fig. 8.7) and there are no volcanic rock exposures in the central portion of the craters. One crater displays a gentle dome of sediments in the middle. Similar sandstone rings are common in the area west of the Nile at Abu Simbel, where very intricate topographic features of sandstone were mapped by the second author. The bedding is almost obscured where the sandstone walls rise 29 to 30 m above the surrounding plains. In many cases, basalt cones occur inside the wall circles, whereas in others the volcanics are not exposed on the surface. The effect of heat and most probably gas emanations may result in more or less the same features.

The available photographs and the brief field survey do not rule out the presence of impact craters in this region. The area between Uweinat and the Gilf Kebir (dashed area in Figure 8.5) should be

Figure 8.8 Enlargement of Landsat image (E-1131-08144) of area southeast of Gebel Uweinat showing circular features in wind-striated terrain.

studied in detail to examine this possibility. Some of the impact craters may have been overlooked because of the abundance of volcanic craters and other volcanic landforms. The situation is reminiscent of Meteor Crater in Arizona. Its origin may not have been recognized if it occurred in the middle of the volcanic field some 60 km to the northwest.

CIRCULAR FEATURES IN NORTHWEST SUDAN

Landsat images reveal the presence of a group of peculiarly circular features (Fig. 8.8) in an area centered approximately 130 km east-southeast of Gebel Uweinat. This area of northwestern Sudan has not yet been explored, and therefore, the nature of these circular features cannot be ascertained.

The circularity of the features is indicated largely by a few discontinuous arcs and knobs. The terrain appears to have been heavily modified by eolian action, and the relatively dark surface is striated by light-colored streaks that trend from northeast to southwest (Fig. 8.8). These bright streaks appear to be accumulations of sand in the form of sheets or dunes (El-Baz and Maxwell, 1979b; El-Baz and others, 1979a).

The circularity of these features is also accentuated by a difference in the texture of the terrain inside and outside the features. Inside the circular structures, the surface is relatively smooth and flat. Outside the terrain is hummocky and lineated. These characteristics are similar to those in old, cratered terrains in the lunar highlands (see Masursky and others, 1978), in the southern hemisphere of Mars (see Mutch and others, 1976), and the plains of Mercury (see Davies and others, 1978).

The largest of these features is approximately 14 km; two others are about 8 km and 7 km, and the smallest is 2.5 km in diameter. Although the nature of these features is not fully understood, they may represent: 1) ancient impact scars on the Precambrian basement; 2) remnants of buried volcanoes; or 3) unusually oriented outcrops of rocks that were more resistant to erosion than the surrounding sandstone.

The 1:1,000,000 scale map of the region shows that all exploration journeys have missed or bypassed the desolate region in which the circular features occur. The map, which was published in 1961 by the British D Survey, War Office and Air Ministry (Jebel 'Uweinat, Map series 1301, sheet NF-35, edition 6-GSGS) indicates that the following explorers visited areas adjacent to the region: Hassanein in 1923, Prince Kemal El-Din in 1925, Bagnold in 1930 and 1932, Sweeting in 1934, Shaw in 1935, and Miskin in 1942.

As shown in Figure 8.9, none of these explorers traveled through the area that encompasses the circular features. The closest approach was made by Sweeting in 1934. The area may have been avoided because

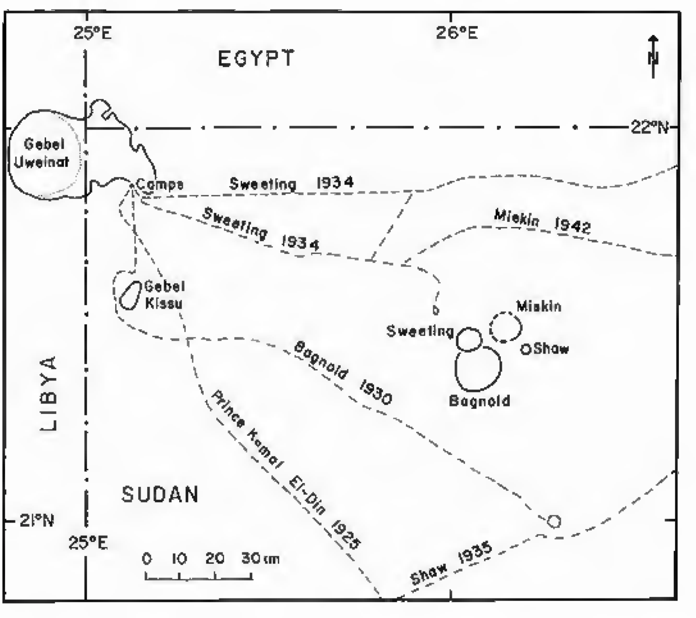

Figure 8.9 Sketch map of circular features southeast of Gebel Uweinat and their proposed names. The features are named after the early explorers who came nearest to the locality.

of the roughness of the terrain, with no especially high mountain peaks to intrigue the travelers. The existence of the circular structures was not known before the Landsat images were obtained in 1972.

The area in which these structures are located displays numerous features that are similar to streaked areas in the Cerberus region of Mars (El-Baz and Maxwell, 1979a), thus adding to the importance of the locality with respect to comparative planetological studies. To allow easy reference to the circular structures in the future, it is here proposed to name them after those early explorers that came closest to the locality. As shown in Figure 8.9, these names and their corresponding circular structures are: Bagnold (14 km), Miskin (8 km), Sweeting (7 km), and Shaw (2.5 km). It is expected that field investigations of these structures will be of value to understanding the crater forms not only on the Earth, but also on other planetary bodies.

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