GEOLOGY OF THE LUNAR FARSIDE CRATER NECHO

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Abstract. The lunar farside crater Necho (30 km diameter) displays intricate morphological and structural characteristics. The highland setting provides a complex impact site when compared with the relatively uniform setting of mare craters. Therefore, the effects of pre-impact topography and structure play a dominant role in Necho’s formation and modification. Necho’s bright ejecta, extensive rays, fresh morphology, and lack of superposed craters indicate that it is extremely young. The asymmetric distribution of ejecta materials may be due to substrate effects, topographic shadowing, or oblique impact.

Necho’s interior is divided into five physiographic units based on morphologic differences: three ‘floor’ units (Necho does not display a true flat floor), one hilly central unit, and the wall unit which includes terraces and smooth walls. The interior of the crater also exhibits an unusual asymmetry in the prevalence of terraced units on the western wall. Interior morphology and terrace orientations are probably the result of pre-impact effects. Structural and topographic orientations associated with three large pre-existing degraded craters dominate the impact site.

1. Introduction

Necho is a young lunar impact crater located in the farside highlands at 5°S 123°E, about halfway between Tsiolkovskiy and King craters (Figure 1). The area surrounding Necho crater, previously called the ‘Soviet Mountains’ (Lipskiy, 1963), was photographed during the Apollo 8 mission in 1968. The Apollo 8 photographs were taken at high sun elevation angles and show the region as very bright due to the presence of overlapping ray systems. With the acquisition of these photographs the presence of a fresh crater at that locality was proven (Whitaker, 1969) although it had been suspected previously (Whitaker, 1962, 1963). Details of the fresh morphology of Necho were further documented when the crater was photographed from lunar orbit during Apollo missions 10, 14 and 17.

Necho’s bright halo dominates an area approximately 180 km in diameter, leading the Apollo 14 crew to name it “the bright one”. In 1973, the crater was named Necho by the International Astronomical Union after an ancient Egyptian pharaoh and pioneer geographer. Necho is shown on Lunar Topographic Orthophotomap 83B4 (1:250,000) and the special scale (1:50,000) Lunar Topophotomap 83B4S1, produced by the Defense Mapping Agency. These maps and the orbital photographs from Apollo missions 14 and 17 were the primary data sources used for the present study of the crater.

Previous work on Necho has included studies of the wall terraces, debris slumps, and boulders (Pike, 1971; Moore, 1971), and suggestion of the presence of volcanic flows (El-Baz, 1971). More recently, Hawke and Head (1977) have studied the occurrence and morphology of impact melt deposits in and around the crater.

The presence of rays is the basis for assigning a Copernican age to Necho (Wilhelms
Fig. 1. Location of Necho crater on the lunar farside (5°S 123°E) showing its position relative to Mare Crisium, Mare Marginis, and Mare Smythii. Necho is located about halfway between the craters King and Tsioolkovskiy. (AS16-M-3023).

and El-Baz, 1977), and morphologic features of the crater are consistent with its young age. The rim crest is very sharp, with smoothly undulating crenulations along the south-eastern and western edges. An unusually large quantity of blocks ranging from 200 m to the limit of resolution of the Apollo 17 panoramic photographs (≈2 m) are found on the crater floor, terraces, wall, and rim. These features, when coupled with the bright ejecta, the overall fresh morphology, and the virtual absence of superposed craters of any size provide evidence that Necho is an extremely young crater, probably one of the youngest lunar craters of its size range.

The crater displays an irregular shape; the diameter of the rim crest ranges from 30 km
in a north-south direction to 35 km east-west, due to predominant slumping on the western wall of the crater. The excessive terracing of a single side of the crater is unique; terraced materials of the west side occupy 60% of the rim crest diameter. The irregular crater floor and the possible presence of an offset central peak are both striking characteristics. Since the crater is not modified by later impacts, these features allow an interpretation of the effects of pre-impact topography, movements associated with the cratering event, and post-impact modification on the present crater form.

The purpose of this paper is to describe and discuss: (1) the ejecta morphology and distribution; (2) the interior materials; and (3) the effect of regional pre-impact topography on the formation, structure and modification of Necho crater.

2. Crater Exterior

The region surrounding Necho crater is distinguished by a wide variety of morphologic types of ejecta and an irregular distribution pattern. The detailed study of rim and ejecta deposits is therefore important because of both the pristine condition of the crater and the possibility of a relation between the irregular distribution of the ejecta and the direction of impact. The area within one crater diameter of Necho’s rim is characterized by several types of terrain here designated hummocky, lineated (3 varieties), and smooth. A bright ray system and numerous secondary craters and chains exist beyond the limits of continuous ejecta.

2.1. EJECTA DEPOSITS

A small patch of hummocky terrain is found on the southeast edge of the crater adjacent to the rim crest (Figure 2). It consists of small-scale closely spaced hills which appear to be mantled. Intermixed with these hills are smooth, flat, low-albedo patches which are similar to deposits that have been interpreted as impact melt (Hawke and Head, 1977). This combination of terrain-types is present only in an area 5-km wide extending for 10 km along the southeast rim.

Radially lineated terrain occurs in patches within two crater diameters of the rim crest (Figure 2). It consists of fine, closely-spaced lineations that are superposed on all types of surrounding terrain, including the rims and floors of underlying degraded craters, and between chains of Necho secondary craters. These lineations are affected by local topography where they are deflected downslope, away from a direction radial to Necho.

In addition to the radial lineations, two small patches of concentric lineations are observable to the northeast and southwest of the crater (Figure 2). These resemble lineations which occur on the terrace edges but are at greater distances from the rim (4–7 km).

Coarser lineations or grooves occur adjacent to the southwest crater rim (Figure 2). Deep, irregular, sub-radial grooves are present in one small patch extending from the rim crest to a distance of approximately one crater radius. Near the rim of Necho the grooves are deflected by topographic variations associated with a degraded 7 km crater.
Numerous smooth, low-albedo deposits occur near Necho’s rim. The surface morphology resembles the smooth floor material of the crater interior. However, the exterior deposits also occur as flows, which appear to have moved radially away from the crater. They are interpreted to be impact melt. An area of abundant melt deposits has been mapped on Necho’s northeastern rim (Hawke and Head, 1977) (Figure 2). This area corresponds to a dark patch in the otherwise bright ejecta near Necho’s northeast rim (Figure 3).
2.2. RAYS AND SECONDARY CRATERS

The pattern of ray distribution around Necho is complicated by the presence of ray systems of several fresh east-side craters (Figure 4). It has been suggested that ray material from Giordano Bruno traveled at least 1300 km into Mare Crisium (Butler and Morrison, 1977), the same distance between Necho and Bruno. In addition, Necho’s bright halo coalesces with the bright ejecta of King crater, and the effect is heightened by several smaller, fresh appearing craters in the region which have their own bright halos.
Fig. 4. Eastern limb region showing the overlapping ray systems of Necho, King and Giordano Bruno. (AS8-14-2493)

It is difficult to determine the extent to which ejecta from these other craters affect the appearance of the ray system of Necho; however, it does appear that Necho’s rays are themselves distributed asymmetrically (Figure 3). The bright region around Necho’s rim averages three crater diameters wide and several Necho rays are at least 300 km long (i.e., ≈ 10 crater diameters).

Secondary craters are numerous around Necho crater. A heavily cratered field extends around Necho beginning less than one crater diameter from the rim crest and extending 1–2 crater diameters in the northwest and southeast directions and 2–3 crater diameters in the northeast and southwest directions. Within this field, the V-shaped pattern
associated with many lunar secondaries occurs here where crater chains cross older crater floors, but is much less prevalent in the more rugged surrounding terrain. Isolated secondaries are also abundant, the closest being approximately 1 crater radius (15 km) from Necho's rim, and the farthest probable secondaries being 8–9 crater diameters away (~270 km). Some of the lines of secondary crater chains are coincident with bright Necho rays. These chains are not all radial to Necho, but they are similar to non-radial loops of ejecta around other well known craters, for example, Copernicus (Shoemaker, 1962; Guest and Murray, 1971).

2.3. DISCUSSION

The ejecta types (hummocky, lineated, and smooth) around Necho crater are concentrated in a band which extends from the rim crest to a distance of less than one crater diameter. This region has a lower albedo than the surrounding ring of bright rays, creating a subtle dark-halo appearance (Figure 3). This inner band of ejecta is surrounded by the heavily cratered zone of secondaries which is characterized by a higher albedo. Other than this large-scale division into two semi-concentric bands, the ejecta distribution is dissimilar to the concentrically oriented zones around fresh mare craters of similar size (e.g., Euler, Timocharis, Delisle, and Lambert). Around Necho, the distribution of terrain types is irregular and the secondary crater field is oriented asymmetrically. It is difficult to separate the most likely cause for distribution of ejecta and secondaries. Most probably substrate, topography, and possibly angle of impact have all had an effect.

Although substrate characteristics have been proposed to account for differences between fresh highland and mare craters (Head, 1976; Cintala et al., 1977), the effects of target properties on ejecta morphology have not been well studied. Identification and delineation of ejecta deposits in the highlands is difficult because "the rugged background tends to distort and mask any superimposed deposits possessing distinctive but subtle patterns", (Mutch, 1972; p. 237). One possible example of a substrate effect on the ejecta of Necho crater is that secondary craters with the herringbone pattern are abundant on the surrounding older crater floors but are relatively scarce in other areas. This is most likely due to the material differences between the plains-filled, degraded crater floors and the more blocky units of the rims.

Topographic effects on ejecta distribution include shadowing by positive features and deposition in areas of low elevation. Hawke and Head (1977) point out that the most abundant exterior impact melt deposits occur in the low to the northeast, and infer a downrange impact direction of north based on the distribution of rays and secondary craters. However, in that direction the ray pattern is complicated by rays from King and Giordano Bruno, and it is difficult to determine the relative contribution from Necho. Based on the location and extent of continuous secondary craters (Figure 2), we believe that topographic effects alone could account for the distribution of Necho ejecta. The outer limit of continuous secondary craters is farthest from Necho to the northeast and southwest, coinciding with older crater floors. The field extent is closest
Fig. 5. Schematic map of Necho crater. The units were mapped on the 1:50,000 Lunar Topophotomap (83B4S1). The principal source for mapping was Apollo 17 panoramic camera photographs. Inset shows boulder and superposed crater distributions for the interior.

to Necho along the rims of these older craters, where topographic shadowing restricted the range of secondary impacts.

3. Crater Interior

The crater interior is here divided into five units (Figure 5) consisting of three floor units, one hilly and central peak unit, and one unit which comprises the wall materials. All units are Copernican in age.
Fig. 6. Abundance of crater interior units. (A) Percent area of mapped units relative to total area of the crater interior. (B) Distribution of bubbled, textured, and smooth floor materials relative to the lowest point in the crater.

The crater floor is not flat; although several of the interior units are relatively flat, they occur over a range of elevations. Floor materials, which vary in elevation from 7780 m (the lowest point in the crater) to 8800 m have been divided into three units, which are informally designated as 'bubbled', textured, and smooth materials. Although morphologically significant, these three units form only 8% of the total area of the crater interior (Figure 6(A)). Bubbled and textured materials occupy the lowest parts of the crater and smooth material occupies areas near the lowest point as well as being superposed on terraces (Figure 6(B)). These three units surround the hilly and central peak material of the crater floor, which makes up another 7% of the crater interior area. The rest of the crater is a wall unit, which includes both terraced and smooth wall materials (85% of the interior area).

3.1. BUBBLED FLOOR MATERIAL

The unit termed 'bubbled floor material' occurs in the northeast corner of the floor, at the lowest points of the crater’s interior. It is a generally horizontal unit, but many
subcircular, rounded, hillocks 30–250m in diameter are included, creating a bubbled appearance (Figure 7). The crests of these hills have a higher albedo than the flatter surfaces surrounding them (as seen on photographs of varying sun angles). The unit exhibits moat-like depressions along the contacts with adjacent hilly and central peak material and several fissures are visible near these contacts. Where moats are not visible, the bubbled floor material laps up over the base of the hills, in one case to a height of 40m above the flat-lying floor. It is possible that the bubbled floor material of Necho represents a type of hummocky material common on fresh crater floors such as Coper- nicus (Howard, 1975) and Petavius B (Schultz, 1976). In the case of Necho, however, this material may have been mantled by falling or flowing debris.
According to Pike’s (1974) depth/diameter data for fresh lunar craters a 30-km-diameter crater would have a floor approximately 3000 m below the rim crest elevation. Because the bubbled floor material occupies elevations 3000 m below the lowest portion of Necho’s rim crest, it is probable that this unit represents a level at or very near the actual crater floor. Because of excessive slumping of wall material, it is likely that the original rim crest diameter was less than the present 30 km. However, only a minor amount of slumped material is present in the lowest part of the crater. Therefore, the bubbled floor material most likely represents an original floor unit.

3.2. TEXTURED FLOOR MATERIAL

The textured floor unit consists of a tongue of material surrounded on two sides by terraced wall materials, and by hilly and central peak materials to the north. Several flow-like characteristics are present in the textured floor material including fissures, ridges, and numerous elongate low hummocks (Figure 7). The unit surrounds some large steep-sided hills, is channelled through others, and contains ridges which are deflected around the hills. These relationships and the relative absence of superposed blocks suggest emplacement of this unit at a late stage in crater formation. The contacts of the textured material with surrounding units (terraced wall material and hilly and central peak material) are scarps that are often lobate in nature but occasionally angular. It appears that the material has mantled underlying low hummocks or blocks.

There are two possible interpretations for this unit; it is either a volcanic flow or a debris slide. The first hypothesis is unlikely, both because of the lack of an apparent source, and the fact that the ‘termination’ of the ‘flow’ (originally interpreted as a volcanic flow by El-Baz, 1971) is proven by topographic maps to be 200 m higher than the lowest part of the unit. In addition, internally derived volcanism is doubtful because of the extremely young age of the crater.

The flow-like aspect of this material could be caused by fine-grained wall material mantling larger blocks but this would not account for the lobate nature of the scarps. Alternatively, an impact produced fluid component could account for both the behaviour of the material on encountering an obstacle, and for the nature of the contacts. The scarp at the highest end of the unit is notably straight, which may indicate the slump of at least one cohesive block. On the basis of these characteristics the unit is here interpreted as a debris slide or flow containing and possibly triggered by a fluidized melt component.

3.3. SMOOTH FLOOR MATERIAL

A unit of smooth, low-albedo material occurs at intermediate elevations on the crater floor and wall, where it appears to be ponded in local depressions. The surface of this unit is flat and is characterized by numerous small cracks or fissures which generally parallel the nearby contacts with other units. Other than these fissures and several small rimless depressions, the unit is uniform in morphology and albedo (Figure 7).

One possible interpretation of this unit is that the material is composed of very fine debris. The cracks could be indications of mantling by this fine material which has drained
into fractures in underlying units. However, the material would have to be very fine to form such flat, uniform deposits; fine ‘dust’ settling on hills or terrace slopes would probably stay there rather than ponding to lower areas.

An alternative hypothesis is that the unit originated as a fluid. According to Howard and Wilshire (1975) impact melt characteristics include: low albedo, ponding to a level surface, flow lobes, leved channels, and cooling cracks and fractures. Hawke and Head (1977) used these criteria to assign an impact melt origin to the smooth floor materials in Necho, as well as similar units outside the crater rim. The fissures most likely originated as tension cracks caused when the shallow edges of a melt pond cooled and contracted while the center was still molten.

3.4. HILLY AND CENTRAL PEAK MATERIAL

A series of rounded, steep-sided hills is located at the base of the wall terraces, surrounded by the three units described above. The hill summits and slopes are mantled by innumerable blocks, and several have deep clefts in which blocks are concentrated. Small patches of fissured smooth and textured material occur between the hills.

The highest point among these hills is greater than 900 m above the lowest point in the crater. Pike (1971) called it a ‘central peak complex’, although topographic data were not available at that time. This high point may represent a central peak, but it is offset from the assumed center of the crater by 5 km in the same direction as maximum slumping. Furthermore, the 900-m height is at the upper limit of crater diameter/to central peak height relationships. According to Wood (1973), a 30-km-diameter crater would have a central peak height of only 520 m. Revision of these data into craters with distinct morphologies (Wood and Andersson, 1978) suggests an average central peak height of 470 m for a crater with Necho’s characteristic morphology. If the hilly materials are partly due to slump as suggested by the displacement of the proposed central peak, then the extreme peak height may be the result of both an original uplift and later modification by inward slumping. A similar mechanism was proposed by Gault et al. (1965) on the basis of impact experiments.

3.5. WALL MATERIAL

The wall unit comprises both terraced and smooth wall materials. Terraced wall materials which slumped along concentric fracture lines occupy about two-thirds of the crater interior. The uppermost terrace averages 4-km wide and appears to have slumped as a single coherent block. The smaller terraces below this appear to have slumped less cohesively; crescent-shaped terrace platforms are interspersed with slopes of more loosely consolidated material. Boulders are strewn on the terraced units (see inset, Figure 5). Concentric lineations are abundant on the terrace edges, and are most likely the result of tension due to the faulting.

The smooth walls of the crater are vertically streaked and are very bright and fresh-appearing. Rubble and blocks cluster at the base of the smooth wall material, indicating that the fresh appearance is due to recent exposure of underlying material by mass
wasting. On the interior smooth walls and terraces, patches of boulders are often associated with bright streaks. This is consistent with slumping of boulders which reveals fresher material. A layer of dark blocky material occurs around a portion of the interior crater wall at the rim crest. It appears to be a source for the abundant boulders which have slipped down both the inside walls and the outer crater rim.

4. Structure

Although Necho is located in a densely cratered highland region, no evidence of the effects of the east-side impact structure of Smythii, Al-Khwarizmi/King, Mendeleev or Tsolkovskiy is prominent. These large craters and basins no doubt contributed ejecta to the Necho impact site, but when compared with the depth of Necho, it is doubtful that this unconsolidated material was effective in causing modification of the original crater. Instead, the topographic and structural variations of the local pre-Nectarian/Nectarian setting dominate the impact site.

4.1. Pre-Impact Topography

The impact site of Necho is at the intersection of the rims of three highly degraded pre-Nectarian craters (Figure 8). These crater rims average 3-km high in the vicinity of Necho, and Necho itself interrupts the rim crest of the largest of the craters. The floor of this crater is the lowest of the three surrounding craters, and is 700 m below the floor of Necho.

Necho does not everywhere display a well-defined raised rim. According to Cintala et al. (1977) the more coherent nature of mare surfaces relative to highland substrates lends itself to central peak formation (probably due to rebound). A similar substrate effect may also be responsible for Necho's poorly developed raised rim. The absence of a shallow, cohesive substrate (as postulated for mare regions) in the vicinity of Necho was primarily caused by the overlapping rims of the three pre-Nectarian craters, and additional contributions of ejecta from other nearby craters. It is likely that in the original, oversteepened transient cavity, the rim crest was higher, and subsequently collapsed during the terminal stages of the cratering event.

The rim crest elevation of Necho crater is conspicuously variable (Figure 11 in Hawke and Head, 1977). This is due to the pre-impact topography. From the southeast clockwise to the northwest, Necho's rim coincides with rim segments of the underlying craters. Therefore, even though Necho does not display a true raised rim in this area (see profile, Figure 5), the rim elevation is enhanced by the high pre-existing topography. By contrast, to the northeast Necho's rim crosses a portion of the floor of one of the older craters. In this area a raised rim is more clearly defined, although the actual elevation is much lower.

Because the northeastern half of the Necho impact occurred on the older crater floor and the southwestern half occurred on the underlying crater rim, it is estimated that the impact occurred on a slope of about 9°. The location of the terraces on the west-southwest sides of the crater is therefore consistent with both the structural orientation of the preexisting crater rims and the topographic slope.
Fig. 8. Top: Regional view of highlands and older craters surrounding Necho crater. Dashed line indicates trace of third ring of Al-Khwarizmi/King basin (Wilhelms and El-Baz, 1977). White line is trace of profile (AS14-75-10300).
Bottom: Profile through Necho from southwest to northeast. Note how the underlying topography affects the appearance and elevation of Necho's rim.

In addition to the influence of the pre-Nectarian crater rims, the only other structural effect observed is that of a north-northeast trending lineament. Within the crater, this lineament breaks the continuity of the terraces, and lies at the boundary between hilly and central peak material to the north, and the textured floor material to the south (Figure 9). Outside the crater rim, however, this lineament is obscured by radially-trending ejecta patterns, and is not apparent in medium and high resolution Lunar Orbiter images of the east side of the Moon.

The north-northeast orientation of the lineament is roughly concentric to the
Fig. 9. Oblique photograph of Necho crater as viewed from the north. Note position of central peak in apparent center of crater, the irregular rim topography and the absence of a distinctly raised rim along the northwest to south sides. Arrows point to trend of lineament through crater. (AS10-28-4012).
outermost ring of the Al-Khwarizmi/King basin as mapped by Wilhelms and El-Baz (1977), approximately 60 km to the northwest. Although the lineament is prominent in both the crater floor and walls, it does not represent a regional feature. Instead, it most likely represents a structural line of weakness at the impact site. Since the orientation is radial to both the northern and southern pre-Nectarian craters, it may indicate the reactivation of a radially trending fracture (Melosh, 1976) caused by either (or both) of these older craters.

4.2. CRATER MODIFICATION

The major modification of Necho crater was the formation of the terraced wall material. Several observations lead to the conclusion that this modification took place during the latter stages of the cratering event. The numerous blocks in the proximal ejecta of Necho were most likely emplaced as ballistic ejecta in high-angle trajectories from the original impact; their appearance on the surface of the uppermost terrace suggests that this terrace was in its present position at the time the blocks were deposited. If the blocks had been located on the rim prior to the formation of the terrace it is likely that they would have rolled during slumping.

The occurrence of impact melt deposits on the terraced walls is also evidence for the timing of terrace formation. Hawke and Head (1977) and Settle and Head (1978) both cite the superposition of impact melt pools on terraces as proof that slumping has taken place during the terminal stages of the crater-forming event.

5. Conclusions

Study of Necho crater included three areas: (1) ejecta distribution; (2) characteristics of the interior units; and (3) pre-impact topography and structure.

(1) Mapping of ejecta, including rays and secondary craters shows an irregular distribution pattern. Substrate differences probably affect morphology more than ejecta distribution. Observations strongly suggest that irregular topography had the major effect on distribution of secondary craters.

(2) The crater interior has been divided into five units based on morphology. These are: ‘bubbled’, textured, and smooth floor materials; hilly and central peak material; and terraced and smooth wall material. The western side of the crater displays considerably more terracing than the eastern wall, and the terraced and smooth wall materials make up 85% of the interior crater area. This ubiquitous presence of one unit in the crater is a unique morphological and structural feature.

(3) The pre-impact setting of Necho crater is characterized by a series of large degraded, pre-Nectarian craters. Their rims overlap at the impact site, creating a complex structural setting. This structure and topography played a dominant role in the formation of Necho's terraces and the variable rim topography. The central peak is situated on the extension of one of the underlying crater rims; this may suggest another example of underlying topographic control on the crater morphology.
Necho may be the most outstanding example of a class of craters dominated by structural characteristics of the pre-impact site as reflected in terrace orientations. Several fresh craters of similar size have been located on the rims of large older craters, in situations comparable to Necho. These include craters on the rims of the farside craters Pasteur, Mendeleev, and Milne, and two others east of the Smythii basin. They will be the subject of studies to document similarities in rim asymmetry and interior morphology as well as terrace formation.

All of the examples found so far are Eratosthenian or Copernican in age, even though none are quite as fresh appearing as Necho. The freshness of these craters insures that we are seeing the results of crater excavation preserved without a significant amount of degradation. Therefore, a study of these craters can be used to interpret the processes of highland crater formation following the example of "the bright one".

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References