

## **Smythii basin topography and comparisons with Orientale**

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**Abstract**—The Smythii basin has the most extensive topographic coverage of any lunar multi-ringed basin. Topographic data are here used to study the morphology and morphometry of Smythii and to make comparisons with similar basins. The depth of the basin is shown to be over 8 km, which is comparable to that of Orientale. The inner ring reaches heights of 3.4 km, while the intermediate ring exhibits little relief. Lowest points in the basin are related to mare ridges. Basin volume is estimated to be  $2.1 \times 10^6 \text{ km}^3$ . Evidence suggests that significant differences in substrate characteristics may have existed for the Smythii and Orientale impacts.

The Smythii basin is a partially flooded, pre-Nectarian age (Wilhelms and El-Baz, 1977) impact basin on the moon's east limb (Fig. 1). Its location at the intersection of the flight paths of Apollo missions 15, 16 and 17 makes it one of the most completely photographed lunar basins. This extensive photographic coverage, often at high Sun elevation angles, made possible the construction of detailed and accurate topographic maps. These maps constitute the most comprehensive topographic coverage of any lunar basin, therefore providing a good source for the study of basin morphology and structure. Smythii itself is of interest because of its limited mare fill, which leaves much of the underlying central basin floor exposed, the abundance of multi-ringed craters found on its floor, and its great age. In addition, its partial filling and size make it comparable to the younger (Imbrian age) Orientale basin. In this paper we document the characteristics of Smythii topography and make comparisons with Orientale.

The maps used in this study include 30 Lunar Topographic Orthophotomaps (LTO's) at 1:250,000 scale with a 100-m contour interval, and a 1:1,000,000 scale map of the basin with a 500-m contour interval. The latter was specially produced by the Defense Mapping Agency/Topographic Center and covers the area from 80° to 100°E and 8°N to 12°S.

### **GEOLOGIC SETTING**

The Smythii basin is located in a region of east limb highlands marked by remnants of the ancient basins Marginis, Al-Khwarizmi/King, and Lomonosov/

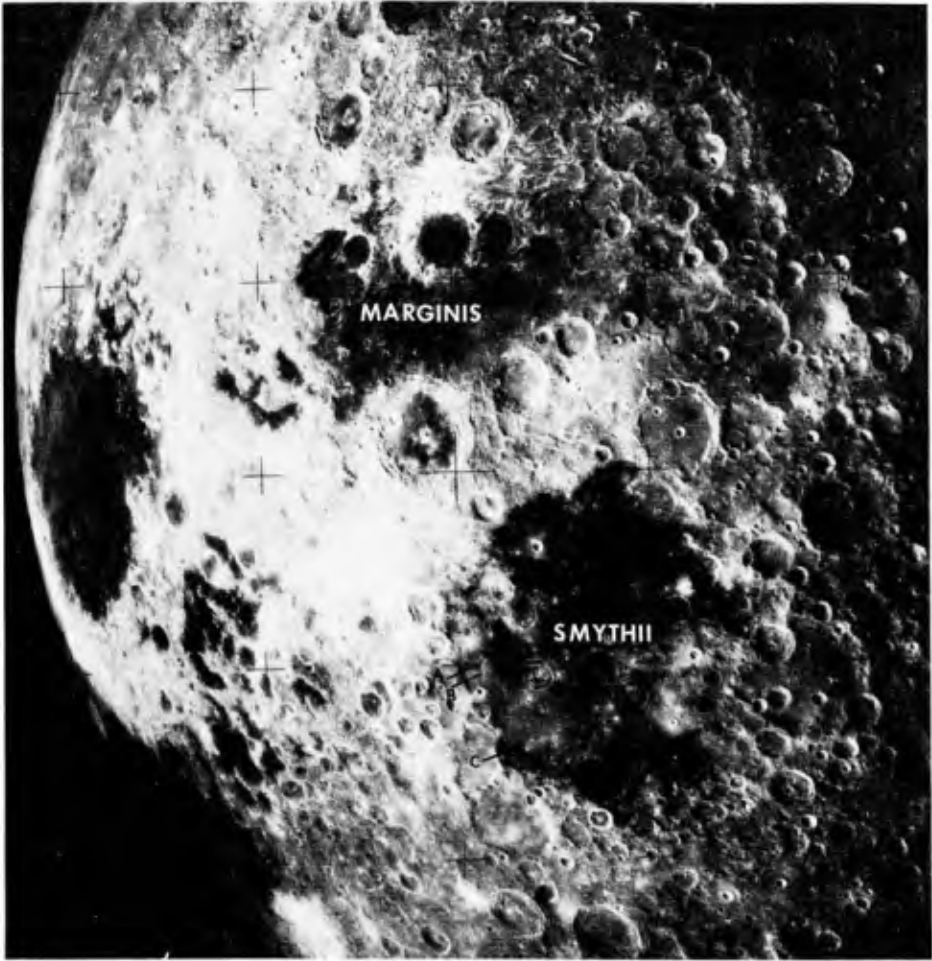


Fig. 1. Apollo 14 view of the Smythii basin and surrounding area. Lines mark approximate traces of profiles shown in Fig. 4 (left). (AS14-75-10304)

Fleming (El-Baz and Wilhelms, 1975). Pre-basin stratigraphy most likely included layers of material ejected from these nearby basins. Calculations using the equations of McGetchin *et al.* (1973) suggest that from 320–360 m of basin ejecta may have blanketed the area prior to the Smythii impact. This assumes that the visible remnants of Marginis and Lomonosov/Fleming and the outer ring of Al-Khwarizmi/King represent the boundaries of basin excavation.

The diameter of the basin ranges from approximately 800 to 870 km. The degraded state of the rings, as well as the absence of LTO coverage for some of the basin's outermost limits make precise measurements difficult. Only faint traces, if any, of a radial pattern exist beyond the outer (third) ring. The area

between the second and third rings (Fig. 2) exhibits a smooth texture (Hartmann and Wood, 1971) and may be a degraded version of what has been previously termed the domical facies or knobby material of Orientale (Head, 1974; Moore *et al.*, 1974; Howard *et al.*, 1974).

The area within the innermost ring, which shall be referred to here as the inner basin (after Stewart *et al.*, 1975), consists mostly of rough-textured, light-colored material in the south and west, and maria concentrated in the northeast. The inner basin has been mapped by several investigators. Stewart *et al.* (1975) mapped three major units on the basin floor: (1) Imbrian mare, (2) a hummocky unit (Imbrian or older) in the south and west interpreted as Crisium ejecta and

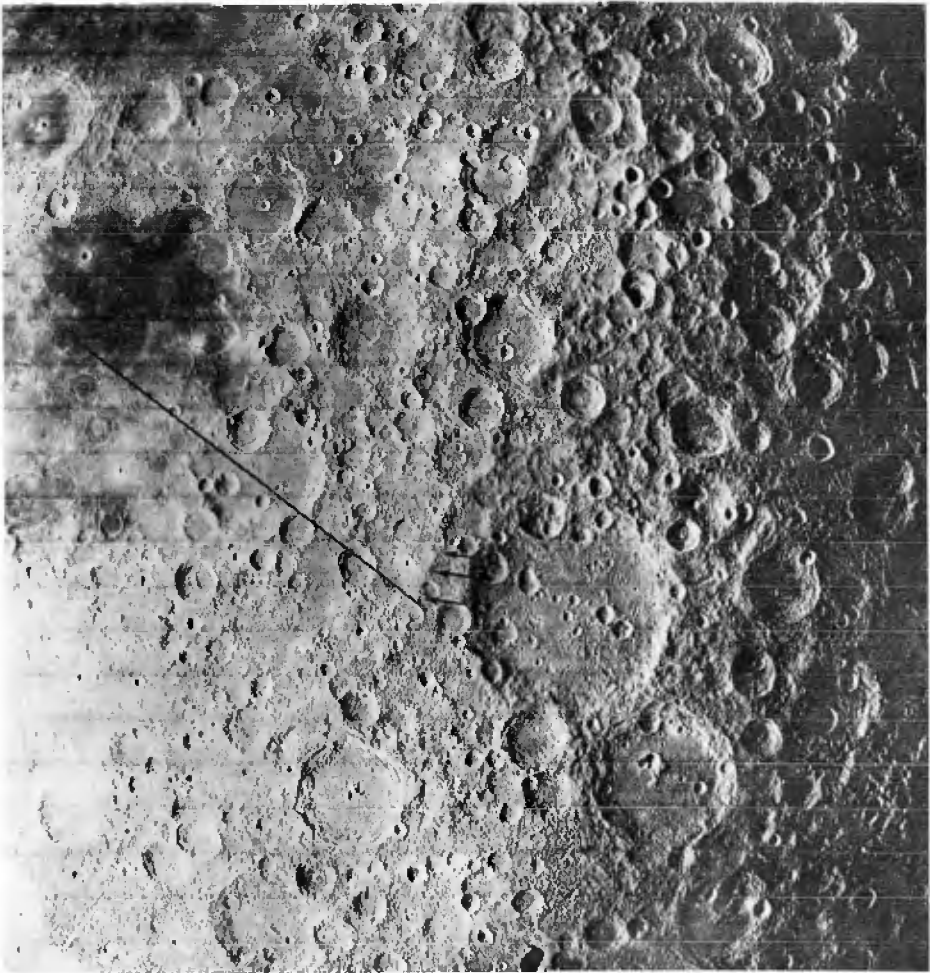


Fig. 2. The eastern Smythii basin. Arrows mark points where profiles in Fig. 4 (right) intersect outer basin ring. Line marks trace of profile depicted in Fig. 5. (LO 11 196M)

(3) an Imbrian plains unit in the northwest interpreted as volcanic. Andre *et al.* (1977) pointed out that Al/Si data do not support a volcanic origin for the plains unit, and because of its chemical similarity to the highlands to the west they suggested this area of the floor was composed of Crisium ejecta. Wilhelms and El-Baz (1977) divided the floor into Imbrian mare, and furrowed and pitted material (Imbrian or Nectarian). A possible division of the latter into hilly and pitted material (in the east) and hilly and furrowed (in the west) has been observed. This observation is supported by low altitude X-ray fluorescence data for southern Smythii, where Al/Mg ratios are higher in the east than the west (Maxwell *et al.*, 1977).

Boyce and Johnson (1978) have determined from crater frequencies that two different age units exist within the Smythii mare fill. One unit ( $3.2 \pm 0.2$  b.y.) is found along the west, south and east boundaries of Mare Smythii, and a very young unit ( $2.5 \pm 0.5$  b.y.) is in the center. Hartmann and Wood (1971) also found evidence of 2 stages of mare filling. A boundary near the edge of the mare, marked by flow fronts and color difference, is visible on Lunar Orbiter photographs (Fig. 3) but it is unclear if this represents the contact between two units of different age or a small flow within one unit. In addition, patches of mare

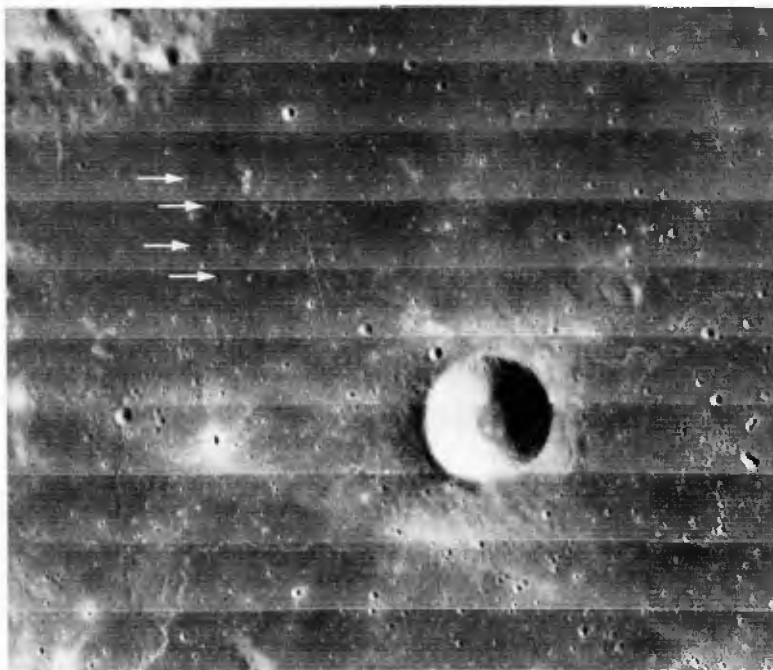


Fig. 3. Lunar Orbiter photograph of northwestern Mare Smythii. Arrows mark a flow front that may represent the boundary between two age units. (LO I 11M)

materials are scattered throughout the inner basin in association with large multi-ringed craters on the basin floor. Dark mantling material is also sometimes associated with these craters (Wolfe and El-Baz, 1976; Wilhelms and El-Baz, 1977).

## TOPOGRAPHY

Previous topographic study of Smythii has been limited by lack of the extensive data now available. Stewart *et al.* (1975) noted that the lowest areas of the basin floor correlate well with the presence of mare basalts. Using estimates of thickness of mare and other basin fill derived by the method of De Hon (1974), they mapped topography of the underlying floor and showed that it generally mimics surface configuration. Andre *et al.* (1977) observed from laser altimeter data of Kaula *et al.* (1972) that in comparison to other lunar features the relief across the Smythii basin is extremely high.

### Basin rings

Remnants of three Smythii rings are visible on Lunar Orbiter and Apollo photographs (Wilhelms and El-Baz, 1977). The inner ring (about 370 km in diameter) is most prominently displayed in a straight segment on the west side of the basin. Here the ring ranges in height from about 1700 m to more than 3400 m above the basin floor. Profiles (Fig. 4) show an eastward slope that is about 12–15° at the base and becomes more gentle towards the crest. The second Smythii ring (about 640 km in diameter) is degraded and exhibits little relief. The third ring is most prominent in the southeast and is similar in profile to the first ring, but exhibits gentler slopes. Base slopes average about 10°. The third ring reaches heights of up to 3800 m above the surrounding terra and more than 8 km above the lowest points on the basin floor.

In profile, both the first and third rings often resemble crater rims which, while not ruling out other mechanisms, may suggest formation in a manner consistent with a nested-crater model (Wilhelms *et al.*, 1977). Wilhelms *et al.* (1977) proposed that the main topographic ring marks the limit of the original crater of excavation and that both outer and inner rings form as crater rims in response to different layers in the crust. They suggested that ring formation may be related to interactions of shock waves with the seismic discontinuities observed at 20 km and 60 km depths. Head (1977) proposed, based on the morphologies of craters of increasing size, that the intermediate ring approximates the original crater and the outer ring forms by faulting at the edge of a megaterrace. While the topographic data available cannot conclusively distinguish between the two theories, they may lend some support to the former. If Pike's (1978) equation defining depth-diameter relations is extrapolated to large lunar basins, Smythii's outer ring diameter produces a result close to the actual depth of the basin. Furthermore,

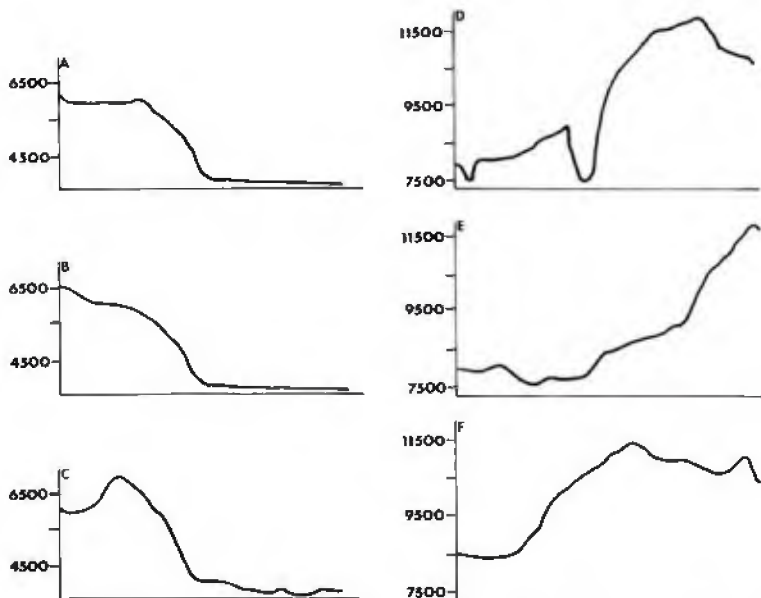


Fig. 4. Profiles across Smythii basin rings. Left, inner ring. Right, outer ring. Profile locations are shown in Figs. 1 and 2. All profiles are west to east. Vertical exaggeration is about 8X.

the intermediate ring of the Smythii basin is exceedingly degraded (much more so than the outer ring), which seems unlikely if it marks the original crater of excavation.

### The inner basin

The inner basin exhibits little relief on the 1:1,000,000 scale map. Therefore, in order to study it in more detail, a sketch map with a 100-m contour interval was constructed by reducing and combining 16 LTO's (Fig. 5). The map displays the slightly elliptical shape of the basin and shows how the continuity of the rim is broken in the northeast by a low region which extends north toward Mare Marginis. Within this low is a "trough" consisting of a string of irregular, breached depressions. The straight and parallel segments of the rims and the similarly oriented lineations in the surrounding terrain indicate faulting along the "trough" and suggest that the origin of the low may be in part structural.

The sketch map indicates that the range of elevations in the mare is from 3400 m to more than 3800 m above an arbitrary lunar radius of 1730 km. Only 7% of lunar maria are found at this low level (Lucchitta and Boyce 1979). As-

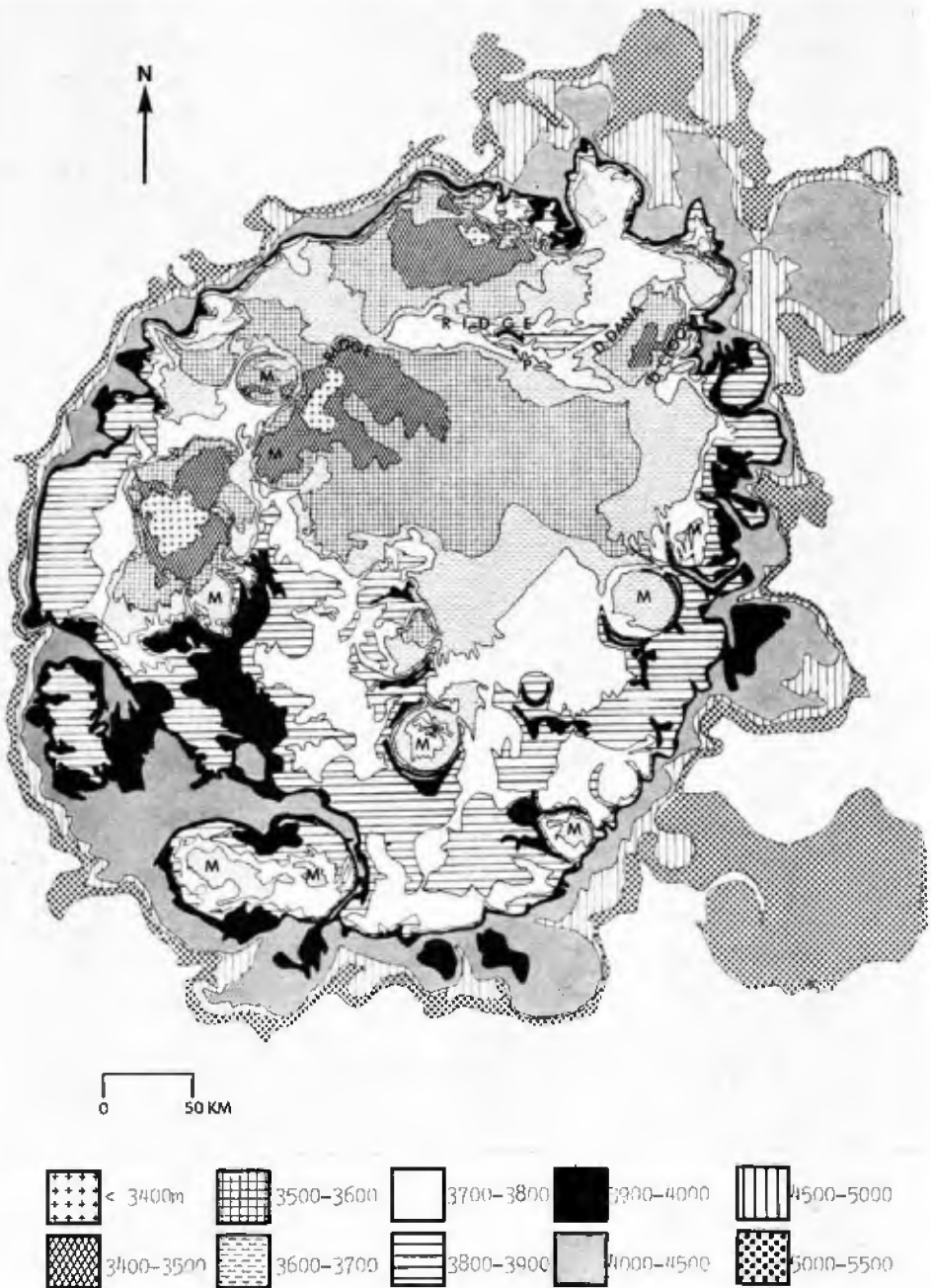


Fig. 5. Sketch map of Smythii topography constructed by reducing 16 LTO's. Small distortions of data were introduced by the reduction process. Note relation of mare ridges to lows in the mare. M designates examples of multi-ringed craters. P marks the crater Pirandello. Note that last three contours represent 500-m intervals.

suming an average mare thickness of 475 m (Stewart *et al.*, 1975), the volume of mare material present is about 18000 km<sup>3</sup>. Hörz (1978), however, states that because of the differences between fresh crater morphology, on which these estimates are based, and the actual degraded state of many craters, values may be overestimated by as much as a factor of 2. In any case it is obvious that the maria cover a considerable depression on the basin floor. The reason for this floor asymmetry is unclear. It is possible that (1) mare concentrated in a pre-existing low and/or (2) the weight of successive mare flows resulted in subsidence of the basin floor. Possible sources of a pre-existing low might include (1) a pre-basin topographic or structural feature (for example, the older Marginis basin directly to the north may have influenced Smythii's configuration) or (2) a post-basin impact that tapped a lava source. However, the evidence of faulting northeast of the basin and the topographic break in the northeast section of the rim adjacent to the inner basin low may represent adjustments accompanying mare subsidence or other post-basin structural deformation. One other possibility is that the basin formed by an oblique impact. Moore *et al.* (1974) state that ejecta distribution and rim topography of Imbrium may be consistent with an oblique impact. Howard and Wilshire (1975) cite evidence that craters inferred to be formed by oblique impacts (based on distribution of ejecta and impact melt) may be deeper on the downrange side. Smythii's shape and northeast rim characteristics may indicate an oblique impact from the southwest. However, the actual response of target materials to an oblique impact of basin size is not known.

There are two major ridge systems in Mare Smythii, one generally trending N-S, the other E-W. Mare ridges are associated with the lowest points in the mare, which may indicate faulting or subsidence along ridges (Fig. 5). In particular, Dorsa Dana and Dorsa Cloos bound a graben (?) more than 100 m deep. The highest Smythii ridge (located near Pirandello) is more than 200 m high.

Numerous multi-ringed craters occur on Smythii's floor. They range from about 30 to 70 km in diameter and exhibit maximum floor to rim heights of from 500 to 900 m. Despite variations in size, the lowest points of 60% of these craters are at the same elevation, within the limits of the 100-m contour "resolution" (Fig. 5). The remaining multi-ringed craters reach depths of up to 200 m lower. Schultz (1976) pointed out the similarity between the floor elevations of these craters and the surrounding mare, and suggested that this was due to a "magmatic" adjustment in craters affected by volcanic modifications.

### Basin volume

The extensive topographic data available for Smythii provides us with an excellent tool to determine basin volume. Two problems arise, however, in making accurate measurements of the geometry and configuration of the basin: (1) the extensive degradation and accompanying infilling have "blurred" the basin structure and (2) some of the outer ring trace is beyond the limits of topographic coverage. A rough estimate may be made by assuming a spherical segment ap-



proximates the present basin geometry (Head *et al.*, 1975). The outer ring is most prominent (that is, less degraded) in the southeast, where it also fortuitously has been topographically mapped. Consequently, we will use the characteristics of the southeastern basin (Fig. 6) as our model. Diameter is 820 km. The highest peaks here are at an elevation of about 11,900 m and are, therefore, about 8.5 km above the lowest points on the present basin floor. Correcting for the average rim height, i.e., the height above the surrounding terrain, here about 1.5 km, and the average decrease in crater radius from the rim crest to the edge of the crater below the surrounding terrain, here about 12 km, (Head *et al.*, 1975), we get a spherical segment with a volume of  $1.7 \times 10^6 \text{ km}^3$ . Comparison of the basin's cross-sectional area (based on the unexaggerated basin profile smoothed to eliminate large post-basin craters) with the approximate cross-sectional area of a spherical segment to scale, shows that the spherical segment may underestimate basin volume by about 20%. The corrected value,  $2.1 \times 10^6 \text{ km}^3$ , will most likely underestimate original basin volume due to erosion and infilling over time (Head *et al.*, 1975).

### Comparisons with Orientale

Perhaps the most obvious similarity between the two basins is their limited mare fill. The maria in both cases are confined to the inner basin, with the exception of a few patches along Orientale's Rook and Cordillera rings. Mare thickness in Orientale has been estimated at about a kilometer (Head, 1979) which is similar to the estimates of Stewart *et al.* (1975) for the thickest portions of Mare Smythii. As mentioned above, the areas between the second and third rings of both basins are also similar. Although extensively degraded, the Smythii terrain still retains a morphology distinct from that outside the outer ring, as has been noted for Orientale (Wilhelms *et al.*, 1977).

In addition, Orientale and Smythii are among the largest lunar basins. Although Orientale's outer ring diameter (940 km, Wilhelms *et al.*, 1977) is greater than Smythii's (average 835 km), its inner rings are smaller (Maunder ring, 330 km; Rook rings, 480 km and 620 km; Wilhelms *et al.*, 1977). Ratios of inner ring diameters to outer ring diameter are .44 and .77 for Smythii and .35 and .66 for Orientale (assuming the outer limit of the Rook Mountains, 620 km, best corresponds to Smythii's intermediate ring). Like Smythii, Orientale is located on a limb, a region of transition between the near and far sides. The depth of Smythii

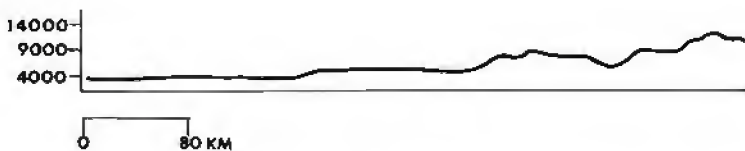


Fig. 6. Profile across southeastern Smythii basin. Trace is marked in Fig. 2. Vertical exaggeration is 4X. Profile is from northwest to southeast.

(from crest of the third ring to lowest points on the inner basin floor) is comparable to the value of about 8 km estimated for Orientale by Howard *et al.* (1974) from limb profiles, Lunar Orbiter photographs, and laser altimeter data. In view of the age of the two basins, this last comparison is surprising. Although rim crest to floor depths are similar, relation of limb profiles to laser altimeter data (Howard *et al.*, 1974) indicates that Smythii lies about 2 km lower than Orientale with respect to an arbitrary lunar radius.

Smythii's apparently large rim to floor depth, in comparison to Orientale, as well as its different ring spacing may relate to pre-impact substrate characteristics. Several workers (Quaide and Oberbeck, 1968; Piekutowski, 1977; Fortson and Brown, 1958) have demonstrated in small-scale impact and explosion experiments that target characteristics and layering affect crater morphology and depth. Ratios of crater diameter to thickness of a surficial layer, as well as physical properties of different layers, have been shown to affect small crater geometry. Piekutowski (1977) has shown in explosion cratering experiments that as depth to an interface began to affect crater morphologies, crater depths were at first reduced slightly. As the ratio of depth to the layer to depth of a crater that would be produced in a homogeneous medium decreased, crater depths first increased, then decreased. Hodges and Wilhelms (1978) have suggested that basin morphology and ring size may relate to target characteristics, particularly the competence of individual layers in the substrate.

Topographic data support the suggestion that significant substrate differences existed in the cases of Smythii and Orientale. The elevations of the two basins indicate that the levels of the pre-impact terrain differed. This implies compositional variations. Several studies have shown the correlation of chemistry with topography (for example, Masursky *et al.*, 1977; Metzger *et al.*, 1974). Alternatively, the lower elevation of Smythii may be related to intense bombardment of the east limb. It is known that the east limb was covered by several large basins prior to the Smythii event. The west limb is so dominated by the materials of the young Orientale that it is difficult to establish if pre-impact conditions were similar there as well. However, it seems reasonable to consider that the exceptionally large number of basin impacts on the east limb may have contributed to some thinning of the crust through redistribution of materials. The physical properties of the crust may also have been affected by fracturing at depth.

Substrate differences might also relate to crustal thickening through time. According to tectonic models (Melosh, 1979), the early lunar crust was <40 km thick during the time of basin impacts. Given the processes of crustal thickening and Smythii's lower elevation, it is possible that the Smythii projectile impacted into a surface closer to the crust/mantle interface than the Orientale projectile. It is also likely that the thickness and properties of the intracrustal layers involved in the Smythii event differed from those of Orientale.

The Nectaris basin, on the eastern near side, is a third basin of similar size with partial mare fill. Ring diameters are 870 km, 400 and 600 km, and 280 km (Wilhelms *et al.*, 1977). It is difficult, however, to extend the comparisons to Nectaris because of the lack of reliable topographic data. The elevation of its

surrounding (i.e., pre-impact) terrain is apparently nearly equal to that of Smythii. This observation, however, is based on data from Lunar Chart (LAC) 96 which has a probable error of more than 300 m. Depth of the basin cannot be measured because discrepancies on adjacent Charts make mare elevations uncertain. Ring spacing, however, is more similar to Orientale than Smythii. Nectaris ring ratios are .32 and .69 (again using the outer edge of the intermediate ring complex). In view of the different ages of the three basins, this configuration may reflect crustal changes through time, as well as local characteristics of crustal chemistry and structure.

## SUMMARY AND CONCLUSIONS

Topographic data have been used to study the morphology and morphometry of the Smythii basin. In the absence of good low to medium Sun angle photography, the topographic base becomes an especially important tool. The characteristics of Smythii topography documented here may have implications for studies of other lunar basins lacking such extensive and detailed topographic data.

Diameters of the basin rings are approximately 370 km, 640 km, and 820–870 km. Profiles have shown that despite the great age and degraded appearance of the outer ring, it exhibits considerable relief, rising more than 8 km above the basin floor. Inner ring heights reach 3.4 km. The basin floor is flooded in the northeast by mare materials. Lows associated with mare ridges suggest post-mare structural adjustments. The location of mare basalts coincides with the lowest areas of the basin floor, suggesting the existence of a pre-mare low and/or post-mare subsidence.

An estimate of basin volume based on the present day topographic profile yields a value of  $2.1 \times 10^6 \text{ km}^3$ . This was calculated using the freshest appearing portion of the basin and therefore overestimates present-day basin volume, but underestimates the volume shortly after the impact event.

Evidence suggests that differences in thickness, composition, and physical properties of the crust may have existed for the Smythii and Orientale impacts and may have influenced the observed basin morphologies.

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