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Martian double ring basins: New observations

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Abstract—Eighteen previously unknown martian basins have been detected on Viking photographs. The smallest basins have diameters 50 to 100 km less than the smallest known basins on Mercury or the moon. On the latter two planets and the earth, basin morphology varies with increasing diameter: central peak (CP) basins have both central peaks and fragmentary peak rings; peak ring (PR) basins have only concentric rings of peaks; and multi-ring (MR) basins have two or more concentric rings. The new Viking results show that on Mars the morphology sequence is PR-CP-PR-MR, and two CP basins occur within the larger PR basin diameter interval. The reasons for the existence of the anomalous small PR basins and the two large CP basins are uncertain, but may be related to unique crustal properties on parts of Mars, or alternatively to unique properties of some impacting bodies.

The diameter distribution of martian basins exhibits three distinct slope segments, with inflections at the same diameters that changes in basin morphology occur. Embayed and ghost craters, rilles, and mare ridges occur on basin floors, suggesting that basins have been the sites of igneous extrusions as on the moon.

Peak rings within martian and lunar basins are almost always composed of isolated peaks or short mountainous arcs, but on Mercury the rings are commonly complete. This remarkable difference may reflect lateral homogeneous physical properties in Mercury's crust or increased efficiency in peak ring production due to high modal velocities for impacting bodies.

INTRODUCTION

Nearly 20 years ago Hartmann and Kuiper (1962) recognized lunar basins—large circular depressions with distinctive concentric rings—as a major class of planetary landform. Since then similar impact basins have been identified on the other terrestrial planets and on the jovian satellites Callisto and Ganymede. Despite intensive study of basins there is still considerable controversy on the origins of rings, depths of excavation, and transient cavity diameters. One observation that was first documented for lunar basins (Stuart-Alexander and Howard, 1970; Hartmann and Wood, 1971) and later extended to basins on Mars and Mercury (Wood and Head, 1976) is that basin morphology apparently varies systematically with basin diameter. *Central peak (CP) basins,* having both a central peak and a discontinuous ring of peaks, appear to be transitional between normal craters and basins. At larger diameters the central peak disappears leaving a *peak ring (PR)*

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basin whose inner ring is generally more massive and continuous than in CP basins. Development of a third (and/or additional) ring is diagnostic of *multi-ring (MR) basins*. Wood and Head (1976) found that for the moon, Mars and Mercury CP basins have diameters (D) of 100–175 km, PR basins range from D = 120–600 km, and MR basins are larger than 350 km.

I now describe 18 martian basins, newly discovered on Viking photographs. Because this paper is primarily concerned with comparisons of basin morphology, photographs of 21 basins are included as documentation of the trends discussed. The new basins range in diameter from 45 to 205 km and include five with CP morphology (previously only 1 martian CP basin was known). Additionally, two previously known PR basins, Lyot and Herschel, are shown to have central peaks and thus are now reclassified as CP basins. Most of these new basins are smaller than basins detected on Mars using Mariner 9 data (Wilhelms, 1973; Wood and Head, 1976), and many are considerably smaller than any basin previously known on Mercury or the moon. The diameter-morphology sequence for Mars, incorporating all known basins, does not conform to the sequence proposed from Mariner photography, cautioning that basin morphology may not be purely diameter dependent, but also may be strongly influenced by other factors.

NEW OBSERVATIONS OF MARTIAN DOUBLE RING BASINS

A search of Viking mosaics available at the National Space Science Data Center, Goddard Space Flight Center, yielded 18 new basins and improved views of most previously known martian basins (Table 1). This listing is not complete because various areas of the planet are not shown on the available mosaics. Multi-ring basins have not been re-examined, this report deals only with double ring (CP and PR) basins. The distribution of presently known martian basins is shown in Fig. 1.

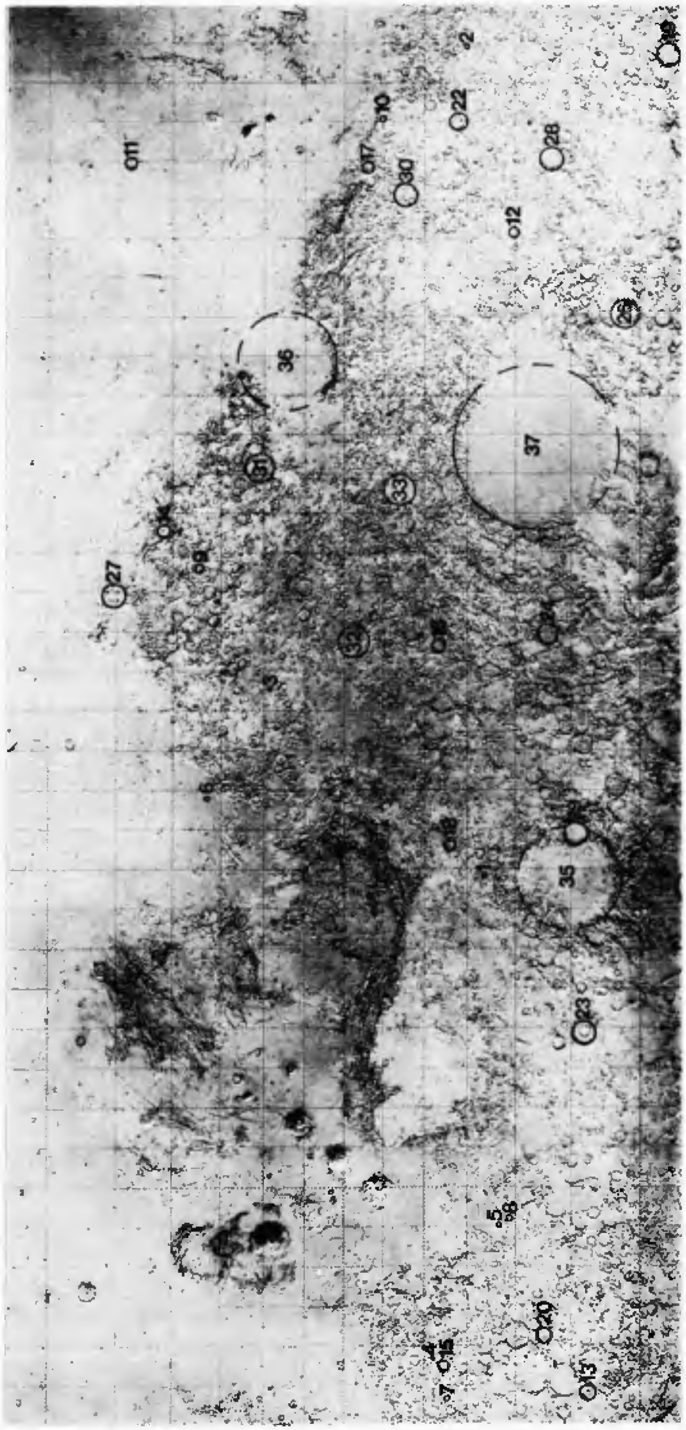
Small double ring basins ($D \leq 100$ km)

Ten of the newly-found basins are significantly smaller than previously known martian basins (all with $D > 135$ km), and all but one have PR morphology. These small basins, four of which are illustrated in Fig. 2, generally have large, but broken inner rings, and smooth floors. One of the largest members of this group, 5-Kd (Fig. 2d), is an excellent example of a PR basin. The massive and continuous (except where completely missing) inner ring is similar to rings in basins twice its diameter. The floor is smooth except for some parts of the bench between rim and ring. Basin 11-Tu (Fig. 2c) is a strange object with a complex interior composed of an elevated circular rough zone surrounding a central pit. Because of the pit—a central peak substitute (Wood *et al.*, 1978)—11-Tu is considered a CP basin. The inner rings of the other small basins are commonly composed of rounded hills or mountains, (e.g., 16-Qg, Fig. 2b), although 12-Xq's ring (Fig. 2a) includes linear elements. Most of these small basins are relatively

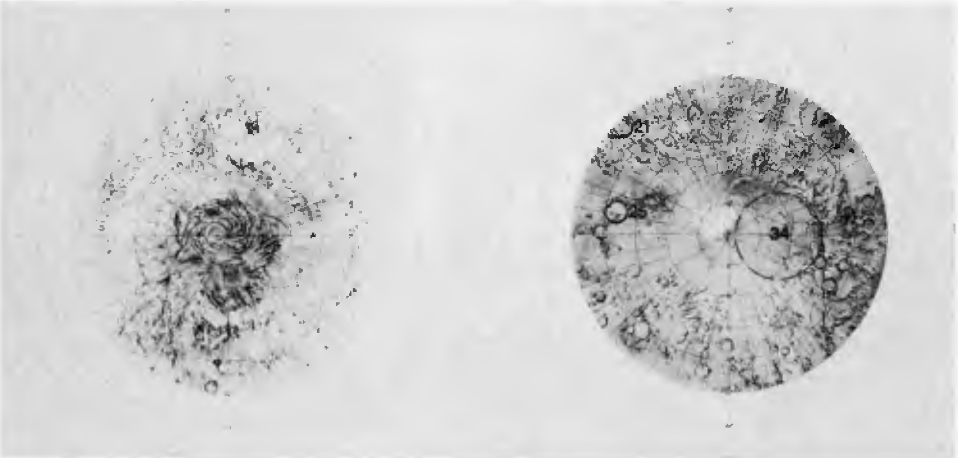
Table 1. Martian basins

No. in Fig. 1	Designation	MC	Lat.	Long.	Terrain Unit	D_{pr}	D	Basin Type	Photo No.
1*	26-Sx	26	−34.2°	41.8°	Nplc	20	45	PR	—
2*	23-Fa	23	−29.7	190.9	Nhc	22	50	PR?	23SE
3*	12-Xq	12	+18.2	355.1	Nhc	30	52	PR	212A28,30
4*	16-Qg	16	−22.9	163.3	Nhc	25	57	PR	635A92
5*	24-Du	24	−37.8	129.5	Nplc	25	58	PR	56A33
6*	11-Tu	11	+23.5	33.8	Nplc	20	60	CP?	211-5034
7*	16-Wc	16	−26.7	173.0	Nhc	33	62	PR	—
8*	24-Dt	24	−39.6	127.9	Nplc	36	73	PR	56A33
9*	5-Kd	5	+35.2	324.6	Nhc	40	95	PR	211-5741
10*	23-Rs	23	−9.2	209.5	Nhc	45	100	PR	23NW
11*	Mie	7	+48.4	220.5	Aps	33	105	CP	211-5510
12*	Arrhenius	29	−40.3	237.0	Nplc,HNk	60	115	PR	211-5673
13	Liu Hsin	24	−54.5	171.5	Nhc	55	135	CP	526A42
14*	Moreux	5	+42.0	315.5	HNk	40	140	CP	211-5664
15	16-Re	16	−25.2	164.5	Nhc	67	145	PR	635A92
16*	Bakhuysen	20	−22.2	344.3	Nplc	65	150	CP	211-5803
17	Gale	23	−5.3	222.0	Y	85?	150	CP	7650473
18*	Holden	19	−26.3	33.9	Nplc	65	150	CP	211-5755
19*	29-Eb	29	−63.6	192.0	Aps	90	160	PR	429B50,52
20	Ptolemaeus	24	−46.2	157.5	Nplc	73	165	PR	526A27-29
21	Phillips	30	−66.5	44.9	Nhc	95	175	PR	527B16,36
22	Molesworth	23	−27.7	210.7	Nhc	87	180	PR	631A17
23	Lowell	25	−52.3	81.3	Z	90	190	PR	211-5736
24	Kaiser	27	−46.4	340.5	Nhc	95	200	PR	94A40,42
25*	Schmidt	30	−72.3	77.5	Nhc	85	200	PR	211-5674
26*	Secchi	28	−58.2	258.0	Nhc,Nm	120	205	PR	6318163
27	Lyot	5	+50.5	331.0	Apc	125	215	CP	211-5819
28	Kepler	29	−47.0	218.5	Nplc	115	210	PR	97A97,99
29	Galle	26	−51.0	30.8	HNbr	100	220	PR	P17022
30	Herschel	22	−14.6	230.2	Nhc	150	285	CP	101A49
31	Antoniadi	13	+22.0	299.0	Nhc	195	390	PR	7003743
32	Schiaparelli	20	−3.2	343.6	Nhc,Hprg	230	460	PR	669K32
33	Huygens	21	−14.0	304.2	Nhc	260	470	PR	623A72-75
34	South Polar	30	−82.9	266.4	Nhc	670	850	MR?	211-5627
35	Argyre	26	−49.5	42.7	Nplc,Nhc	640	1375	MR	211-5428
36	Isidis	13,14	+13.1	272.5	Nhc	1170	3000	MR	—
37	Hellas	27,28	−42.1	292.2	Nhc,Nplc	1285	3675	MR	—

NOTES. *No. in Fig. 1:* * = newly recognized basin. *Designation:* Number-letter designations are from Batson *et al.* (1979): 26-Sx is crater Sx on Mars Chart (MC) 26. *Terrain Unit:* Geologic unit in which basin formed. See Scott and Carr (1978) for description and interpretation of each unit. Y = Nplc, HNpd, Hpr; Z = Nplc, Nhc, Aps. D_{pr}: Peak ring diameter in km. *D:* Basin diameter in km. *Basin Type:* CP = central peak and peak ring; PR = peak ring only; MR = multi-rings. Double ring basins (CP and PR) are further classed as small (No. 1–10), medium (11–18), large (19–29) and very large (30–33). *Photo No.:* Viking mosaic numbers are preceded by "211" or "P". Rev. and frame numbers are for individual Viking frames: 56A33 is frame 33 taken during orbit 56 of Viking Orbiter 1 (A). No photos for — .



(a)



(b)

Fig. 1. Distribution of martian basins; numbered as in Table 1. Base map is USGS 1:25 m shaded relief map of Mars.

fresh, displaying remnants of ejecta, and none appear to have been modified by unusual erosional processes (cf. Schultz and Glicken, 1979).

Medium size double ring basins (100 < D < 150 km)

There are eight basins in this diameter range and six are CP types. At least three different varieties of inner ring morphology are present in this group:

1. Liu Hsin (Fig. 3b) is the martian type-example of a PR basin (Wood and Head, 1976), and Mie (Fig. 3a) and Moreux (Fig. 3c) are similar. Mie lacks a prominent central peak, however, and Moreux's peak ring is defined only by a clump of hills, a low scarp and a suggestive annular albedo feature.
2. The three largest basins in this group, with diameters of 150 km, all have central peak structures and weakly developed peak rings. Gale (not illustrated) has a small but prominent central peak and well defined arcs of a central ring that is highlighted by a low albedo annulus. Holden (Fig. 4b) and Bakhuysen (Fig. 4a) both have eccentrically located peaks that partially define incomplete central pits. The inner ring of Bakhuysen is largely defined by a few small hills and the edge of an interior zone of floor roughness that appears to be somewhat elevated above the much smoother bench zone. A nearly radial crater chain, 125 km long, is located 90 km to the SW of the crater's rim. Only a few hills on opposite sides of the central pit and a low ridge hint at a peak ring within Holden. The bench area is smooth with a narrow, lunar-like rille along at least 90° of its southern sector. A large

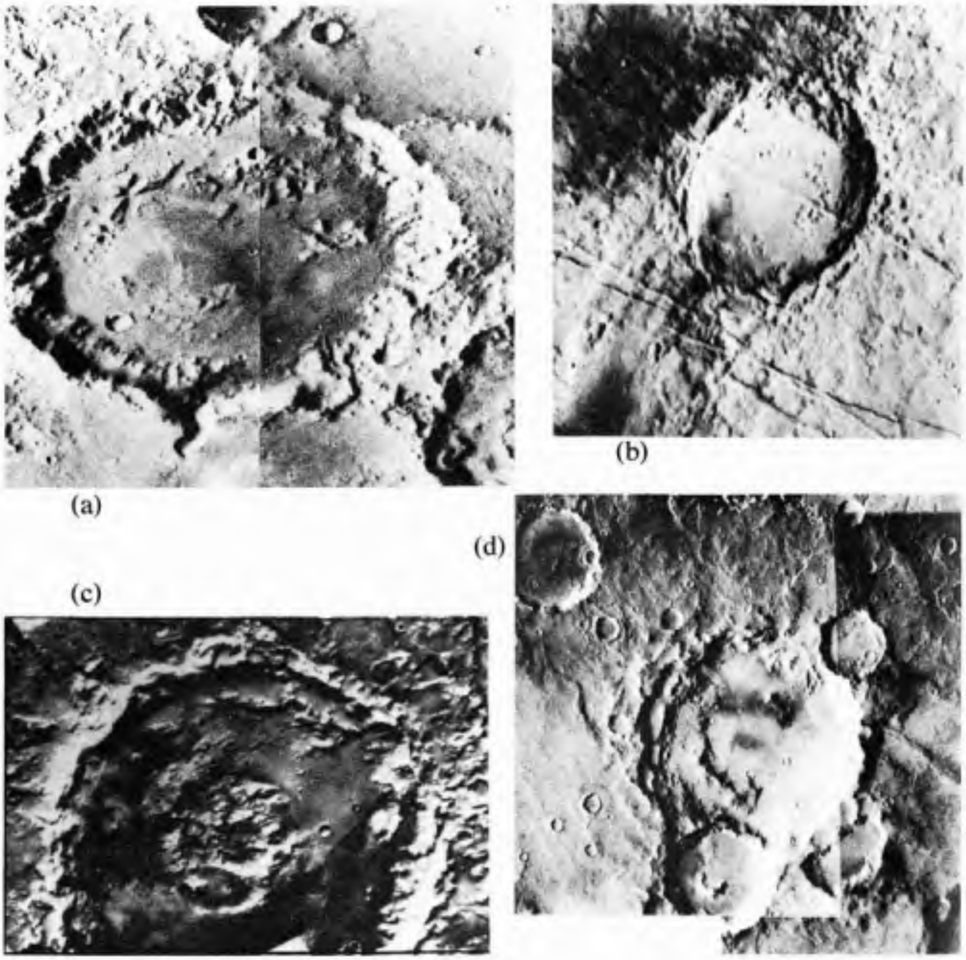


Fig. 2. Small double ring basins of Mars: (a) 12-Xq, diameter (D) = 52 km, Viking frames 212 A28,30. (b) 16-Qg, D = 57 km, Viking frame 635 A92 (c) 11-Tu, D = 60 km, from Viking mosaic 211-5034. (d) 5-Kd, D = 95 km, Viking mosaic 211-5741.

subradial valley (Erythraea Fossa) extends 220 km beyond the SE rim of Holden, the much wider and more nearly radial Uzbai Vallis extends to the SW, and a smaller crater chain trends to the north.

3. Included in this group of largely CP basins are two of PR morphology. The inner ring of Arrhenius (not shown) is represented by only a few small hills, but basin 16-Re (Fig. 3d) has a very well defined inner ring composed of arcuate mountain ranges. The entire floor of 16-Re is covered by a smooth mare-like unit with abundant north-south striking mare ridges. There is no evidence for central peaks in either of these basins.

Large double ring basins (150 < D < 250 km)

Peak rings of basins with diameters of 150 to 250 km are generally massive, but short, mountainous arcs. Lowell (Fig. 5d) has a nearly complete (360°) mountainous ring, but most large basins have continuous arcs that comprise less than 90°, with the remainder of the rings being traced by low hills and a sense of

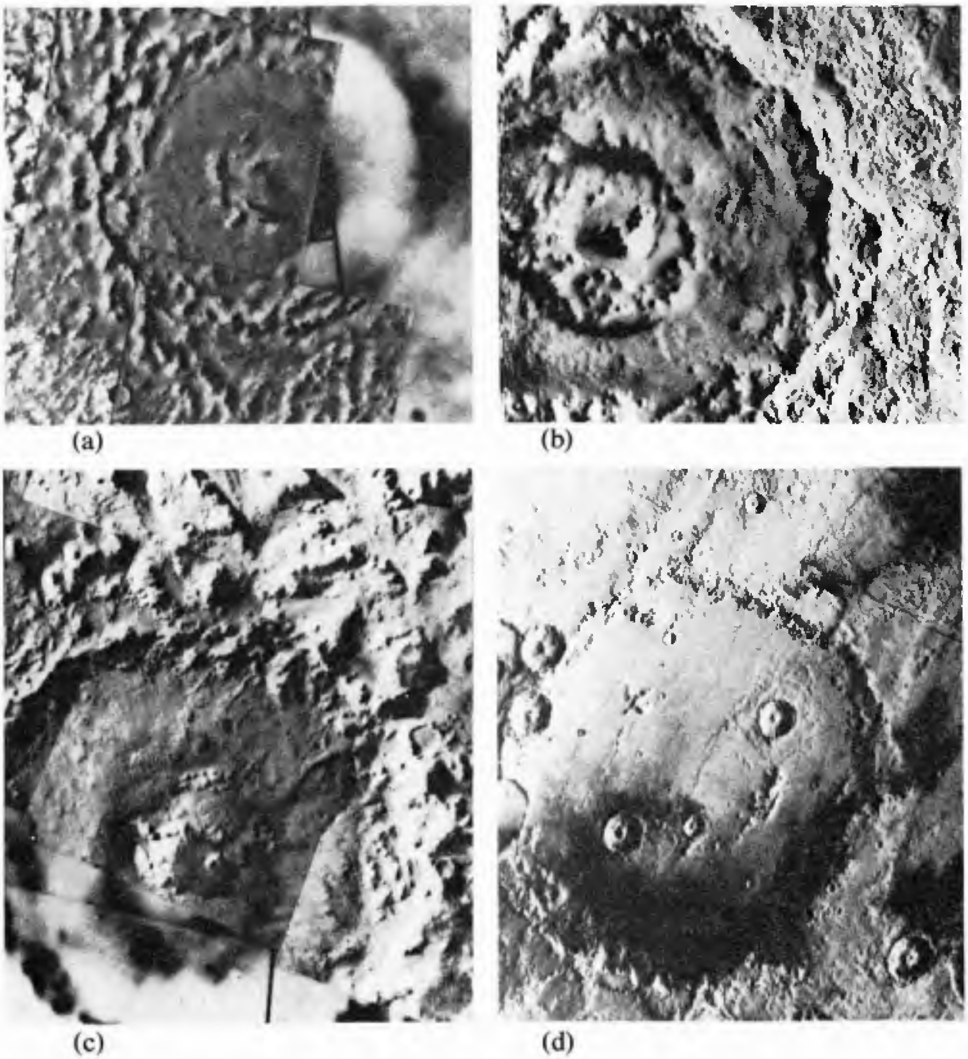


Fig. 3. Medium size double ring basins: (a) Mie, D = 105 km, Viking mosaic 211-5510. (b) Liu Hsin, D = 135 km, Viking frame 526 A42. (c) Moreux, D = 140 km, Viking mosaic 211-5664. (d) 16-Re, D = 145 km, Viking frame 635 A92.

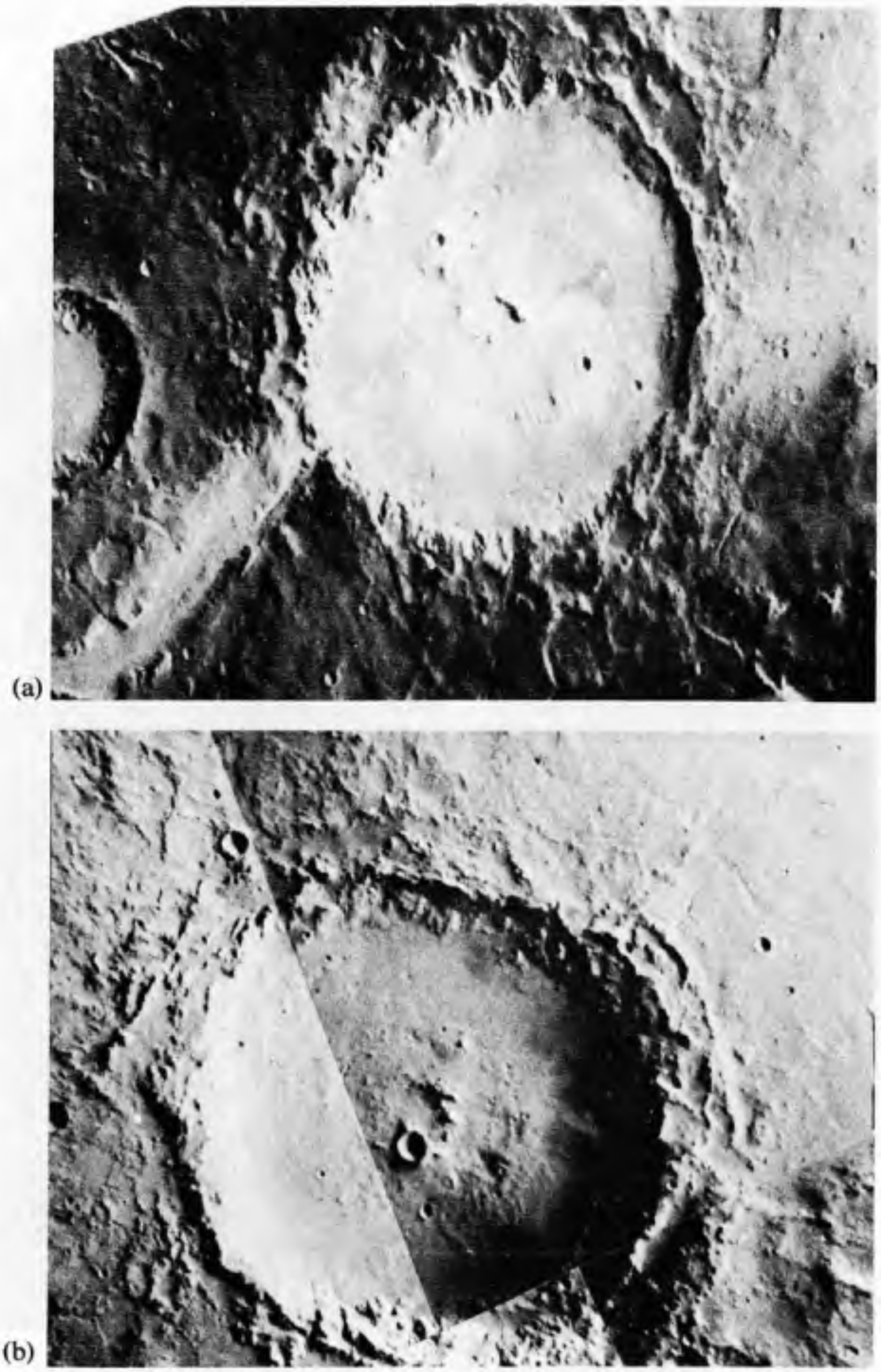


Fig. 4. (a) Bakhuysen (D = 150 km, Viking mosaic 211-5803) and (b) Holden (D = 150 km, Viking mosaic 211-5755) are medium size double ring basins, like those in Fig. 3, but they are unusual in having fragmentary central pits instead of massive central peaks.

circular symmetry. Most of the large basins have smooth, lunar mare-like materials (occasionally showing mare ridges, e.g., Ptolemaeus, Fig. 5b) within their peak rings and in parts of their bench zones, but the benches also often contain hills and mountain masses suggestive of higher and older surfaces. Archimedian style craters (craters embayed or filled by smooth, mare-like materials) occur on the floors of Ptolemaeus, 29-Eb, Molesworth (Fig. 5c) and Kaiser (Fig. 5e), implying emplacement of floor materials significantly after basin formation.

Lyot (Fig. 6a), with a diameter of 215 km, is morphologically unlike any other basin in the large or very large basin groups. Lyot has a continuous and mountainous peak ring, similar to that of Lowell (Fig. 5d), and a large, irregular central peak. The overall morphology of Lyot is reminiscent of the much smaller basin Liu Hsin (Fig. 3b). Although it has small patches of smooth material, most of the floor of Lyot is blocky and rough, again similar to Liu Hsin.

Very large double ring basins ($250 < D < 500$ km)

The very largest martian double ring basins are characterized by inner rings that are much less conspicuous than those in smaller basins. Currently, these largest basins are only depicted in low resolution Viking photographs, which, combined with their apparently old and degraded state, hinders interpretation. The inner rings of these basins lack the mountainous character common in smaller basins, and instead appear to be ridge-like (Antoniadi and Herschel). Schiaparelli (Fig. 7b) does not have a single ring, but rather, like Caloris on Mercury, has a broad zone of anastomosing wrinkle ridges. Huygens' (Fig. 7c) inner ring is defined by a few ridges and scarps but appears to be best marked as the boundary of a lower, relatively smooth region. At least one flat-floored, concentric rille (reminiscent of those around the lunar Humorum basin) occurs in the bench zone. Herschel (Fig. 7a) is the most remarkable of these very large basins for it possesses an indisputable central peak complex. In fact, Herschel is the largest authenticated crater in the solar system with a central peak.

Possible other basins

The basins described above and listed in Table 1 are ones that I have examined on Viking or good Mariner 9 photographs. Other basins may well exist; in particular, South, Korolev and Milankovic appear to have basin structure in the shaded relief drawings of Batson *et al.* (1979), and Croft (1979) lists five additional basins that I have not been able to check on Viking photographs. Much more ancient and highly speculative basins have been proposed by Schultz and Glicken (1979), but even if these features once existed they now provide little significant morphological information. Malin (1976) also listed some features not included in Table 1, but his criterion for the use of the term "basin" was simply large diameter and many of his entries lack double ring structures.

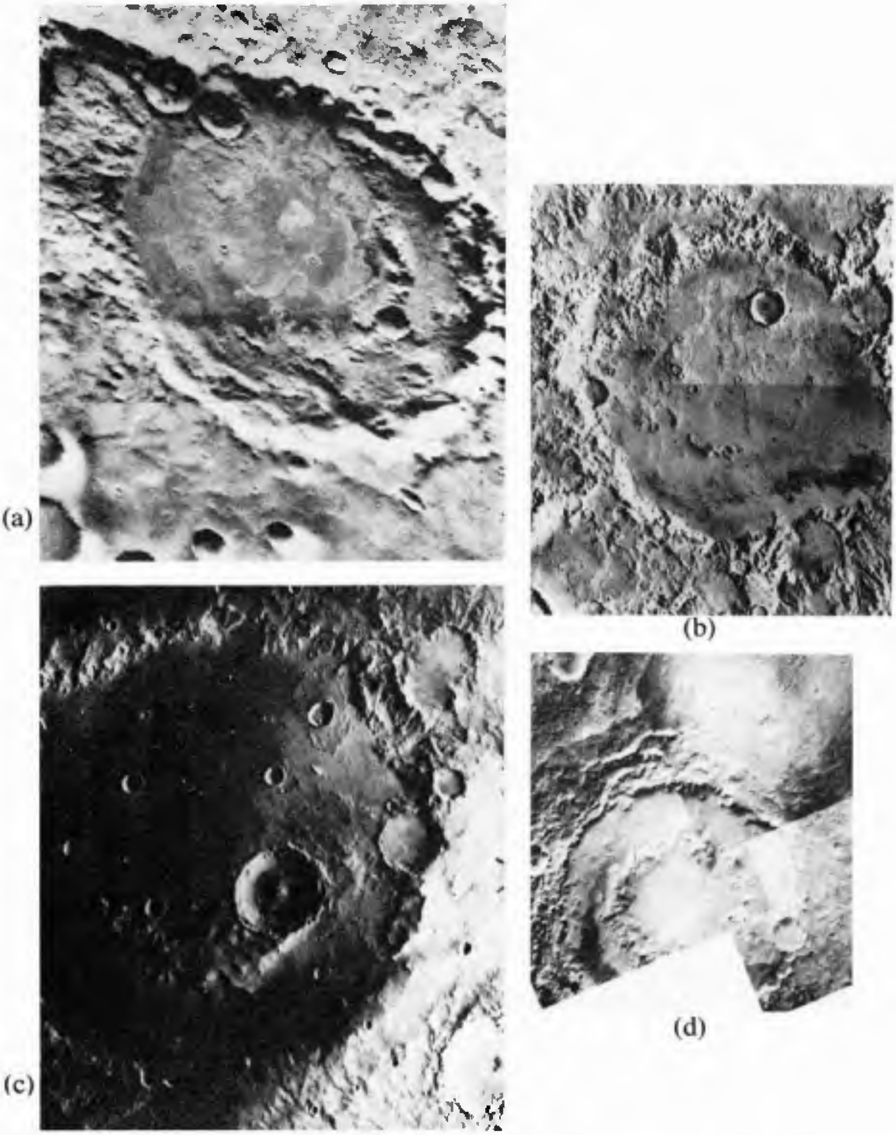
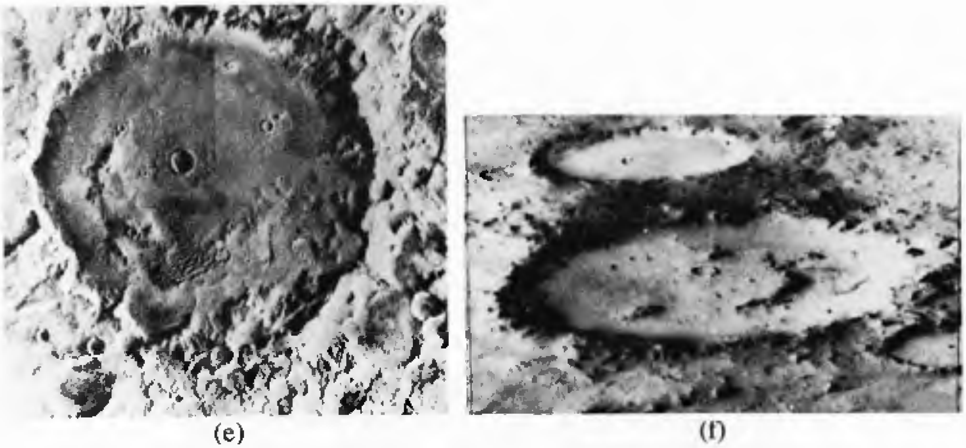


Fig. 5. Large double ring basins: (a) Phillips, D = 175 km, Viking frame 527B 16,36. (b) Ptolemaeus, D = 165 km, Viking frame 526 A27-29; note concentric structure within crater breaking NE rim (upper left) of Ptolemaeus. (c) Molesworth, D = 180 km, Viking frame 631 A17. (d) Lowell, D = 190 km, Viking mosaic 211-5736; see mosaic 211-5141 for a lower resolution but more complete view of Lowell. Note that a floor ridge in a crater on Lowell's eastern (left) rim lies along the trace of the basin rim.



(e) Kaiser, D = 200 km, Viking frames 94 A40,42. (f) Galle, D = 220 km, Viking mosaic P17022; see also 211-5428.

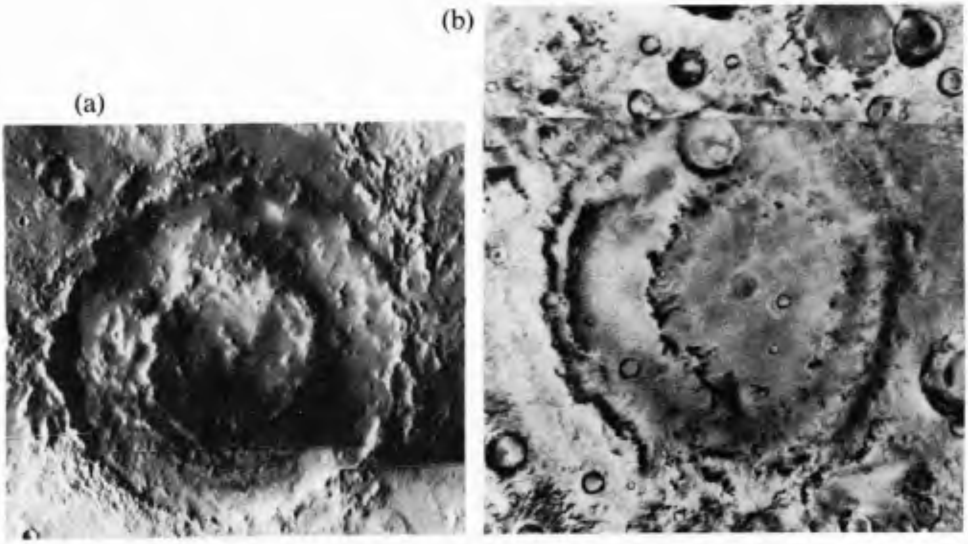


Fig. 6. Large double ring basins: (a) Lyot, D = 215 km, Viking mosaic 211-5819. Both Lyot and Herschel (Fig. 7a) have central peaks, unlike other basins in their diameter groups. (b) Kepler, D = 210 km, Viking frames 97 A97,99 (rectified). The center of Kepler's inner ring is offset 15 km from the center of the basin rim.

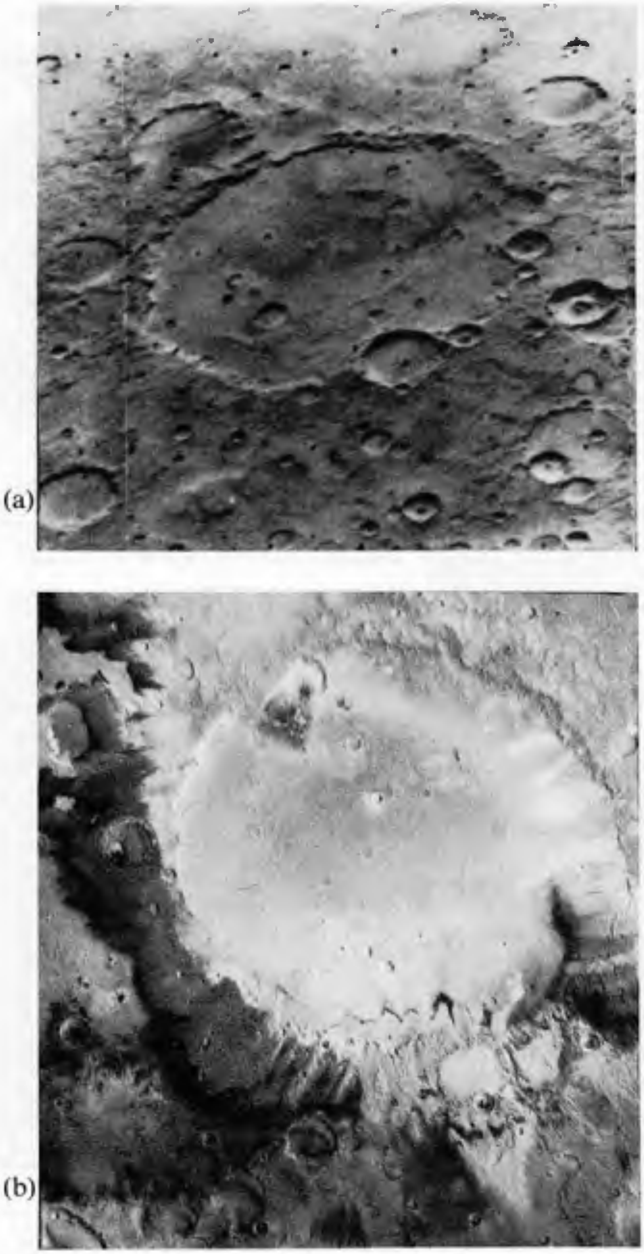
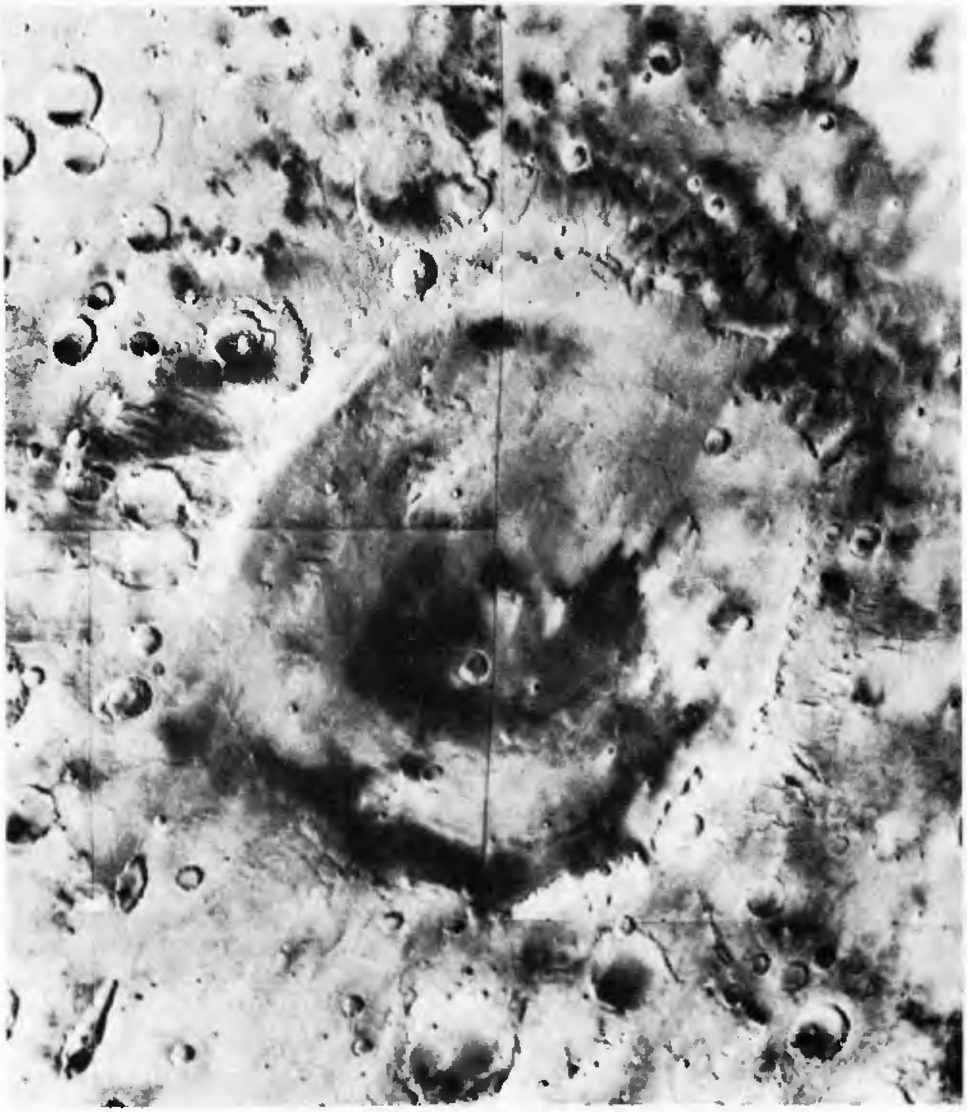


Fig. 7. Very large double ring martian basins: (a) Herschel, D = 285 km. Viking frame 101 A49. (b) Schiaparelli, D = 460 km, Viking frame 669 K32.



(c)

(c) Huygens, D = 470 km, Viking frames 623 A72-75.

DISCUSSION OF BASIN OBSERVATIONS

These new observations reveal that diameter dependent differences in the morphology of martian basins are more complex than previously proposed (Wood and Head, 1976). The simple progression with increasing diameter from central peak craters to CP basins to PR basins to MR basins observed for the moon and

Mercury (Wood and Head, 1976) does not *appear* to be valid for Mars. Table 2 shows, in contrast to the lunar and martian cases, that CP basins are not restricted to a single diameter interval, and that PR basins occur at smaller diameters than CP basins. Nonetheless, martian CP basins are strongly concentrated in the 100 to 150 km diameter interval, and 13 out of 15 (87%) of the larger basins are PR types. Thus, for basins greater than 100 km diameter, the diameter dependent sequence in basin morphology seen on Mercury and the moon does *generally* hold on Mars. Accepting this, the obvious questions are: What is the origin of the PR basins with diameters less than 100 km? Why are there two CP basins (Lyot and Herschel) at large diameters where only PR structure is seen on Mercury and the moon?

Small PR basins

The smallest basins on the moon and Mercury have diameters of 140 km and 90 km, respectively (Wood and Head, 1976). The considerably smaller diameters and PR morphology of the small martian basins (Fig. 2) raises the question of whether these basins may have been produced by some different process that also forms concentric rings. As an example, two separate types of inner rings are found in lunar craters: nested rims within craters a few hundred meters in diameter (Quaide and Oberbeck, 1968), and concentric craters, typically 6–7 km wide (Wood, 1978). Because of the small sizes of craters with these features, neither type is likely to be confused with basins. A potentially more confusing analog exists on Mars, where many craters up to about 200 km in diameter (Hodges *et al.*, 1980) have central pits (Wood *et al.*, 1978). These pits often (especially in large craters) lack raised rims or have only low hills, whereas basin inner rings are usually defined by rather large hills and arcuate mountain ranges.

It is difficult to argue that the small PR basins were formed by processes different from the larger basins because: (1) The morphology of some of the small basins is nearly identical to the larger ones; compare 5-Kd (95 km, Fig. 2d) and Phillips (175 km, Fig. 5a). (2) The distribution of the small PR basins (nos. 1 to

Table 2. Characteristics of martian double ring basins.

Basin Class	Diameter Range	Basin Type		D_{pr}/D	Peak Ring Continuity	Peak Ring Morphology
		PR	CP			
small	45–100	9	1	0.45±.07	180°–360°	large hills
medium	100–150	2	6	0.43±.10	90°	small hills
large	150–250	10	1	0.50±.05	90°–180°	mt. ranges
very large	250–500	3	1	0.51±.02	180°–360°	ridges

Diameters in km; Basin Type: PR = peak ring; CP = central peak. D_{pr} = diameter (km) of peak ring; D = diameter (km) of basin.

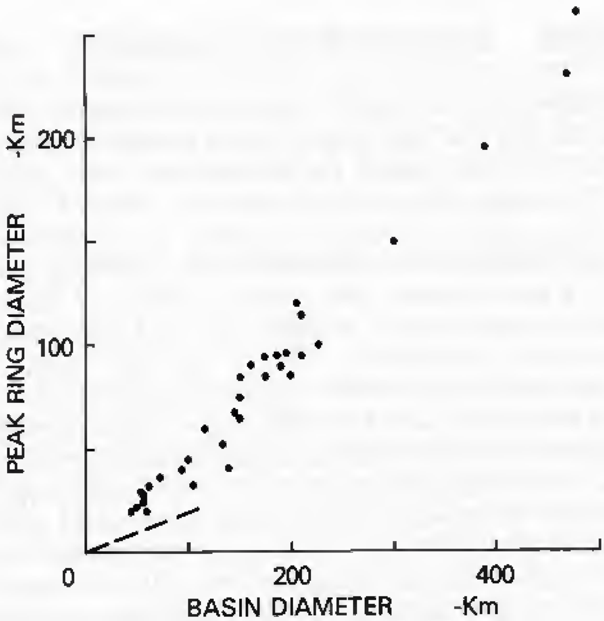


Fig. 8. Relation between basin diameter (D) and peak ring diameter (D_{pr}) for 33 martian double ring basins:

$$D_{pr} = 0.54D - 8.19 \text{ km}.$$

Dashed line is central pit diameter (D_p) versus crater diameter (D) for 15 central pit craters (from Wood *et al.*, 1978):

$$D_p = 0.17D - 0.13 \text{ km}.$$

10 in Fig. 1) appears no different from the distribution of the larger basins, arguing against control by a unique terrain type. Additionally, various of the small PR basins have neighboring craters of comparable diameter and degradational state that lack basin morphology. (3) The relation between basin diameter (D) and peak ring diameter (D_{pr}) is continuous (Fig. 8) from the smallest (45 km) to the largest (470 km) double ring basin, implying that all belong to the same population,

$$D_{pr} = 0.54D - 8.19 \text{ km} \qquad (r = 0.98, n = 33).$$

I conclude that small double ring basins on Mars are most likely to be formed by the same general processes as the larger basins.

The relationship between peak ring and basin diameters argues against the proposal that central pits evolve with increasing crater diameter into peak rings (Hodges, 1978), because the central pit diameter to crater diameter relation (Wood *et al.*, 1978) is considerably different (dashed line in Fig. 8). Further evidence against that proposal is (1) the occurrence of central pits within three basins: 11-Tu, Holden and Bakhuysen, and (2) the observation that peak rings occur on all planets, but central pits are unique to Mars, Ganymede and Callisto.

POSSIBLE ORIGINS OF THE ANOMALOUS BASINS

There is little doubt that basins are simply end members of the impact crater diameter spectrum, and that their morphological peculiarity (concentric and radial structure) is but the final stage in the diameter dependent evolution of crater morphology. The origins of basin rings, however, remain a controversial topic. Each of the various models of basin ring formation (summarized by McKinnon and Melosh, 1980) assumes that differences in morphology from central peak craters to CP, PR and ultimately MR basins is a diameter dependent sequence, reflecting either increasing depth of excavation and sequential intersection of critical layers (Hodges and Wilhelms, 1978), or little understood relations between morphology and energy (e.g., Dence and Grieve, 1979). Thus, the anomalous small PR basins and the two large CP basins require a special origin. Explanations may center around the character of the impacted target or of the projectile.

On Earth, target strength (sedimentary versus crystalline rock) strongly influences the diameter of transition from simple to complex crater morphology (Grieve and Robertson, 1979) and similar target-morphology effects have been documented for craters on Mars (Wood *et al.*, 1978), the moon, and Mercury (Cintala *et al.*, 1978). It is unlikely, however, that target characteristics can account for the small PR basins because of the close association of similar size craters and basins (as mentioned above). Additionally, the most unusual target characteristic of Mars—the imprisoned subsurface volatile layer—produces characteristic structures (fluidized craters, central pit craters) that appear to be globally distributed on Mars (Mouginis-Mark, 1979; Hodges *et al.*, 1980), whereas most craters of small basin diameter (50 to 100 km) lack basin morphology. In other words, fluidized and central pit craters are ubiquitous on Mars but small basins are rare. If small basins are common on Ganymede and Callisto—the only other known bodies with important subsurface volatile deposits—it will be difficult to refute the claim that substrate characteristics are important in the formation of small basins.

It may be that anomalous characteristics of the projectiles, not of the target, produced the anomalous basins. Theoretical (Roddy *et al.*, 1980) and experimental (O'Keefe and Ahrens, 1980) studies suggest that low density impacting bodies can form shallow craters with complex interior morphology (central peaks and possibly peak rings). Thus, if the main sequence of impact craters CP, PR and MR basins were formed by impacts of relatively dense projectiles (e.g., Apollo objects or asteroids), perhaps the anomalous basins resulted from impacts of less dense bodies (e.g., comets). Following up on this speculation, we can estimate the relative frequency of comet to asteroid impacts on Mars for two different diameter intervals. Between 50 and 100 km diameter there are 10 anomalous small basins and 1244 normal martian craters (R. Arvidson and E. Guinness, pers. comm.), suggesting that low density impacting objects were rare. For the diameter range (200 to 300 km) of the two anomalously large CP basins (Lyot and Herschel) there are approximately 18 other craters and PR basins (counted from Batson *et al.*, 1979), yielding a comet impact frequency of 10%. The two estimates of low to high density impactors could be used to suggest that comet impacts become increasingly important on Mars at large crater diameters. This speculation is weakened, however, by the observation that anomalous basins are not observed on the other terrestrial planets, which should have been cratered by even more comet impacts than would have Mars (Hartmann, 1977).

BASIN MORPHOLOGY ON MARS AND OTHER PLANETS

Rings

The morphology of martian peak rings varies with basin diameter (Table 2). In small double ring basins the rings are comprised of large conspicuous hills and mountains that span 180° to 360° of the ring. Medium diameter basins are predominantly CP types and their peak rings are often alignments of inconspicuous and isolated hills. Dark annular albedo features often accentuate small scale roughness associated with rings. Except for Liu Hsin, actual segments of the inner rings of medium size basins usually have a cumulative arc length of less than 90°. Inner rings within large basins are no longer circles defined by isolated peaks but tend to be arcuate mountain rings. Except for Lowell and Lyot, which have complete inner rings, large basin rings usually extend only 90° to 180°. The rings of very large martian double ring basins are defined by ridges and occasional hills, are nearly complete (180° to 360°), but are low and inconspicuous.

Roughly similar diameter dependent differences in ring morphology are seen in basins on Mercury and the moon. One intriguing interplanetary difference in basin morphology is that peak rings are often complete circles on Mercury. Lowell (Fig. 5d) and Schrödinger are commonly given as examples of martian and lunar PR basins, respectively, but in fact the completeness of their rings is nearly unique on those planets. In contrast, ten basins on Mercury have virtually unbroken peak rings and most other mercurian inner rings have continuous arcs of 270° to 360°. If peak ring continuity is related to substrate homogeneity (as is outer ring development; Head and Solomon, 1980), Mercury must have a remarkably homogeneous crust, whereas the moon, and especially Mars, must have sharp lateral variations in crustal properties. Alternatively, it may be that the higher modal velocities for impacts on Mercury (Hartmann, 1973) translates into a greater efficiency in peak ring formation.

Peaks

The Viking observations of Martian basins may help explain an apparently anomalous observation on Venus. Radar images of Venus reveal numerous circular features that are often interpreted as impact craters, and many have radar bright centers that have been compared with central peaks (Campbell *et al.*, 1979). These central spot craters are as wide as 280 km, much larger than any previously known central peak crater on Mars, Moon or Mercury. The large central spot craters on Venus may actually be basins similar to the martian CP basin Herschel, with a central peak that returns a radar bright spot, and a peak ring too low to produce a radar return.

Plains

The floor of nearly every martian basin is smooth, and lunar-like mare ridges and ghost craters occur. These observations suggest that (1) the smooth material was emplaced after impacts had occurred on the basin floor, and (2) the smooth material forms ridges and buries craters similarly to lunar mare basalts. This interpretation was previously reached for the larger martian basins (Scott and Carr, 1978; Wood and Head, 1976) and also appears true for the smaller basins.

DIAMETER FREQUENCY DISTRIBUTION

A cumulative frequency-diameter plot for the martian basins listed in Table 1 exhibits three different slope segments (Fig. 9). It is unlikely that the relatively abrupt changes in slope are due to selection or degradation effects because the inflections occur at diameters that subdivide basins into different morphological classes. Figure 9 illustrates that there is an excess of small, medium and large double ring basins (D < 250 km) compared to the number of very large double ring basins and multi-ring basins. Additionally, there is a relative deficiency of

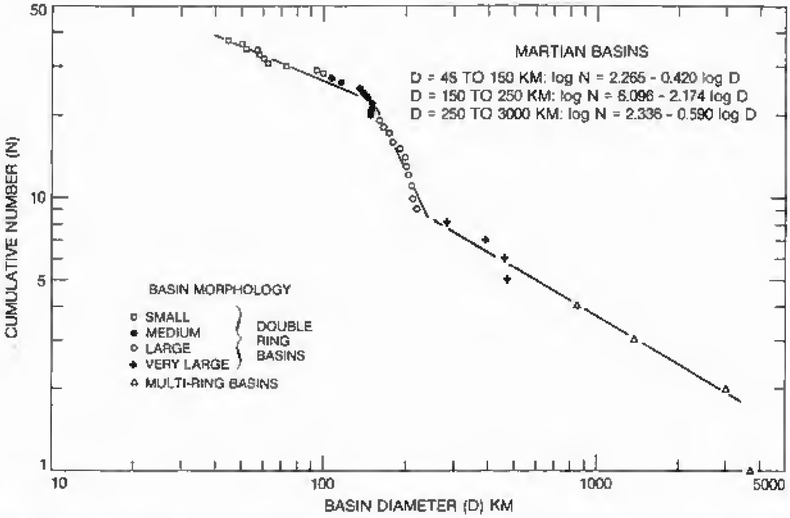


Fig. 9. Log cumulative basin frequency versus log basin diameter for all martian basins in Table 1.

small and medium size double ring basins (D < 150 km). The similar distributions of the latter two morphological types are further evidence that the anomalously small PR basins are part of the overall basin continuum. Correlation of basin morphology and relative abundance for Mars, Mercury and the moon (Wood, in prep.) adds a new and as yet little understood element to basin investigations.

CONCLUSIONS

Examination of Viking photomosaics has resulted in the doubling of the number of known basins on Mars; more undoubtedly await detection. Basins have been classified according to ring morphology and a diameter dependent sequence apparently exists:

a) small basins (45 < D < 100 km) are almost exclusively (9 out of 10) PR types;
b) medium size basins (100 < D < 150 km) dominantly (6 of 8) have CP morphology;
c) large basins (150 < D < 250 km) are PR types with one exception (10 of 11);
d) very large double ring basins (250 < D < 500 km) have PR morphology (1 CP type out of 4) with ridge rings rather than peak or massif rings;
e) multi-ring basins (only 4) occur at D > 500 km.

This morphology sequence does not conform to the CP-PR-MR progression on the moon, Mercury and Earth. The small martian basins, however, are 50 to 100 km smaller than any basin on Mercury and the moon, supporting the view that they are unique to Mars. On Earth there are significant terrain influences on crater and basin morphology that encourage the speculation that localized unique characteristics of the martian crust led to basin formation at diameters where craters would normally be formed. Alternatively, following theoretical and experimental evidence, the anomalous PR basins (and perhaps the two large CP basins) may have resulted from unique characteristics of the impacting body (e.g., low density comet). Both interpretations have obvious weaknesses.

Abrupt changes in the slope of the diameter distribution of martian basins (Fig. 9) are correlated with changes in basin morphology.

Martian basins commonly have smooth floors, ridge and rille structures, and embayed and ghost craters, all reminiscent of the lunar mare. Although there are undoubtedly many processes that form smooth surfaces on Mars this evidence plus the obvious abundance of volcanic landforms (Scott and Carr, 1978) implies that small to very large basins on Mars have localized igneous extrusions.

Peak ring morphology and continuity are generally similar for basins on Mars and the moon, but on Mercury peak rings are much more complete. This dramatic difference in peak ring structure may reflect a homogeneous crust or higher modal impact velocities for Mercury.

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