Papers Presented To The

Conference On Comparisons Of Mercury And The Moon

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PREFACE

This volume contains papers which were accepted for publication by the Organizing Committee of the Conference on Comparisons of Mercury and the Moon. Papers were solicited which address one of the following major topics:

- I. Internal structure, origins of magnetic fields, and thermal evolution
- II. Surface morphology and crustal evolution
- III. Regolith processes and remote sensing
- IV. Future missions

The Organizing Committee consisted of J. B. Adams (*University of Washington*), S. E. Dwornik (*NASA Headquarters*), J. W. Head (*Brown University*), J. W. Minear (*Johnson Space Center*), V. C. Oberbeck (*Ames Research Center*), R. O. Pepin (*Lunar Science Institute*), P. H. Schultz (*Lunar Science Institute*), C. H. Simonds (*Lunar Science Institute*), S. C. Solomon (*Massachusetts Institute of Technology*), and J. R. Underwood (*West Texas State University*).

Logistic and administrative support for this conference has been provided by P. P. Jones (*Administrative Assistant/Symposia Office, Lunar Science Institute*). This abstract volume has been prepared under the supervision of M. S. Gibson (*Technical Editor, Lunar Science Institute*).

Papers are arranged alphabetically by the name of the first author. An index lists the papers which were submitted to address one of the four major topics. Additional indices by author and subject are included.

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MERCURY: EVIDENCE FOR AN ANORTHOSITIC CRUST FROM REFLECTANCE SPECTRA, J.B. Adams, Department of Geological Sciences, University of Washington, Seattle, WA 98195, and T.B. McCord, Institute for Astronomy, University of Hawaii, Honolulu, HA 96822.

Reflectance spectra of Mercury from 0.335μm to 1.064μm were measured in 1969 (McCord and Adams, 1972) and in 1974 and 1975 (Vilas and McCord, 1976). The recent spectral data do not show an absorption feature near 0.95μm; therefore, there is no evidence for the presence of pyroxene. The featureless steep continuum of the Mercury curve cannot be reproduced by silicate minerals or by homogeneous glasses. The common Fe^{2+} charge-transition bands that occur in the spectra of terrestrial, meteoritic and lunar rocks are notably absent in the Mercury spectrum. Lunar soil samples, characterized by the presence of heterogeneous inclusion-filled glass, have a continuum slope similar to the Mercury curve. Lunar samples, however, have an absorption band near 1μm which in mature soils is primarily due to an Fe^{2+} charge-transition in agglutinitic glass. Reflectance measurements of mineral and agglutinate separates from lunar soils shows that the 1μm band in mature soils deepens as a direct function of the FeO content of the bulk soil. The absence of a distinct 1μm band in the Mercury spectrum is only reproduced in the spectra of mature lunar soils having less than 6% FeO such as occur at Apollo 16. Increasing amounts of FeO such as in the Apollo 14, 15 and 17 upland soils (and all mare soils) produce a noticeable Fe^{2+} absorption near 1μm that departs from the smooth continuum of the Mercury curve.

If it is correct to model the Mercury spectrum on the lunar soils, we can conclude that much of Mercury is covered by mature lunar-like soil containing <6% FeO. Again by analogy with the moon, it is probable that the surface of Mercury observed telescopically is anorthositic in composition. These conclusions are compatable with Mariner 10 data (Hapke *et al.* 1975) which show extensive heavily cratered areas with albedos slightly brighter than the lunar highlands.

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RAYED CRATERS ON THE MOON AND MERCURY

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Lunar craters with bright ray systems generally exhibit morphologies by which they are classified as "fresh", ie Class 1 or 2. Rayed craters on Mercury are also thought to be fresh, although the resolution of the Mariner 10 imagery is not sufficient to show small-scale topography.

The size-frequency distributions of lunar Class 1 and 2 craters, as well as that of the mercurian post-Caloris craters, have been previously studied. These distributions approximate a power law of the form $N = aD^b$ where N is the number of craters of mean diameter D per unit surface area and a and b are constants. The value of the exponent, b, for fresh lunar and mercurian craters has been found to range from -1.5 to -2.0.

The present study generated a pair of size-frequency plots for the rayed craters larger than 7 km in diameter on the Earth-facing side of the Moon and the southern hemisphere of Mercury. These plots indicate that the rayed crater distributions also approximate the power law, but the value of the exponent, b, is near -1.5 for the Moon and -1.0 for Mercury. This indicates that the rayed crater population may not be representative of the larger population of fresh craters on either body. Specifically, as compared to all fresh craters, the number of small rayed craters is low by at least a factor of 2 on both the Moon and Mercury.

The proposed mechanisms for crater ray degradation are all basically surface processes, which would obliterate the rays of large and small craters with equal speed. Thus, the observed size-frequency distribution for the rayed craters should reflect the distribution at the time of formation. The fact that this distribution differs from that for fresh craters in general on the Moon and Mercury may be indicative of differences in the populations of impacting bodies which formed these craters.

INFORMATION ON GRAVITATION OBTAINABLE FROM A MERCURY ORBITER MISSION

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The new spacecraft transponder being developed at JPL appears capable of achieving 15 cm overall range accuracy at S and X band in time for a 1983 or 1984 Mercury Orbiter mission. An alternate modulation scheme and higher modulation frequency probably are needed, but the costs appear quite small compared with the overall mission cost. Improvements in the ground system and antenna calibration techniques to about the same accuracy appear feasible. Thus, we have investigated the accuracy of gravitational information obtainable from measurements of the Earth-Mercury distance over various time intervals. If the problem of spacecraft orbit determination with respect to Mercury's center of mass can be solved so that the overall center-center distance accuracy is 30 cm, the expected accuracy for determining the PPN parameters β, γ, α_1, α_2, α_3, and ζ_w plus $\dot{G}$ and J_2 for the sun is very high. This conclusion is based on a worst case error analysis where the rms of the systematic errors is taken as 30 cm. Contributions from random errors are expected to be smaller. While the analysis is done for metric theories, the high range accuracy also would optimize the chances of small perturbations due to non-metric theories showing up. The worst case accuracies expected for a 2-year extended mission, which we believe are pessimistic by a factor of about 4, are as follows: 4.8×10^{-3}, 2.6×10^{-4}, 2.5×10^{-3}, 9.9×10^{-5}, 2.4×10^{-7}, and 3.0×10^{-5} for the PPN parameters in the order given above; 1.4×10^{-12} for $\dot{G}/G$; and 2.8×10^{-7} for J_2. In view of the above results, it seems worthwhile to consider the trade-offs involved in a joint Planetary Science and Physics mission in which attention is given to improving the spacecraft orbit determination capability. The use of a sub-satellite in a favorable orbit might be necessary.

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Al/Si VARIATION IN APOLLO 11, 12, AND 15 MARE BASALTS AND REGOLITH SAMPLES: John C. Butler, Geology, University of Houston, Houston, TX 77004

The direct measurement of Al/Si ratios in the uppermost portion of the lunar regolith by the Apollo 15 and 16 missions makes one optomistic concerning possibilities for future unmanned geochemical surveys of the moon and other planetary bodies. These data have proven extremly useful in examining large scale lateral chemical heterogenieties and in mapping local chemical variations. Previous investigators have noted that the between site chemical variations reflect compositional differences in the parent material which is primarly the local bedrock. The ability of variations in measured Al/Si to mark the highlands-mare material clearly has been demonstrated and a nearly complete trace and major element analysis has been obtained for the lunar highlands regolith by making certain assumptions and having access to ground-truth observations. Without access to ground-truth chemical analyses (which will be the situation for initial geochemical surveys of other planetary bodies) the present system will not yield absolute values of Al and Si. Chemical analyses of Apollo 11, 12 and 15 basalt and regolith samples have been extracted from the lunar data base in an attempt to discover how much information in contained in the Al, Si, and Al/Si variation (Table 1.)

TABLE 1.

Sample	Mean Si	Mean Al	C Si	C Al	rAl:Si	rAl:Al/Si
Apollo 11 Basalts	18.98	5.00	.026	.145	-.044	0.980
Apollo 11 Fines	19.61	7.21	.026	.036	-.024	0.782
Apollo 12 Basalts	20.87	5.12	.054	.204	.248	0.938
Apollo 12 Fines	21.61	7.30	.083	.083	.432	0.961
Apollo 15 Basalts	21.50	4.84	.047	.187	.373	0.954
Apollo 15 Fines	21.83	7.70	.019	.211	.379	0.964
Apollo 12 and 15	21.44	5.93	.044	.294	.350	0.977

At a given site the regolith samples tend to have higher Al, essentially the same Si and higher Al/Si ratios than the mare basalts from the same site. The correlation between a ratio and its numerator is a simple function of the coefficients of variation of the parent variables (Al and Si) if the Al:Si correlation is zero. As Si has a relatively small coefficient of variation the correlations between Al and Al/Si are quite large except for the Apollo 11 fines. Plots of Al/Si versus Al exhibit a strong positive linear trend. There is a considerable difference between the trends for the Apollo 11 basalt and regolith samples. However, there is no statistical difference between the lines of organic correlation for the Apollo 12 and Apollo 15 basalt and regolith samples. In fact, the Apollo 12 and 15 basalt and regolith samples can be combined into a single data set (Table 1) for which the equation of organic correlation is Al=22.89(Al/Si) - 0.397. These preliminary analyses suggest that it may be possible to estimate the Al content of the lunar surface materials from the measured Al/Si ratios with relatively small associated errors.

MERCURY CRATER ANALYSES: AN AUTOMATED DATA GATHERING AND HANDLING SYSTEM.

M.J. Cintala, C.A. Wood, S.U. Grenander, M.E. Dibner-Dunlap, T.A. Mutch, and J.W. Head, Dept. Geol. Sci., Brown University, Providence, R.I. 02912.

Mariner 10 returned the first spacecraft imagery of the planet Mercury[1], providing coverage of 30-40% of the surface. An automated data gathering program has been designed and implemented to analyze this new data in a comprehensive, systematic manner. Particular emphasis has been placed on crater locations, morphologic characteristics, states of degradation, and morphometry. The data system is similar to that previously utilized for Mars and direct comparisons can be made between the two planets[2,3], and with data from the Moon[4]. Data were recorded using a Hewlett-Packard digitizer/calculator and a tape output device. The digitizer consisted of a magnetic board with fixed orthogonal grid and hand-held digital cursor, which could be placed anywhere on the board and, on command from the operator, would transmit its X-Y position to the calculator. Crater dimensional parameters were digitized, including rim crest diameter and floor diameter. Shadow measurements were made for determination of crater depths and central peak heights. Other crater parameters digitized include information on rim crest sharpness, continuity, shape and elevation, and rim morphologic characteristics; a qualitative estimate of crater depth; floor flatness, texture and other characteristics; crater associations (single, doublet, cluster, chain); crater wall type; and general crater degradational class and morphological type for comparison with lunar data[4]. Thus far approximately 2600 craters are in the Mercury data bank.

Data obtained with this program allow intra- and interplanetary correlations and analyses of the following types: crater areal distributions, diameter distributions, degradational sequences, morphological variations of craters with size, substrate, and planetary environment. Preliminary results from these analyses appear elsewhere in this volume.

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Global Tectonics of Mercury and the Moon

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A study of the tectonic features of Mercury indicates that it s global stress field has been very different from that which shaped the surface of the moon.

The lunar grid system, consisting of rilles, valleys, crater chains, etc., suggests that the surface has been subjected predominantly to tensional stresses, possibly by tidal interaction between the earth and moon. Compressive features of global distribution are not recognized on the moon although mare ridges may be in part the result of local compressive stresses.

Locally, Mercury displays lunar-like tectonic features, but the major manifestations of its tectonism are the lobate scarps which appear to be globally distributed. Morphology and transectional relationships indicate that the majority of lobate scarps are thrust or reverse faults resulting from a global compressive stress field. An apparently unique lunar structure near Aristarchus has a morphology very similar to the mercurian lobate scarps, but its dimensions are small compared to most mercurian scarps.

Current planetary interior models suggest that cooling and partial solidification of the large mercurian core is responsible for its compressive tectonics.

Corrections for abstract "Double Ringed Basins on Mars, Mercury, and the Moon."

Equation 3 should read: D = 1.35d+63
Delete last sentence in second paragraph.

DOUBLE RINGED BASINS ON MARS, MERCURY, AND THE MOON. R. A. De Hon, University of Arkansas at Monticello, Monticello, AR 71655.

A progression from small, simple craters to complex craters with central peaks and multi-ringed basins is recognized on Mars, Mercury, and the Moon. Double ringed basins form a distinct class characterized by a high, rugged outer rim crest and a lower less rugged, concentric inner ring. A preliminary least-squares fit of basin diameter versus inner ring diameter is described by the linear equation:

$$D = ad+b \qquad (1)$$

where D is the outer rim diameter (rim crest) in Km
d is the inner ring diameter in Kn
a is the slope of the regression line
b is the Y intersect (onset value of ringed basins)

The empirical equations for double ringed basins on Mars, Mercury, and the Moon are:

Mars	- -	$D = 1.71d+38$	(2)
Mercury	- -	$D = 1.52d+49$	(3)
Moon	- -	$D = 1.66d+64$	(4)

The transition from double ringed basins to craters with single central peaks is marked by intermediate stages of peak rings and peak clusters. Double ringed basins occur to the lower limits of 125 Km for Mars and Mercury and 140 Km for the Moon. Below these limits, multiple peaks are arranged in a ring pattern with diameters that constitute a continuium in the linear function to the limit at which simple peaks occur. One reason for the apparent greater frequency of double ringed basins on Mercury is that the onset value (b) is lower than that for the Moon.

The onset value for transition from central peak craters to ringed basins may be a function of characteristics of both the impacting body and the planetary environment. Variations from the nominal onset value for any one planet are probably a function of surface layer thickness. The scarcity of double ringed basins on Mars and the Moon precludes the use of onset values for delineating major variations of the surface layer, but there is a strong possibility of mapping gross variations of the Mercurian upper crust.

ON DYNAMIC FLATTENING OF MERCURY

SH.SH. Dolginov, IZMIRAN, Akademgorodok, Moscow, USSR.

The Mercury's magnetic field can be explaned by the mechanism of precession dynamo, within which have been also explaned the magnetic field intensities of the other planets and the Moon [1,2] , if to admit that the Mercury, possesing a liquid core[3], has :

1. The angle of rotation axis inclination to the orbit plane $\alpha \geqslant 3^\circ$.
2. Dynamic flattening $f \geqslant 2 \cdot 10^{-4}$.

The indicated magnitude of f is nearly 300 times greater than the predicted value [4] , but it is close to the observed value of Moon's dynamic flattening.

With the shown assumption there would be removed the difficulties related to the explanation of Mercury's field origin considered in [5] .

Experimental determination of the Mercury's dynamic flattening with the help of a Mercury's orbiter would be of the same time a test of the precession dynamo model.

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SCARPS, RIDGES, AND TROUGHS ON MERCURY by Daniel Dzurisin, California Institute of Technology, Pasadena, Ca., 91125

Scarps, ridges, and troughs on Mercury can be classed as planimetrically linear, arcuate, lobate, or irregular. Large arcuate scarps with rounded crests and steep faces cut intercrater plains and large craters. They are 100 km to 500 km long, 0.2-1.1 km high, and are planimetrically concave with respect to points above their crests. Arcuate scarps most likely record a period of global compression on Mercury near the end of heavy bombardment.

Large, planimetrically lobate scarps consist of two or more linear segments joined by curved segments. Azimuths of linear segments are consistent with those of nearby lineaments, suggesting structural control of the scarps' lobate outlines.

Planimetrically irregular escarpments cut smooth floors of many large mercurian craters. Transectional and morphologic considerations require that most are of tectonic origin. Restriction to crater floors may indicate that these scarps formed in response to local stress fields centered beneath confining craters.

Several large mercurian ridges developed in intercrater plains are planimetrically linear in extent, although some are irregular in detail. Their azimuths are consistent with those of other lineaments nearby. They locally obscure segments of crater rims and floors without destroying associated topography. A speculative model for their formation involves lava extrusion from pre-existing crustal fractures.

Finally, planimetrically irregular scarps, ridges, and troughs cut smooth plains inside and outside Caloris Basin. They together define patterns radial from the basin center and concentric with the crater rim. Most are tectonic features perhaps formed in response to basin excavation and smooth plains emplacement in and around Caloris Basin.

INTENSE BOMBARDMENT AS A POSSIBLE REASON OF EARLY GEOCHEMICAL DIFFERENTIATION OF THE INNER PLANETS

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The good preservation of very ancient ($>3.5 \times 10^9$ years) rocks and relief features observed on some planetary surfaces indicates that information about early planetary processes may still be available. Lunar, Martian and Mercurian data are generally interpreted as showing an early differentiation accompanied by separation of a relatively thick crust abundant in refractories and by intense cratering of the crust. There is some evidence that these processes do not only coincide in time but have a genetic relationship. It is well known that during the process of impact cratering the projectile and some part of the target are heated, partially fused and vaporized. In this process refractories tend to accumulate in target remnants and volatiles tend to escape. It should be noted that the latest stage of accretion of planetary bodies must have occurred with the heaviest cratering and therefore would have the same tendency of chemical differentiation. Because of the weak gravity field of minor bodies (Moon, Mercury), volatiles can escape from the planet. In the case of larger bodies volatiles would accumulate in the upper shells to form the primary atmosphere and hydrosphere, having a significant influence on the composition of the planetary crust.

Extending this model, one can visualize the outer parts of planets as being assemblages of previous projectiles. This means that, during the growth of the planet, the planet-forming matter has gone through the "thermal barrier". The characteristic of the process is that it resembles zone melting, because the total mass of matter which has differentiated can be very large. However, at any given moment of time the mass of heated matter can be rather small. In this way, the conception of the total melting of the outer part of the planets becomes unnecessary for the formation of the crust.

A SCALING LAW FOR THE MAGNETIC MOMENTS OF MERCURY AND THE MOON: J. W. Freeman, Dept. of Space Physics & Astronomy, Rice University, Houston, Texas, 77001.

An empirical scaling law has been developed which relates the magnetic moment of a body to the 1.25 power of the product of the spin-rate and core volume[1]. The law is reasonably successful when applied to the planets from Mercury to Jupiter with both mars[2] and Venus[3] having somewhat lower magnetic moments than predicted. Mercury shows good agreement with the Earth, Jupiter and the Sun.

When applied to the present Moon using an upper limit magnetic moment of 10^{19} gauss cm^3[4], the scaling law yields an upper limit on the core radius of several hundred kms. This number is compatible with magnetometer results[5].

We next apply the scaling law to the primordial moon by assuming that the surface rocks were magnetized by a dynamo driven dipole field whose surface field was 1 gauss. We find that the required spin-rate, core volume product is about 2×10^{21} rad $cm^3 sec^{-1}$. For a Moon whose core radius is half the lunar radius the requisite spin period would be about 2.5 hours.

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PRODUCTION OF SIMPLE MOLECULES ON THE SURFACE OF MERCURY; Everett K. Gibson, Jr., TN7/Geochemistry Branch, NASA Johnson Space Center, Houston, TX 77058

The initial examination of the returned lunar samples showed the regolith materials were either enriched or saturated in solar wind-derived elements and/or compounds (e.g., H, H_2, He, C, CH_4, Ne, N_2, H_2O, CO, CO_2, etc.). The solar wind irradiation of Mercury's surface will result in the production of simple molecules on the planet's surface.

From experimental studies on lunar samples and analogues it has been found that the irradiation of silicate materials with H, C, N ions, approximating the solar wind energies, results in the production of simple molecules (e.g., H_2, CH_4, H_2O, N_2, CO_2). The energetic particle bombardment provides large numbers of dislocated oxygen atoms in the silicate lattices of the surface materials which combine with the solar wind ions. These S.W. ions and produced molecules are retained in the outermost layers of the lunar soil grains. At temperatures below 400°C, the following gaseous species are evolved from lunar soils: H_2, H_2O, CH_4, He, and CO_2. The majority of the H, C, and N atoms found in the lunar soils are extra-lunar and result from solar wind implantation. As the lunar soils mature, the elemental concentrations of H, C, and N reach a saturation level.

With Mercury residing only 0.386 AU from the Sun, the solar wind ion flux should be 6.7 times greater than that observed for the Moon, provided the Mercurian planetary field does not shield the planet. It has been previously noted that a larger fraction of the solar wind ions captured by the magnetosphere of Mercury are expected to reach Mercury's surface because the planet occupies a significantly larger portion of its magnetosphere than does the Earth in its magnetosphere. Therefore, a significantly larger fraction of the solar wind ions captured by the Mercurian magnetosphere can reach the surface of the planet. The solar wind flux for the surface of Mercury should be 6.7k the lunar flux. "k" represents the fraction of ions which are trapped within the magnetosphere and reach the surface by a variety of paths.

The previous models of the Mercurian surface being void of volatile species should be re-examined in light of the lunar sample studies. The solar wind flux of ions at the Mercurian surface, the planet's temperature regime (temperature ranges of 100° to 325°C for dayside and -143° to -173°C for night side), and the long rotational period of the planet (88 days) all support the model that volatile compounds and phases may be produced on the surface of the planet. During the sunlight periods, the surface temperature may be sufficient to "outgas" a portion of the regolith resulting in a migration of these volatile species (H_2, H_2O, CH_4, CO_2, etc.) to the dark side of the planet. The volatile phase evolution may play an important role in the weathering of the silicate materials found on the surface of Mercury.

THE MOON AND MERCURY AS BODIES SHAPED BY ACCRETION. T. Gold,
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The internal composition of Mercury and the Moon are very different, as judged by their density. The estimated proportion of iron is only 10 percent for the Moon, but 57 percent for Mercury. For a similar value of rock-borne radioactivity Mercury would have heated about four times less. A limited amount of rock melting on the Moon would correspond to a complete absence of any melting on Mercury. Thus, if one wanted to ascribe the extremely similar surface appearance to a similar combination of internally caused melting and external bombardment, one would need to invoke a much higher value of rock radioactivity for Mercury and a fortuitous correspondence of time-sequence and extent of the internally and externally caused effects.

The radar evidence for the Moon is clear: there is no widespread broken-up bedrock at a shallow depth underlying the regolith; no way is known in which the regolith could have been produced by the grinding action of impacts from a solid crust, and result in the low, long-wave reflectivity and intense limb-darkening. Mercury appears to be similar also in this respect. Thus, both bodies appear to have a deep layer of regolith, compacting with depth but without a sudden transition in the first several hundred meters. Only accretion of the regolith can have produced this. The flat fill of low ground on both bodies must then be due to a surface transport mechanism. Electrostatic transport due to solar wind electron bombardment on Mercury would be ~ 7 times faster than on the back of the Moon--the front face of the Moon has the added benefit of electrons accelerated in the terrestrial magnetosphere. A surface for Mercury intermediate in extent of flat fill between the back and the front of the Moon seems appropriate. The striking similarity of the surfaces of the two bodies is then explained as being due to similar external action in the last phases of the accretion of both.

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COMPOSITION AND MICRORELIEF OF THE MERCURY REGOLITH; Bruce Hapke, Dept. of Earth and Planetary Sciences, University of Pittsburgh, Pittsburgh, Pa. 15260

Optical, thermal and radar remote-sensing measurements indicate that Mercury is covered with a relatively thick layer of soil similar in texture to lunar regolith. Photometric limb profiles imply that the average small scale ($\sim$ few cm) slopes on Mercury are about half those on the moon, probably because of higher gravity. Continuing analysis of Mariner 10 data and new earthbased observations support the conclusion (Hapke, et al., 1975, J. Geophys. Res., 17, 2431) that the surface of Mercury is lower in TiO_2 and FeO than the moon. The 1.0 μm Fe^{+2} band is virtually absent in the reflection spectrum of Mercury (McCord and Vilas, 1976, DPS/AAS Meeting, Austin, paper 139); the vacuum UV albedo of Mercury is lower than the moon's (Wu and Broadfoot, 1976, DPS/AAS Meeting, Austin, paper 138); both of these observations are consistent with a low-Fe regolith. No bands in the green or blue are visible in the Mercurian spectra, implying the absence of Ti-rich glasses and minerals such as ilmenite, rutile or perovskite. However, some Fe must be present, since the overall similarity of the Mercury and lunar albedos and spectra implies similar amounts ($\sim$ 0.5%) of submicroscopic, metallic Fe. The low FeO content is consistent with recent theories of condensation in the solar nebula (e.g., Lewis, 1972, Earth and Plan. Sci. Let., 15, 286), but the low TiO_2 is not.

MORPHOLOGICAL DEGRADATION OF MERCURIAN CRATERS. J.W. Head, C.A. Wood and M.J. Cintala, Dept. Geol. Sci., Brown University, Providence, R.I. 02912.

More than 2600 craters on Mercury have been subdivided into 5 degradational classes using criteria developed in previous studies of lunar craters. Class 1 craters are sharp rimmed, and each successive class is increasingly blurred, broken, battered and fragmentary. Additional morphologic and morphometric data, obtained with an automated data gathering system, allow detailed characterization of modifications and processes involved in crater degradation on Mercury.

The preliminary degradation trends illustrated in the table below are for craters of all diameters within a particular class, and thus reflect morphological changes due to diameter as well as degradation variations. Observable continuous degradational trends with increasing class are as follows: rim crest continuity and circularity decrease; craters become shallower; flat floors become more abundant; central peaks become less common. These trends are compatible with an interpretation of impact dominated erosion and infilling of craters, with decrease in crater depth, burial of central peaks, and widening of crater floors, similar to the lunar continuous degradation sequence.

The anomalous persistence of raised rims as degradation increases may result from concentration of ejecta near the crater itself due to the high gravitational field of Mercury. Removal of the rim would thus require substantially greater obliteration than on a planet of lower surface gravity, such as the Moon.

Table 1: Degradation Trends in Mercurian Craters

Parameter	Class 1	Class 2	Class 3	Class 4	Class 5
No. of craters	1229	604	475	178	141
Continuous rims (%)	97	67	32	9	1
Circular rims (%)	90	80	73	65	58
Raised rims (%)	99	88	84	76	82
Deep (%)	96	50	5	2	0
Shallow (%)	0	3	28	60	89
Flat floors (%)	25	43	75	91	89
Visible floors with central peaks (%)	25	12	10	7	4

IMPLICATIONS OF A RADIOGENIC ATMOSPHERE ON THE INTERNAL STRUCTURE OF THE MOON AND MERCURY; R. Richard Hodges, Jr., The Univ. of Texas at Dallas P. O. Box 688, Richardson, Texas 75080.

Rates of supply of radon and ^{40}Ar to a planetary atmosphere are important indicators of the present distribution of radioactive uranium and potassium within the planet. In the moon the rate of formation of radon is probably about 630 ton/yr, while its rate of effusion to the atmosphere is roughly 80 gm/yr. From these rates and the 3.8 day half life of radon it is easy to show that the mean transit time for radon atoms from point of creation to the lunar atmosphere is less than 90 days. The rate of release of ^{40}Ar to the lunar atmosphere is about 3 ton/yr which corresponds to about 6% of the total decay of potassium to uranium in the moon.

The rapidity of effusion of radiogenic gases from the moon has far reaching implications. These elements are formed in nuclear reactions which release energies the order of 5 meV. In the dry lunar regolith the dissipation of the recoil energy must result in entrapment of the resultant atoms in solid rock. Release by weathering is too slow to be significant and diffusion can be ruled out on the basis of the excess ^{40}Ar in returned lunar samples.

The only reasonable mechanism for rapid release of the radiogenic gases is through their formation in a liquid or semimolten material, so that recoil energy is absorbed without trapping. Seismic data indicate that a semimolten zone exists below about 600 km in the moon. Since this must be the source of both radon and argon, it is necessary that uranium and potassium presently exist at great depths. This rules out total differentiation and core formation early in lunar history. A possible scenario is that an early, impact induced melting of the moon extended only to a depth of about 1000 km differentiating the outer region while leaving a deep zone of primitive material. Subsequent radioactive heating of the central region has probably caused a second differentation of the interior, forming a core and concentrating radioactive elements roughly between 600 and 1000 km depth.

Whether radiogenic gases are presently escaping from Mercury remains an open question which hopefully will be answered by future experiments. Textural similarities seem to exist in the lunar and Hermian regoliths, although weathering by the solar wind has probably been much less on Mercury due to its magnetic field. The high daytime temperature of Mercury may enhance the diffusion of argon and helium from soil grains, but this process should be too slow to release the short lived radon. Thus the presence of argon or nonsolar helium on Mercury may not have such profound implications on internal structure as on the moon. If their release rates are small enough to allow a regolith source the ratio of the abundances of these gases may be interpreted in terms of the K/U ratio in the soil. A large rate of escape of either gas, or the mere presence of radon on Mercury should imply the presence of radioactive elements at great depths, and hence a nonclassical internal distribution of elements.

ORBITAL GAMMA-RAY DATA AND LARGE SCALE LUNAR PROBLEMS; Norman J. Hubbard, NASA Johnson Space Center, Houston, TX 77058 and Danuta Woloszyn, Lunar Science Institute, Houston, TX 77058.

Recently available orbital gamma-ray data (Beilefeld et al., 1976) have been examined to see what new information can be gained about the Moon. The limitations and advantages of the data are as follows. The data are only for large surface areas. However, because of this "small scale" effects are eliminated or reduced by the resulting averaging effect. The data are for a limited number of elements and of limited precision and accuracy. On the other hand, the elements Th, K, Fe and Mg are among the best for studying the Moon. and the precision for Th, K and Fe is quite adequate for many problems. The data probably seldom apply to a single rock type but, they can often be used as representative of the upper meters (mare areas) to kilometers (highlands) because of local mixing by cratering and the differences between large areas can be interpreted as differences in the relative abundances of a set of rock types or as different petrogenetic provinces. This study is also somewhat limited simply because the regions defined by Beilefeld et al. are not always the best for a given problem.

Major results are: First, there are several distinct petrogenetic provinces visible in the orbital gamma-ray data. Second, the regions where "KREEP" (the high Th material) is most abundant, and where it is mixed with mare material, have a narrow range of elevations. This suggests that "KREEP" filled a portion of the lunar surface to a common level, i.e. "KREEP" was emplaced as lava flows or as fluidized material. Third, the materials of the central highlands have higher Mg and Th concentrations and much lower K/Th ratios (500 vs 1,200) than the average materials of the lunar farside. In light of this, how accurate is our knowledge of the petrogenesis of the lunar highlands, since it is largely based on samples from the central highlands? Fourth, the basalts in Mare Serenitatis are mixed with the least amount of non-mare material. This is consistent with the reduced vertical mixing expected because of the thick fill of mare basalts in this basin. Fifth, the Big Backside Basin is filled with at least two types of material, one which approaches mare basalts in chemical composition and one which has a highland composition.

BIELEFELD M. J., REEDY R. C., METZGER A. E., TROMBKA J. I. and ARNOLD J. R. (1976) Surface chemistry of selected lunar regions. Proc. Lunar Sci. Conf. 6th, in press.

LARGE IMPACT EFFECTS ON MERCURY AND THE MOON.* H. Grady Hughes and Thomas R. McGetchin, University of California, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, NM 87545

A number of recently developed models of the thermal evolution of the terrestrial planets (1,2) include a phase of intense heating of the outer layers due to early bombardment of accreting material. The resulting planetary structure consists of a brecciated solid surface overlying a molten layer, which in turn overlies a solid interior. The base of the solid lithosphere grows deeper with time, while the molten layer decreases in thickness, and for most of the planets is crystallized in less than about 2 b.y. It was during this early semi-molten phase of the moon that the large impact basins were formed and the mare basalts erupted. Large basins on Mercury and Mars presumably were also formed at this time.

We are investigating the large scale effects of impacts on layered planets using two multipurpose computer programs -- KACHINA (3), a hydrodynamic code capable of treating multiphase flow and phase transitions, and TOODY (4,5), a shock-propagation code which includes the effects of material strengths, elastic-plastic behavior, material failure, etc. The following aspects of the problem are of particular interest to us:

1. Near-field effects, including the extent and depth of the region of material failure as a function of the velocity and mass of the impacting object, and the scaled depth of the molten layer.
2. Global shock propagation, including effects near the impact point and at the antipodal point due to
   (a) the presence or absence of a large dense planetary core, and
   (b) the size and depth of near-surface molten layers.

*Work performed under the auspices of the US/ERDA

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CRATER CHRONOLOGY: RESETTING OF K-AR AGES BY CRATERS OF 1-20KM SIZE FROM STUDIES ON THE RIES AND BRENT CRATERS.
E. K. Jessberger,[1] M. Dence,[2] B. Dominik,[1] J. Hartung,[3] T. Kirsten,[1] and O. A. Schaeffer,[1,3] [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany, [2]Earth Physics Branch, Dept. of Energy, Mines, and Resources, Ottawa, Canada, [3]Dept. of Earth and Space Sciences, State Univ. of New York, Stony Brook, N.Y. 11794

There is a good bit of discussion concerning the meaning of the ^{39}Ar-^{40}Ar ages of lunar highland rocks. On the one hand, there is the idea that all the highland rocks have ^{39}Ar-^{40}Ar ages which represent the times of the formation of large major basins on the moon. On the other hand, there is the idea that the highland rocks have ^{39}Ar-^{40}Ar ages which represent the times of formation of cratering events much smaller than the major basin formation. On the basis of the ages so far measured, it is difficult to reach an unequivocal conclusion. One is forced to make some sort of "reasonable" ad hoc assumption. The correct interpretation of the highland rock ages is of no small significance for the cratering chronology on the Moon, Mars, and Mercury.

We have undertaken a study to determine how impact cratering affects ^{39}Ar-^{40}Ar ages using samples from two terrestrial craters with well-established ages, the 24-km-diameter Ries crater in southern Germany and the 4-km-diameter Brent crater in Ontario, Canada. Preliminary results have been obtained for hornblende separated from rocks experiencing different shock pressures found in the Ries ejecta. Surface samples, as well as sub-surface samples from a 1200-m-long drill core, have been studied. The ^{39}Ar-^{40}Ar plateau ages were not reset by the Ries cratering event. Preliminary ^{39}Ar-^{40}Ar plateau ages for K feldspars from within and below the melt zone at the Brent Crater were affected by the cratering event. Moderately shocked K feldspars from the Brent Crater yield a ^{39}Ar-^{40}Ar age intermediate between the age of the country rock and the time of the impact event. A more strongly shocked and heated K feldspar sample, which is partially re-crystallized, yields a ^{39}Ar-^{40}Ar age significantly less than that for the cratering event. The crystallization age of a whole rock sample melted during the impact event is not significantly different than the previously accepted age for the event.

The results will be discussed as to implications for lunar cratering chronology.

CHONDRULE FORMATION ON MERCURY, Elbert A. King, Dept. of Geology, University of Houston, Houston, Texas 77004 (present address: Mineralogical Institute, University of Tübingen, 56 Wilhelmstraße, 74 Tübingen)

A number of lunar sample investigators have documented the occurrence of impact-produced chondrules in the lunar rocks and regolith, e.g. King et al., 1972, 1972a; Kurat et al., 1972; and Nelen et al., 1972. King et al. (1972) have suggested that the formation of chondrules may be the normal result of the impact bombardment of a silicate **planetary surface.** Chondrules have been noted associated with at least one terrestrial impact crater in basalt (Fredriksson et al., 1973). It is now apparent that many chondrules are produced by the processes associated with large impacts, particularly the crystallization of shock-melted droplets and the abrasion of clasts in base surge flows.

Spectral reflectivity data (McCord and Adams, 1972) have shown that the surface of Mercury may be rather similar in composition to the regoliths of the lunar maria. The bulk density of Mercury (approx. 5.5 gm/cm^3 as contrasted with approx. 3.34 gm/cm^3 for the Moon) has long been used to **infer** that Mercury has a greater proportion of iron than the Moon. However, the probable greater proportion of iron, together with the position of the planet near the Sun, may also indicate a greater proportion of magnesium and other refractory elements common in basic and ultrabasic rocks. These compositions appear to favor chondrule formation.

The greater gravitational acceleration of approaching bodies that will impact the planet (because of the planet itself as well as the Sun) will result in many impacts of greater energy than on the lunar surface. The greater energies of impacts on the surface of Mercury will result in more shock-melting than on the Moon, thereby producing more shock-melted droplets that may form chondrules. It is concluded that Mercurian chondrules will be at least as abundant as lunar chondrules, probably more abundant.

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MODIFICATION OF FRESH CRATER LANDFORMS: EVIDENCE FROM MERCURY AND THE MOON, Michael C. Malin, JPL, Pasadena, CA 91103, and Daniel Dzurisin, Caltech, Pasadena, CA 91125.

Continued analyses of craters of Mercury seen in Mariner 10 images have been compared to studies of lunar craters performed by Pike (1974, 1976) and Smith and Sanchez (1973). Preliminary work reported in Gault et al. (1975) suggested that several parameters, including the break in slope of the depth/diameter relationship, the diameter of onset of central peaks, the diameter of onset of terracing and the relief of central peaks, varied proportionally with planetary gravitational acceleration. However, further study has revealed little if any support for this suggestion. Table I, below, presents power law coefficients acquired by least squares analysis of mercurian and lunar craters. Percent differences are all within the (real) scatter of the data. While motion of material cannot proceed without the action of gravity, it appears that other factors govern both the form of, and extent to which, transient and post cratering modification occurs.

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Table I

		Moon		Mercury		Moon-Mercury
	Diameter (km)	Slope	Intercept	Slope	Intercept	Δ % < 100 km
Depth/Diameter	< 15*	1.010	0.196	0.980	0.176	10-15%
	> 15*	0.301	1.044	0.260	0.910	20-30%
Floor diameter/ rim diameter	> 20	1.249	0.187	1.194	0.269	15%
Rim Width/ diameter	> 20	0.836	0.467	0.708	0.645	10%
Peak relief/ diameter	> 22	0.900	0.032	0.545	0.118	± 28%

* Break in slope: Moon @ depth = 2.1 km, diameter = 10.7 km
Mercury @ depth = 1.6 km, diameter = 9.8 km

MERCURY ORBITER MISSION: SCIENTIFIC ASPECTS, Michael C. Malin, Jet Propulsion Laboratory, Pasadena, CA 91103; Norman J. Hubbard, Johnson Space Center, Houston, TX 77058.

The next stage of study of the terrestrial planets will consist of detailed geophysical/geochemical/geological reconnaisance from planetary orbiters. For Mercury, it has been suggested that a spacecraft in polar orbit, with a lunar polar orbiter-class payload, can address the major scientific objectives of the next phase of exploration of that planet. Owing to several engineering constraints, the Mercury orbiter mission is a difficult one. This limits the quality and nature of the scientific return.

There are two mission profiles currently being discussed: 1.) a 1983 ballistic orbiter in a 6 hour elliptical orbit (500 km x 7430 km) that will provide data sufficient to address many major science questions, although the data set will be degraded by poor southern hemisphere coverage and non-optimal lighting conditions; and 2.) a 1984 SEP (Solar Electric Propulsion) orbiter in a 1.9 hour (500 km) circular orbit which will provide uniform coverage and a data set comparable to that provided by Lunar Polar Orbiter. The 1983 ballistic trajectory requires about 2.7 earth years and uses two Venus swingbys to reach Mercury with an adequately slow approach velocity to permit orbit insertion with existing propulsion systems. The 1984 SEP mission gets there much faster (1.5 years) and with a slower approach velocity, but presents a more severe thermal environment due to the low altitude circular orbit.

The major areas of scientific interest are: the chemical composition of the crust, crustal evolution, the gravity field and figure, the thermal history of Mercury, magnetic and magnetospheric features and processes, atmospheric processes and solar physics/relativity.

MERCURY, MOON, AND MARS PLAINS AND VOLCANIC FLOWS;

Harold Masursky, U.S.Geological Survey, Flagstaff, Ariz. 86001.

Recent mapping in the Michaelangelo (H-12) quadrangle of Mercury and examination of the other photographs indicates that a variety of impact craters of differing sizes and preservation are present. In addition, extending to the north are cratered plains that resemble those on the Moon and Mars. The lunar and Martian lowland plains are characterized by lobate flow fronts, domes with summit craters, dark halo craters, sinuous rilles and chains of craters along graben. These features attest to the volcanic origin of the plains materials. In contrast, upland plains on all three planets are more heavily cratered and their volcanic nature is not apparent although Mars has young volcanic rocks in the uplands also. The Cayley plains at the Apollo 16 landing site on the Moon are a good illustration of impact reworking of the possibly originally volcanic plains material.

The Mercury plains lack the diagnostic volcanic features mentioned above of the younger lava plains of the Moon and Mars. Either they are impact ejecta plains or are heavily cratered enough to have obscured their origin. On the Moon the younger volcanic flows occur in the mare basins, which apparently are topographically low enough to be flooded. The portion of Mercury visible to us lacks the assymetry of the Moon and Mars and does not have low basins and high uplands. The plains materials, if they are lavas, are confined to an early episode of emplacement equivalent in age to the Cayley plains on the Moon. No extensive volcanic flooding has occurred since then unless it is confined to the 60 percent of the planet not viewed by Mariner 10.

ORIENTALE AND CALORIS

John F. McCauley, U.S. Geological Survey, 601 E. Cedar Avenue, Flagstaff, AZ

Applications of experimental explosion crater data to Orientale and recent geologic mapping of the basin in its entirety have produced a new stratigraphy and genetic model for Orientale that is also applicable to Caloris. The Hevelius Formation is divided into four major facies. The materials that lie mostly between the outer Montes Rook and the Montes Cordillera are elevated to formational status and separated into two facies; the basin floor materials (exclusive of the mare) are given a formational name.

The inner basin scarp of Orientale is thought to be a structural bench representing the 60 km seismic discontinuity. The elongated and complexly fractured domes of the basin floor formed by centripetal compression in the last stages of the cratering sequence. The inner Montes Rook are considered a central peak ring produced by more extensive centripetal compression earlier in the cratering process. The outer Montes Rook and the nonlineated knobby and associated smoother materials that overlie the Cordillera scarp around much of its circumference are the uppermost parts of the overturned rim flap which formed early in the cratering event. The knobs and smaller massifs are probably coherent blocks quarried from beneath the 60 km discontinuity. They were among the last materials to leave the basin and unlike the lineated Hevelius which formed earlier by disaggregation of the rim flap, secondary cratering, and the ground surge, these late arriving deposits had little radial momentum and were locally contained by the Cordillera scarp. The Cordillera scarp, best seen on the east side of the basin but poorly developed and discontinuous on the west, is a primary feature formed early in the crater excavation process by basinward motions of the walls and the fractured zone beyond the rim of the expanding cavity. The Cordillera scarp is overlain by ejecta over most of its extent, and post-basin internal slumping previously thought to be important must be a subordinate process in development of the scarp.

The basin fill in Caloris has no counterpart in Orientale but the materials between the most prominent scarp and the weakly developed outer scarp appear to be the degraded and possibly mantled equivalents of the massifs and knobs associated with the outer Montes Rook. The radially lineated terrain that generally lies beyond the outer scarp of Caloris is considered the subdued counterpart of the Hevelius Formation which generally shows the same spatial relation to the outer scarp of Orientale (the Cordilleras). Thus, the prominent innermost scarp of the Caloris basin is the equivalent of the outer Montes Rook. Beyond this scarp is the overturned flap covered by large blocks and massifs derived from a deep horizon in Mercury where the bedrock is more coherent than the upper, impact brecciated layers. The radially lineated deposits, as in Orientale, are earlier arriving basin ejecta and secondary crater materials mixed with the pre-basin surface all of which were modified by the ground surge. This unit originated from shallower and less coherent horizons than the deposits nearer the basin rim. This comparison between Orientale and Caloris suggests that one or more buried ring structures should be present inside Caloris and that Mercury is also layered internally as is the Moon. The differences in spacing and development of the ring structures or circumferential scarps of Orientale and Caloris are probably gravitational effects.

MERCURIAN TECTONICS: A CONSEQUENCE OF TIDAL DESPINNING? by H.J. Melosh and D. Dzurisin, Division of Geological & Planetary Sciences, Caltech, Pasadena, Ca., 91125.

Strom (1) has reported a global pattern thrust faults on Mercury. Dzurisin (2) has found that lineaments in the incoming quadrant have predominant NE-NW trends. The lineaments trend roughly N52°E and N57°W in the equatorial (20°S to 20°N) region, very close to the trends expected for shear fractures due to E-W (azimuthal) compression. The acute opening angle between these sets of lineaments increases toward the south pole (south of 50°), where the dominant trend is N27°W.

Melosh (3) has made a theoretical study of the stresses and associated fractures due to spindown of a planet. For a planet with a thin (less than 200 km thick) lithosphere, stress differences can reach several kilobars; faulting is thus expected. The azimuthal (E-W) stress is always larger (more compressive) than the meridional (N-S) stress. As the planet is despun, shear faulting begins at the equator (where stress differences are largest), then proceeds toward the poles. Shear fractures with the observed orientation develop in the equatorial region. Poleward of 48° the pure despinning model predicts (unobserved) E-W trending graben and other tensional features. This tensional regime can be suppressed by allowing a slight (.1-.2%) decrease in radius during the despinning process. This decrease in radius could be due to general cooling or phase transformations in the upper mantle. If the decrease in radius continues after Mercury has been substantially despun, net horizontal compressive stresses can exceed vertical stresses, leading to thrust faulting. The net stress in the crust is a superposition of the stress field due to despinning and that due to the decrease in radius. If the azimuthal stress component due to despinning still dominates, these thrust faults will have an E-W throw and should exhibit trends falling within the quadrant N45°W to N45°E.

We thus propose that the lineaments and thrust faults on Mercury are due to a combination of tidal despinning and a slight global contraction. The model predicts that the lineaments formed before the thrust faults as some data (2) suggest. The apparent change in trend of the lineaments near the poles is not explained by the model. This trend change may be a local effect, since the area involved is not large. Mapping of larger areas near the poles might resolve this question.

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LUNAR POLAR ORBITER. J. W. Minear, NASA Johnson Space Center, Houston, TX 77058, T. V. Johnson, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91103

Lunar Polar Orbiter (LPO) is an important step in the exploration of the solar system. This inportance stems from three primary reasons. First, the LPO represents excellent planetary science. The Moon provides the most accessible record in the solar system of early planetary evolution, including chemical differentiation, igneous and tectonic activity and the effects of heavy meteorite bombardment. As a representative member of the terrestrial planets and of a number of other solar system objects, the Moon will advance significantly our understanding of the early formation and evolutionary processes of planetary objects. Global geochemical and geophysical data provided by the LPO mission will be timely in their contribution to our present understanding and data base for the Moon. These data will allow the testing and extension of hypotheses that are based largely on data from a few lunar sites. The existing absolute chronology, the numerous and varied data from lunar samples and the surface experiment packages will permit the maximum science to be derived from the global LPO data. Secondly, LPO represents a new class of spacecraft in instrument complement and in spacecraft evolution. Such spacecraft can provide a high degree of commonality in the types of measurements made on the terrestrial planets. The scientific success of such missions depends on extensive interaction and correlation of the data from different experiments. Finally, the Moon is a logical way-station in our continued exploration of space, whether as a base for scientific exploration or resource utilization. LPO will provide the global geochemical and topographic survey necessary for such future activities.

DYNAMICAL PHENOMENA IN THE INTERIOR OF MERCURY AND THE MOON. S.K. Runcorn, Institute of Lunar and Planetary Sciences, University of Newcastle-upon-Tyne NE1 7RU, UK.

The explanation of the anomolous rotation rate of Mercury requires that its moments of inertia A and B differ by about 1 part in 10^5. Tracking data on Mariner 10 also shows that the second harmonic of its gravitational field departs from the hydrostatic model. In this respect Mercury resembles the Moon, of which the second harmonic in its gravitational field is about 20 times that expected on hydrostatic theory. The importance of solid state creep in the long term behaviour of planetary mantles suggests that the non-hydrostatic figures of Mercury and the Moon are not due to distortions imposed in their early history and retained by the finite strength of their interiors, even though this property is appropriately invoked in their lithospheres, where the temperatures are below half the melting point: The higher surface temperature of Mercury and its greater radius suggest that its lithosphere is thinner than that of the Moon, perhaps 100 km and 300 km respectively. Gravitational anomalies of the scale of the mascons seem unlikely in Mercury and the tracking observations may simply suggest that the planet has appreciable low degree harmonics in its gravitational field in addition to its second degree harmonic.

Thermal convection occurring through solid state creep below the lithosphere has been suggested to explain the non-hydrostatic figure of the Moon and this hypothesis would seem applicable to Mercury as well. It can be proved that a second degree harmonic must be present in the convection pattern to give the observed differences in the moment of inertia, but the pattern may be more complex and other low harmonics may be present. In the case of Mercury the "mascon" observations may be explained in this way and indeed the large iron core of Mercury would be expected to favour harmonics of degrees 5-7 in the convection pattern in the silicate mantle. The very clear hemispherical asymmetry in the Moon and the suggestion of a similar one in Mercury are explained in terms of a single cell or first degree harmonic convection pattern in their early history. Convection in the mantle is necessary if the core of Mercury is convecting. It seems unlikely that that part of the crust of Mercury which is sufficiently below the Curie point can have sufficient permanent magnetization to explain the observed magnetic field of Mercury. Consequently, weak dynamic action must be invoked within Mercury's core.

MOON-MERCURY: BASINS, SECONDARY CRATERS AND EARLY FLUX HISTORY,
Gerald G. Schaber and Joseph M. Boyce, U.S. Geological Survey, Flagstaff, Az. 86001

New data pertaining to the size frequency distribution of lunar and mercurian basins >200 km diameter have been analyzed. A total of 60 lunar basins have been identified. Thirty-four such features have been recognized on 40 percent of the planet Mercury. Many of the mercurian basins recognized during this study are very subdued and were verified by careful mapping of secondary craters and secondary crater chains for the entire imaged portion of the planet. These maps will be presented. Assuming that Mercury is equally cratered on the as yet unseen side, a total of 81 basins of >200 km diameter may be present on the entire planet. The cross sectional area of the Moon is one-half that of Mercury; however, if equivalent surface areas are considered, Mercury is 1.6 times less cratered by basins of this size than is the Moon. Taking into account velocity and gravity difference discussed by Wetherill (1975) this difference is close to 1.75. This finding is in opposition to the recent findings of Malin (1976) and Wood and Head (1976) but is in agreement with earlier statements by Murray et al., (1974). The apparent deficiency of basins on Mercury as compared to the Moon could be caused by 1) a non-uniform distribution of basins on Mercury, 2) recognition of all the basins being prohibited by extreme erosion of their rims, ejecta deposits and secondary craters; and/or 3) a lower flux of basin producing size objects in the vicinity of Mercury as compared to the Moon. We feel the later is the most reasonable.

The abundant secondary craters on Mercury (Gault et al., 1976) is perhaps better understood than is the rather remarkable preservation state of these features. Scott (1976) has suggested that the state of preservation of Mercury secondaries as compared to the lunar ones may be due to the higher velocity of secondary debris resulting in deeper and larger craters. We feel that velocity is a contributing factor but that the preservation state of the secondaries could also be due to a lower flux of small primaries that would erode these features. This is consistent with our observation that the flux of large objects in the vicinity of Mercury may have been lower than that of the Moon.

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EVIDENCE FOR VOLCANIC MODIFICATION OF MERCURIAN CRATERS, P. H. Schultz, Lunar Science Institute, Houston, Texas, 78705.

Initial studies of Mariner 10 imagery concluded that Mercury exhibits volcanically derived plains units within and around the Caloris Basin and within much older basins (1, 2). In the absence of unequivocal volcanic landforms (e.g., sinuous rilles, volcanic shields), other indicators of volcanism must be used in order to test these interpretations. On the Moon, volcanic modification of impact craters commonly produces not only mare-flooded craters but also differential floor movement and fracturing within craters on the margins of the maria (3,4,5). Fracturing and floor uplift are believed to be typical precursory stages of complete crater inundation by capping layers of mare basalts (5).

Preliminary studies indicated that Mercury also exhibits evidence for crater floor modification (6); however, insufficient surface resolution prevents compilation of an inventory comparable to that for the Moon. A large dark-haloed mercurian crater (110 km in diameter; latitude -1.5°, longitude, 140°) exhibits many characteristics of lunar floor-fractured and mare-filled craters. The northwestern two-thirds of the crater floor is inundated by dark plains materials, whereas the southeastern third of the crater contains an extended slumped wall region with possible concentric fractures. Color ratio data (7) reveal that the dark plains materials exhibit a pronounced red color in contrast to the blue walls and bright floor materials. Moreover, the low-albedo inner ejecta blanket corresponds to a notable red halo. The crater morphology resembles the partly mare-inundated lunar crater Posidonius, and the red halo is characteristic of many floor-fractured craters (Posidonius, Gassendi, Pitatus) and mare-inundated craters (Plato, Archimedes, Kunowsky). A red halo surrounds at least ten other mercurian impact craters and occurs on the floor of at least five other craters on the western hemisphere of Mercury. Most bright-rayed mercurian craters exhibit blue ray systems similar to lunar highland craters (e.g., Byrgius). Although several recent lunar impact craters exhibit weak red ray systems (8), this coloration largely expresses the relative contrast to the blue maria. Many post-mare craters blend with the surrounding maria (Aristillus, Timocharis), whereas the red haloes of the pre-mare craters Plato and Archimedes contrast not only with the maria but also with the highlands.

Other evidence for internal processes affecting crater interiors on Mercury includes both dark plains materials at the base of multi-ringed craters similar to the dark annular rings within lunar mare basins and large (10 km), irregular, rimless depressions in certain plains-filled craters.

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MERCURY SECONDARY CRATERS, D. H. Scott, U. S. Geological Survey Flagstaff, Arizona 86001

Geologic mapping of the Kuiper quadrangle of Mercury indicates that secondary craters are much better preserved than those on the Moon around primary craters of similar size and morphology. Among the oldest recognized secondary craters on the Moon associated with craters 100 km across or less, are those of Posidonius. These secondaries are probably middle to upper Imbrian in age as they are older than the basalts filling Mare Serenitatis but younger than smooth plains material. Many craters in the Kuiper quadrangle with similar dimensions and an equivalent or even more degraded appearance have fields and clusters of readily identifiable secondary craters. These apparent differences may be in part due to the lower ballistic range of ejecta on Mercury and consequent visual accentuation of crater forms due to the greater concentrations of secondaries around the area of impact. On the other hand, such dense arrays of secondary craters would seem to promote interaction between their ejecta clouds which would contribute to the further subdual of their topographic forms. For this reason, I propose another alternative or contributing factor for the better state of preservation of Mercurian secondaries relative to those on the Moon. Ideally the ratio of the ballistic ranges for ejecta at constant velocity on Mercury compared to the Moon is equivalent to the ratio of the gravitational forces at the surfaces of the two planets and amounts to 0.44. Comparative studies of ejecta deposits on the Moon and Mercury, however, by Gault and others (1975) show that the ratio is about 0.65; thus, the actual range on Mercury exceeds the theoretical. If we assume that this is due to higher ejection (and impact) velocities on Mercury, the ratio of these velocities may be calculated from the following relationships:

$$\frac{Rm}{R_l} = g_l \mu^2_m \Big/ g_m \mu^2_l = 0.65$$

where g_l/g_m = ratio of Moon and Mercury gravity, $\mu^2_m \,/\, \mu^2_l$ = ratio of Mercury and Moon ejection velocities.

The results show that ejection velocities on Mercury may be about 1.23 times larger than those on the Moon. Higher velocities should produce deeper or possibly proportionately larger secondary impact craters and this may account for their better preservation with time.

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THE GEOLOGY OF THE KUIPER QUADRANGLE OF MERCURY, D. H. Scott, U. S. Geological Survey, Flagstaff, Arizona 86001, R. A. De Hon, University of Arkansas, Monticello, Arkansas 71655, J. R. Underwood, Jr., West Texas State University, Canyon, Texas 79016.

The Kuiper quadrangle is located in a heavily cratered equatorial region of Mercury (25°N to 25°S lat., 0° to 72°W long.). A zone about 10° wide along the eastern part of the quadrangle is beyond the evening terminator. The large range (more than 50°) in both illumination and viewing angles across the map area precludes a high degree of mapping consistency, particularly in an east-west direction. West of approximately 55°W longitude, most of the geologic units cannot be specifically identified because of high sun angles; here the mapping is more generalized and units are not subdivided.

Major geologic units include smooth and rough terra materials, smooth and cratered plains materials, and intercalated and superposed materials of impact craters and basins. The oldest rocks in the quadrangle comprise the smooth terra unit and the rim materials of highly degraded large craters and basins. The smooth terra material has moderate relief characterized by numerous overlapping degraded secondary craters, low subdued hills, and an abundance of old craters and basins. The younger rough terra unit consists of sharp fresh appearing hills and hummocks formed by the overlapping rim materials and ejecta blankets of medium-to large-sized relatively young craters. Its albedo seems to be somewhat higher than that of the smooth terra material.

The two plains units cover about 50% of the quadrangle, occur within craters, basins, and topographically low areas, have relatively flat surfaces, and albedos similar to that of the smooth terra. The younger smooth plains material has a much lower crater density than the cratered plains unit. It mostly occupies the floors of craters and basins and has lobate scarps resembling lava flow fronts in places. Except for its relatively low albedo and the general absence of wrinkle ridges it resembles lunar mare materials. Possibly it is analogous to the Cayley plains that occur within many lunar craters. The older and more densely cratered plains unit is similar to the patches of pre-Imbrian plains in the Maurolycus region of the Moon.

At least six multiringed basins varying from about 200 km to 440 km in diameter and many prominent craters occur in the quadrangle. There appears to be a regular progression between large craters having nearly circular central rings of peaks and basins having two or more well developed rings. The cratered terrains generally have a higher albedo than the plains units and the 50 km crater Kuiper has the highest recorded albedo on the planet. Secondary crater fields and crater chains are abundant around fresh craters and large basins.

Structural features such as rilles, mare ridges, collapse depressions, and lineaments, which are common on the Moon, are sparse or absent in this part of Mercury. Some normal faults transect the floors of crater or follow basin margins and polygonal crater rims are not uncommon. Northeast and northwest trends apparently prevail but without statistical relevance. No volcanic landforms or materials, possibly excepting the smooth and cratered plains units, have been recognized. However, several small exceptionally dark patches in the western map area may represent late stage flows of basalt or pyroclastic mantling material.

THE RELATIONSHIP BETWEEN CRUSTAL TECTONICS AND INTERNAL EVOLUTION IN THE MOON AND MERCURY; Sean C. Solomon, Dept. of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass. 02139.

Events in the internal evolution of a planet can produce strong signatures on the crustal tectonic history. As the temperature distribution in a planet evolves, the volume of the planet will change with time because of thermal expansion. Volume changes should be accompanied by visible changes in the planetary surface, e.g., great thrust faults during compression or grabens and rift valleys during expansion. Large-scale differentiation events can result in both additional volume changes and conversion of gravitational energy to heat available to drive surface volcanism. The observed crustal tectonic features on the moon and Mercury can conversely be applied as tests of possible thermal and differentiation history models.

On the moon, the absence of any geologic features suggestive of global volume change limits the change in radius to no more than perhaps 1 km in the last 3.8 b.y. Such a limit provides a stringent constraint on thermal history models for the moon, particularly on the initial temperature distribution. The only class of models satisfying the limit on radius change begins with the outer 200 km of the moon at near melting temperatures and the inner portions of the moon cold. With increasing time, there is a close trade-off between contraction of the lithosphere and expansion of the deep interior. This constraint on the initial temperature distribution is important for understanding the source of early heating in the moon and for limiting the depth of a primordial "magma ocean."

Changes in the temperature distribution with time in a planet not only produce volume changes but give rise to thermoelastic stresses throughout the interior. Such thermoelastic stresses will relax quickly in regions where the material is hot enough to creep, but in a relatively cool lithosphere they may be stored for relatively long periods of time or be relieved suddenly by faulting. In lunar thermal models successfully satisfying the limit on total volume change, the change in tangential stress with time in the crust is initially toward greater tension but later toward greater compression. This change from expansion and tension to contraction and compression occurs at a time near cessation of mare volcanism for several of the models, suggesting that the state of stress in the lithosphere may be an important control on planetary volcanism.

In Mercury, a major source of volume change is core formation. The segregation of an iron core from an originally homogeneous planet leads to an increase in mean temperature of 700°C and an increase in radius of 17 km. The absence of large extensional features that would accompany such an expansion indicates that core formation must predate the oldest surface features on Mercury. A source of substantial initial heat is thus required for Mercury as well as the moon. After core differentiation in thermal models of Mercury, the lithosphere cools and the planet contracts by 2 km in radius, in good quantitative agreement with the amount of contraction inferred by Strom and others from the dimensions of the observed lobate scarps. Solidification of any but a tiny fraction of Mercury's core is excluded by the geological limit on change in surface area.

MERCURY, THE MOON AND MAGNETISM, D.W. Strangway and H.N. Sharpe,
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The discovery of a significant magnetic field on Mercury has offered us an opportunity to reconsider possible mechanisms for the origin of planetary magnetic fields. The earth's field has a present day field of dynamo origin. The moon however, has only remnants left of ancient magnetic fields. These fields are only locally present, but they are often of several gammas or more. There is no plausible explanation for these, other than the presence of magnetized rocks. Most workers agree that the rocks are carrying a memory of an ancient magnetic field, although we presently cannot reconstruct the geometry of this field. There is still considerable controversy over whether the early field was due to a cool moon carrying a memory, or whether it was due to a dynamo formed in an early hot moon, which subsequently died out leaving a metallic core.

Models of accretion of the Moon suggest that a cool interior for the first 1-2 billion years is quite possible and hence it is possible that the present remnants of field are the result of a moon magnetized during or shortly after accretion, in early plasma fields.

This same arguement can be applied to Mercury. If the present field is the result of a magnetized interior at a temperature below the Curie point of iron a number of conditions must be met i) accretion took place so that the interior was well below the Curie point ii) the radioactivity was sufficiently low that the planet has not heated up greatly iii) accretion took place in the presence of a magnetic field. All of these conditions can be met for reasonable models and therefore imply that Mercury's present field could be a memory of an early solar system field.

The model proposed would imply that Mercury was an even more primitive planet than the Moon, and that it had accreted cool and the interior remained cool. Of course crustal melting would be probable at the time of initial formation so that the outer parts of Mercury were differentiated to form a light crust.

In these models it would be implied that the Moon may well have had convective overturn in the latter part of its history, while Mercury may not have heated enough to require convection.

Preliminary Comparison of the Crater Diameter/Density Distribution of Lunar and Mercurian Intercrater Plains

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The morphology, stratigraphic relationships, and crater diameter/density distribution of the lunar "Pre-Imbrium Pitted Plains" southwest of the Nectaris basin is very similar to that of the mercurian intercrater plains. A comparison of the crater population between 7 and 100 km diameter in the lunar "Pitted-Plains" (population index -0.5) and the adjacent heavily cratered terrain in the vicinity of Clavius (population index -1) shows that there is a significant deficiency of craters <∿40 km diameter in the "Pitted Plains" relative to the heavily cratered terrain. This suggests that the pitted plains have obliterated many of the craters <40 km diameter and are therefore younger than the heavily cratered terrain.

The two most likely explanations for the origin of the lunar "Pitted Plains" are (1) basin ejecta (probably from the Nectaris basin) or (2) a pre-mare episode of highland volcanism in this region. The lunar highlands one basin radius from Imbrium (Albategnius region) show a diameter/density distribution similar to the "Pitted Plains." However, contrary to the southern heavily cratered terrain (Clavius area) where the density of the more degraded craters (Classes 4 and 5) is significantly less than the fresher craters (Class 3), the Albategnius area shows the density of the more degraded craters is greater than the fresher craters. This indicates that the effect of basin ejecta a one basin radius is to alter the fresher craters (Classes 1-3) to more degraded ones (Classes 4 and 5). The "Pitted Plains," on the other hand, display an abundance of fresher craters (Class 3) and a marked paucity of the more degraded types (Classes 4 and 5). Furthermore, the crater density and population index within an annulus of one basin radius from Nectaris is virtually identical to that of the Clavius region indicating a similar age. This, together with the lack of degraded craters on the "Pitted Plains," suggests that the "Pitted Plains" are <u>not</u> primarily basin ejecta, but may possibly represent a pre-mare epoch of highland volcanism.

Although the overall density of the mercurian intercrater plains is less than the lunar "Pitted Plains," they show the same population index and paucity of degraded craters suggesting they have a similar relative age and origin as their lunar counterparts. Therefore, a significant fraction of the mercurian intercrater plains may be younger than the more heavily cratered terrain and represent a period of volcanism intermediate in age between the smooth plains and the heavily cratered terrain.

THERMAL MODELS AND STRUCTURES OF THE MOON AND MERCURY,

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Thermal evolution models and internal structures of the Moon and Mercury are calculated and compared. Although these two planets are of similar size (their radii differ by about 700 km) and may have had similar thermal evolution histories, their densities, compositions and structures differ significantly. The lunar structure and evolution history are much better constrained by Apollo and other data. Mercury models are based primarily on the planet's high mean density, the assumption that this is due to iron, and the Mariner 10 observations.

Thermal evolution models are calculated taking into account conduction, convection, and differentiation. The requirement that the Moon was accreted hot or heated relatively early in its history is also applied to Mercury. Thus Mercury differentiates early, forming a crust. Because of its large surface area to volume ratio, the lithosphere thickens rapidly. Core separation takes place during the first billion years, and this contributes a heat pulse for further mantle differentiation. However, convection transports this heat relatively rapidly. In the past 3 billion years, cooling is the dominant process in both planets.

At the present time, the Moon has a thick and layered lithosphere of approximately 1000 km. Partial melt may exist in the deep interior. Mercury has a relatively thin silicate mantle (700 km thick) and a large iron core of about 1700 km radius. The mantle is most likely solid and the core may be solid or molten depending on the presence of heat sources. To maintain a molten outer core (to sustain the magnetic field), it is necessary to have heat sources within the core.

HISTORY OF BASIN DEVELOPMENT ON MERCURY, Newell J. Trask,
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One of the major morphological differences between Mercury and the moon is the extent to which fields of secondary impact craters are present around major impact craters and basins on Mercury. The state of preservation of these craters and basins and their relationship to the surrounding interbasin areas are key elements in constructing early Mercurian history. I have analyzed 95 craters and basins larger than 100 km in diameter on Mercury that are favorably located with respect to sun angle, viewing angle and resolution, and have categorized the craters and basins as follows:

1) Well-defined field of surrounding secondary impact craters	40
2) Poorly-defined field of surrounding secondary impact craters	14
3) No surrounding field of secondaries, relatively high intact raised rim	17
4) No surrounding field of secondaries, relatively low intact raised rim	13
5) No surrounding field of secondaries, rim interrupted, possibly embayed by surrounding intercrater material	4
6) Unclassifiable	7

Many of the basins in category 1 have flat floors, low rims and superposed smaller craters and would thus fall into the more degraded morphological categories of other workers. The subdued morphology of these features must be due to processes such as isostatic adjustment and not to extensive impact erosion which would also eliminate the fields of secondary craters.

The 54 craters and basins of categories 1 and 2 are spread evenly over the heavily cratered parts of the planet, ruling out a major planet wide episode of crater obliteration and resurfacing after their formation. Many of these 54 basins and their secondary fields have undergone minor modifications explainable by tectonic adjustments, impact erosion and downslope movement of surface material.

The erosive effect of these secondary swarms surrounding large craters and basins must have been significant. Many craters and basins in categories 3 and 4 have clearly been strongly modified by the swarms of secondaries from the younger features in categories 1 and 2.

The 4 features in category 5 provide some evidence that the intercrater surfaces of the heavily cratered terrain on Mercury are in part coeval with heavy bombardment. The widespread occurrence of categories 1 and 2 and the presence of apparent secondary impact craters on most intercrater surfaces indicate, however, that heavy bombardment continued after most of the intercrater surfaces formed.

MERCURIAN AND LUNAR IMPACTITES; J.L. Warner[1], C.E. Bickel[1,2], R.J. Floran[1], W.C. Phinney[1], and C.H. Simonds[3]. ([1]NASA Johnson Space Center, Houston, TX 77058;[2]San Francisco State Univ., San Francisco, CA 94132; [3]Lunar Science Institute, Houston, TX 77058)

The Apollo sample collection from the lunar highlands is dominated by impact-produced rocks known as polymict breccias. Similar breccias comprise the bulk of the impact deposits associated with terrestrial craters. By analogy, breccias are the major rock type to be expected on all heavily-cratered terrains; e.g., the surface of Mercury.

Based on extensive studies of fragmental and impact-melt polymict breccias from the Moon and terrestrial craters, the thermal history of impact-deposited debris is modeled as a mechanical mixture of cold fragmental material and hot-to-superheated melted material; both produced by a shock-wave passing through the target. These materials are violently stirred in tens of seconds such that the two components are evenly disseminated one in the other on a scale of cubic millimeters. The mixture achieves an internal thermal equilibrium in less than 100 seconds, and then loses heat to its surroundings in a manner similar to shallow igneous intrusions. The proportion of melt in the mixture is a function of distance from the point of impact and the size of the impact. The percentage of melt in the mixture determines the equilibrium temperature which in turn determines both the type of polymict breccia formed (e.g., impact-melt breccia or vitric matrix breccias) and the types of petrologic process that may occur (e.g., clast digestion, rapid nucleation, etc.).

Interpretation of physical and chemical history of cratered terrains such as the lunar and Mercurian highlands relies extensively on the analysis of clasts and matrices of breccias.

Lithic and mineral clasts are interpreted in terms of the protolith (pre-existing rock) that was transformed by impact into the various types of breccias. Much of the understanding of the early, planet-wide differentiation of the Moon has been gained by the study of plutonic clasts within breccias. It is essential, however, to consider any systematic biases of clast populations in the light of the thermal model for breccia lithification which predicts the amount of clast digestion as a function of the system's liquidus, the proportion of fragmental and melt material in the mixture, and the initial temperature of the melt component.

The chemical components of lunar highland breccias consist primarily of (1) a refractory component with a composition that approximates gabbroic anorthosite that is concentrated in the clasts and has been identified with the composition of the lunar crust, and (2) a less-refractory basaltic component known as KREEP that is concentrated in the matrix and may represent volcanic material that erupted as a result of the intense early bombardment.

The difference in gravity between the Moon and Mercury dictates that equal-sized projectiles will have a higher terminal velocity and a larger kinetic energy on Mercury. A Mercurian crater produced from an equal energy event will have a smaller diameter and mimic the morphology of larger craters. Although these phenomena should have no effect on the breccia-forming processes, the distribution of lithologic types as a function of position and crater size will be effected and thus new breccia types are expected.

MORPHOLOGICAL CHARACTERISTICS OF FRESH CRATERS: MERCURY, MOON AND MARS
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The occurrence of impact craters with similar morphologies on different planets provides a test of the effects of varying planetary environments on the impact process. Evidence has been presented previously that crater morphology and morphometry may be influenced by gravity, target characteristics and impact velocity. Preliminary data from comprehensive cataloging of thousands of craters on Mercury, Moon and Mars allow significant revision of previous statistics and interpretations.

The frequency of occurrence of wall terraces and central peaks in fresh craters is a sensitive, easily determined index of crater morphology. Only sharp-rimmed, fresh craters (class 1 of Arthur et al.) were analyzed to minimize degradational effects. The new data (Fig. 1) show that terraces and peaks are considerably less abundant in mercurian craters than previously expected. Lunar central peaks, however, are more common than indicated earlier. Comparison of the frequency of occurrence of terraces and peaks as a function of crater diameter for Mercury, Moon and Mars (Fig. 1) shows that the onset diameters of terraces are similar for all three planets, but terraces on Mercury are progressively 10-30% more common than on Mars, with lunar terraces intermediate in abundance. Central peaks are 20% more frequent on the Moon than on Mercury until diameters of ~50 km when all fresh craters on both planets have peaks. Central peaks are remarkably less abundant on Mars, suggesting that eolian infilling has buried peaks even in fresh craters.

The general similarity of terrace and peak distributions on planets where the gravitational field strength (g) differs by a factor of 2.3 (Moon and Mercury), coupled with the poor agreement where g is nearly equal (Mercury and Mars) strongly suggest that other factors are more important than g in effecting crater morphology. There is no obvious correlation between terrace and peak abundances and modal impact velocities. Since no factor appears to dominate in controlling crater morphology, it may be necessary to investigate combinations of factors, including gravity, impact velocity and projectile, target and substrate characteristics.

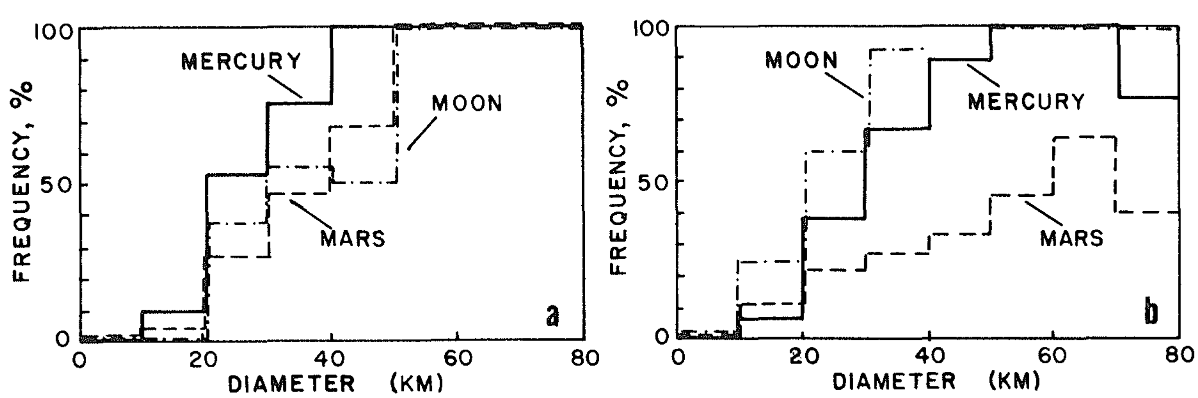

Fig. 1: Diameter frequency distribution of (a) terraces and (b) central peaks.

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