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SIGNIFICANT ACHIEVEMENTS IN THE PLANETARY GEOLOGY PROGRAM - 1975-1976

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16. Abstract

Recent developments in planetology research as reported at the 1976 NASA Planetology Program Principal Investigators meeting are summarized. Important developments are summarized in topics ranging from solar system evolution, comparative planetology, and geologic processes, to techniques and instrument development for future exploration.

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FOREWORD

The purpose of this publication is to summarize the research conducted by NASA's Planetary Geology Program Principal Investigators (PGPI), and is a digest of the 1976 PGPI meeting abstract document (NASA TM X-3364). Important developments are summarized in topics ranging from solar system evolution, comparative planetology, and geologic processes, to techniques and instrument development for future exploration.

The accomplishments of any science program are a reflection of the people who take part in it. The content of this document is a testimony to the PGPIs who have produced significant advances in the exploration of space. They represent a group of people dedicated to advancing the frontiers of geology past the traditional limitation of the planet Earth.

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Introduction

The annual meeting of the Planetology Program Principal Investigators was held March 8-10, 1976, in Flagstaff, Ariz., at the Center for Astrogeology, U.S. Geological Survey. The papers presented there represented the high points of research carried out in the Planetology Program of NASA's Office of Space Science, Division of Lunar and Planetary Programs. The purpose of this paper is to present a summary of the research and significant developments in Planetology for this year, based on the oral presentations at this meeting. Additional information on the reported research, and reports of work in planetology during the past year, are contained in the abstract volume prepared for the annual meeting and are available as "Reports of Accomplishments of Planetology Programs, 1975-1976" (NASA TM X-3364; available from the National Technical Information Service, Springfield, VA 22161; price $8.75) and "A Bibliography of Planetary Geology Principal Investigators and Their Associates, 1974-1976" (NASA TM X-74315; available from the Planetary Geology Program Office, NASA Headquarters, Washington, DC 20546).

Material for this paper was drawn from summaries prepared by session chairmen at the annual meeting (M.H. Carr, USGS; Duwayne M. Anderson, NSF; J.R. Underwood, West Texas State Univ.; R. Greeley, Univ. Santa Clara and NASA Ames; L. Soderblom, USGS; J. King, SUNY Buffalo; E. Morris, USGS; D. Scott, USGS; E. Shoemaker, Cal Tech; H. Masursky, USGS; J. McCauley, USGS; H. Holt, USGS) and was compiled and edited by J.W. Head, Brown University.

Solar System Evolution, Comets, and Asteroids

The evolution of the solar system, the origin of satellite systems of the outer planets, and the frequency and origin of comets and asteroids, all are significant topics in terms of setting the stage for individual planetary histories and for understanding the interaction of planets with solar system debris to produce the cratering record.

H. Alfven and G. Arrhenius (Univ. Calif., San Diego) emphasized the need for a general theory for the formation of secondary bodies around a primary body which would explain formation of satellite systems in addition to the solar system. Satellite systems, rather than the solar system as a whole, may provide more information on which to base such models because of uncertainties in the early history of the sun. Applying various dynamic constraints which suggest focusing of condensed matter into jet streams, Alfven and Arrhenius outlined three main types of planetary development: (1) in the case of Mercury, Venus, Earth and Jupiter the parent jet streams are exhausted catastrophically during the early stages of planet growth, (2) in the case of Mars, Moon, and Saturn catastrophic growth occurs at the end of planetary accretion, (3) the growth of Uranus, Neptune, Triton and Pluto is characterized by slow accretion.

A.G.W. Cameron and W.R. Ward (Harvard College Observatory) reported on new models of the primitive solar nebula that take into account viscous dissipation within the nebula. It appears that if the velocity of the meridional circulation current approaches the speed of sound, large scale violent turbulence will be introduced. The presence of such turbulence validates use of a theory of a viscous accretion disk. Typically, the viscous couple rises to a maximum with increasing radial distance, then decreases toward zero at the outer edge of the disk. Various models are being explored, but early emphasis is on steady flow models in which accreting matter is transported outward and inward from the maximum region and in which the surface density of the disk is at a steady state. The central mass, external gas accretion rate, and total angular momentum of the collapsing interstellar cloud are varied to define different models.

F. Fanale (Jet Propulsion Laboratory) provided additional evidence that the surface of Io is covered largely by Na and S-rich evaporite deposits which formed as H_2O emitted from the satellite was lost to space, and suggested that Na is transferred from the surface of Io the surrounding cloud by sputtering of Jovian magnetspheric protons. This hypothesis is supported by the visible and near-infrared spectrum of Io, models of formation of Io, calculations of H_2O loss from Io, and meteorite studies which indicate that extensive salt deposition occurred in carbonaceous chondritic meteorites.

James Pollack (NASA Ames) reported on calculations on the gravitational contraction history of Jupiter and Saturn which show that both planets contract very quickly during the first million years, a behavior analogous to that of a pre-main sequence low-mass star. After this period their centers exhibit partial electron degeneracy and resist further contraction although the outer envelope continues to contract. The model of Jupiter, after 4.5 b.y. evolution, achieves a radius and luminosity close to observed values, but the Saturn model is less successful, giving a luminosity three times that presently observed. Models for both planets indicate former luminosities much higher than those presently observed and suggest that radiation from the planets may have been an important factor in formation of the satellites.

E. Shoemaker and E.F. Helin (Calif. Inst. Tech.) presented the latest results in their search for planet-crossing asteroids. Total numbers of Earth crossing and Mars crossing objects have been estimated on the basis of the numbers already discovered and the probability of discovery. They estimate that there are 800 $\pm$ 400 Earth-crossing and 30,000 $\pm$ 15,000 Mars crossing asteroids brighter than magnitude 18. These numbers translate into fluxes of $2 \times 10^{-14} km^2 yr^{-1}$ and 5 to $8 \times 10^{-14} km^2 yr^{-1}$ respectively at the orbit of Earth and Mars. The difference between Earth and Mars is considered marginally significant, and they suggest that the flux rates of Venus and Mercury are roughly the same as the Earth.

F. Whipple (Harvard College and Smithsonian Astrophysical Observatories) speculated on the possibility of formation of a 'cometary nebula' within Jupiter's orbit and accumulation of significant amounts of cometary material on the Earth. He suggested that the cometary flux within Jupiter could have attained a million times its present value during the 10^7 to 10^8 years after formation of the planet. If the solar wind were unable to cope with such an increase then a 'pile-up' of cometary nebula with a density many orders of magnitude greater than the present might result. One possible outcome would be accretion of significant amounts of cometary gas and solids by the Earth.

Additional topics of research reported on in the abstract volume included asteroid fragmentation processes (C. Chapman), Orbital resonances in the solar system (S. J. Peale), the reality of comet groups and pairs (F. Whipple), orbital linkage of comets of intermediate period (B. Marsden), orbit determination of nearly-parabolic comets (B. Marsden and Z. Sekanina), statistics of anomalous tails of comets, and the existence of interstellar comets and probabilities of encounter (Z. Sekanina).

Planetary Studies

Mars-D.H. Scott (USGS) reported on the progress of the Mars geologic mapping program. Thirty quadrangles are being mapped at a scale of 1:5 million and a number are available and in press (see Table 1). Scott and M.H. Carr (USGS) also reviewed the 1:25 million scale geologic map of Mars which summarizes much of the 1:5 million mapping and which will be available in the near future. Summaries of the geology of three quadrangles were presented: (1) Eridania, R. DeHon, Univ. Arkansas at Monticello; (2) Casius, R. Greeley, Univ. of Santa Clara and J. W. Guest, Univ. of London Observatory; (3) Thaumasia, G. E. McGill, Univ. Mass. Additional contributed papers dealt with the Phaethontis quadrangle (J. H. Howard, Univ. Georgia), Arabia quadrangle (J. S. King, SUNY, Buffalo), and the geologic setting of the Cydonia region (J. R. Underwood, Jr., West Texas State Univ.), and Mars nomenclature (H. Masursky).

R. Simpson, G. Tyler, and H. Howard (Stanford) reported on radar studies of Mars designed to help characterize the physical properties of the regolith at the several designated Viking landing sites. The 3.8 to 70 cm wavelength observations provide an indication of large-scale roughness and of the bulk density over an area of about 6 by 100 km in an east-west orientation. The dominant scattering component of the regolith in the equatorial region, where the results are the most definitive, is wavelength dependent over a few tens of centimeters. There may be areas of extreme roughness with rms slopes of up to 10° with bulk densities of 1 g/cm^2 or more. There is clear indication that the surface of Mars is heterogeneous on large scale, with rms slopes varying from 0.5 to 5° in adjacent areas.

Mercury - A systematic geologic mapping program of the Mercury surface at a scale of 1:5,000,000 was described by H. Holt (U.S.G.S.). As with the Mars mapping program, this effort is a joint undertaking between the Planetology Program Office of NASA, the U. S. Geological Survey and NASA supported institutions. The objective of the Mercury Geologic Mapping Program is the publication of a 1:5,000,000 scale Geologic Atlas of Mercury to be produced from Mariner 10 data. The planet Mercury is divided into 15 quadrangles at a scale of 1:5,000 (Table 2) and the Mariner 10 imagery extends over 9 quadrangles, varying from full coverage to as little as 40 percent coverage. Shaded relief maps and controlled photo-mosaics are being provided as base maps for compilation of stratigraphic units and geologic structures. An atlas of Mariner 10 imagery is also being prepared by M. Davies (Rand Corp.). Davies is also completing the Mercury control net from Mariner 10 data. Preliminary results of Mercury mapping were reported by K. Blasius (Planetary Sci. Inst.), M. Malin (Jet Propulsion Lab), and R. DeHon (Univ. Arkansas at Monticello).

Photometric analysis of Mariner 10 images of Mercury (B. Hapke, Univ. Pittsburgh) show pronounced polar darkening of about 3:1; that is, the calculated equatorial normal albedos are about 3 times as bright as the albedos at 70° to 80° latitude. If this polar darkening is substantiated it would imply that the solar wind is more important to mercurian surface darkening processes than meteorite impact effects. Preliminary published mercurian normal albedos, calculated using an average lunar photometric function, are substantially higher than those of morphologically similar lunar areas. However, the geometric albedo of Mercury calculated with the measured integral Mercury photometric function is about as low as the Moon's. This result indicates that the differential photometric function used to calculate mercurian normal albedos is incorrect. It is of great importance to define the real mercurian photometric function because of its implications for both the geochemistry of the crust (a higher albedo implies a low Fe-Ti content) and surface darkening processes. D. Dzurisin and E. Danialson (Cal Tech) reported on revised albedo measurements of Mercury.

Venus - Recent Earth-based radar images of the surface of Venus obtained at the Goldstone Tracking Station of the Jet Propulsion Laboratory were interpreted by M. Malin and R. Saunders (JPL). Only a few percent of the surface has been imaged by radar and the smallest discernible features are approximately 20 km across. The imaged areas contain about 30 probable craters, ranging in diameter from 40 to 350 km. Within the imaged regions occur large areas that are not cratered, as well as regions that contain many large craters, a characteristic in common with Mars, Mercury and the Moon. Most of the venusian craters have gross morphology similar to impact craters on other planets, except that venusian crater floors are very shallow, nearly at the same elevation as the surrounding terrain. The frequency of the large craters in the most cratered region of the radar images is comparable to crater frequencies on the more cratered regions of Mercury, the Moon and Mars. These venusian craters and the nearby terrain should be approximately the same age as their counterparts on the Moon, and are therefore much older than any known terrestrial features.

Other venusian features have been interpreted geologically as large fault valleys, continental-size plateaus, mountain ranges, and volcanoes. The high resolution surface images transmitted by the

Soviet spacecraft Venera 9 and 10 showed a rocky planetary surface with weathering and erosion strongly suggested. A potential terrestrial analog to the venusian surface (pressure and viscosity conditions) is the terrestrial ocean floors at about 1-2 km depth. Ocean current velocities of approximately 1.5 cm/sec are capable of moving particulate material while current velocities up to 10 to 20 m/sec seem possible on both Venus and beneath the oceans. Sidelooking sonar images of the shallow ocean floors show barcan-like dune features several hundred meters wide and a few tens of metres high, as well as broad valley systems.

Additional thoughts on the geology of Venus were presented in abstracts by C. Sagan (Cornell) and R. Arvidson (Washington Univ.).

Comparative Planetary Geology

D. M. Anderson (N.S.F.) and L. W. Gatto (U. S. Army Cold Regions Lab) reported on a comparison between Martian fretted terrain and thermokarst depressions in the arid Yakutian lowland in eastern Siberia. These latter depressions are 5-10 km across and up to 40 m in depth. They are one to two orders of magnitude smaller than the martian features and originate by melting of 80 to 90 percent ice by volume in a thick loess blanket.

V. R. Oberbeck (NASA Ames) compared craters and plains on Mercury, the Moon, and Mars. Mercurian intercrater terrain is apparently older than heavily cratered terrain. Since intercrater terrain contains mostly small subdued secondary craters, and heavily cratered terrain contains primary craters larger than about 30-40 km, it was proposed that there was a deficiency in bodies necessary to produce craters smaller than 30 km during the late bombardment of Mercury. If the observed falloff is due to obliteration, then the obliterative episode, such as a late phase of basin formation, must have followed production of many craters smaller than 100 km. However, the deficiency is observed on the Moon in areas apparently unaffected by basin ejecta, and is also observed on Mars. The probable deficiency in production of small primary craters during the late heavy bombardment of Mars, Mercury, and the Moon, can be related to the processes responsible for production of bodies impacting the inner planets. Tidal disruption of very weak bodies before impact may be a very important process in this regard.

R. Arvidson (Washington Univ.) focused on the modification of Martian uplands for clues to processes operating over martian history. Fresh looking craters $\gtrsim 8$ km are retained without significant modification beginning with oldest plains formation. Fretted terrain is as old or older than most heavily cratered plains; therefore fretting appears to have taken place very early in martian history. Uplands volcanism dominates the southern hemisphere. Tectonic breakup of northern hemisphere leads to ground water breakout. Ice-regolith mixture exposed on slopes leads to scarp retreat and fretting. Older aeolian debris is redistributed by wind, and there may be later sporadic volcanic activity and channel formation, but the uplands have been relatively unmodified since then.

M. J. Cintala, J. W. Head, and T. A. Mutch (Brown Univ.) reported on the characteristics of fresh martian craters as a function of diameter and compared these with the Moon and Mercury. Bowl-shaped craters dominate the fresh crater population below about 15 km. The onset of central peaks occur at about 5 km. Craters above about 15 km often have terraced walls, central peaks, and hummocky floors; at diameters of 40 km and greater, these features dominate fresh martian crater morphology. Central peak onset occurs at smaller diameters on Mars and the Moon than on Mercury. Since Mars and Mercury have a similar surface gravitational acceleration (greater than twice that of the Moon), gravity-controlled crater features should appear at similar diameters on the two planets.

L. Soderblom (USGS) presented a summary of the evolution of the major features and landforms of the terrestrial planets within the framework of a time scale derived from crater density distributions. It was concluded that Mars has had a continuous evolution of its surface throughout its history. New surface is created at a rate of roughly 20 percent of the total area of that globe per billion years. This is a rate considerably greater than that derived for the moon or Mercury (about 15 percent per billion years).

Additional research reported on in the abstract volume included possible Earth analogs for some martian channel features (J. C. Boothroyd, E. J. Simpson, Univ. Rhode Island, and D. Nummedal, Univ. South Carolina), comparison of lunar and planetary imagery (P. Schultz, Univ. Santa Clara).

Planetary Surface Processes

General - Some of the basic problems included (1) determining the composition of the ices present on the surfaces of the outer planets and their satellites, (2) the degassing history of Mars and its implications for storage of volatiles in the megaregolith and (3) the surface characteristics of Phobos and Deimos. L. Lobofsky and J. Conel (JPL) discussed the types of ices expected on the outer planet satellites in addition to solid methane and ammonia and gave the ice spectra for various exotic compounds that might be present. Recent advances in the experimental procedures and instruments necessary to measure the composition of outer planet ices were also discussed. F. Fanale (JPL) discussed the degassing history of Mars, a topic of significance in the interpretation of the photogeology of Mars, particularly the ubiquitous collapse features, chaotic terrain and both the large and small channels. Fanale suggested that the total amount of volatile material degassed from the interior of Mars is on the order of 100 to 1000 times that now present in the atmosphere and the polar caps. This is based on presumed high concentrations of Argon 40 in the Martian atmosphere. The excess volatiles over those now observed must be stored both physically and chemically in a surface layer (megaregolith) that would be up to 2 km thick. This permafrost layer might be in or out of equilibrium with the present atmosphere. It may contain hydrated iron oxides (limonite), clay minerals and water. Exchange of carbon dioxide between the atmosphere and the regolith may occur as a result of diurnal and seasonal variations in insolation. These exchanges may account for the previously observed variations in surface pressure that do not appear to correlate with advances or recessions of the polar caps. M. J. Noland and J. Veverka (Cornell) presented the final results of their photometric studies of Phobos and Deimos. The integrated brightnesses of Phobos and Deimos are slightly different with the ratio of the relative reflectance of Deimos to Phobos being 1.15. The presence of several bright patches on Deimos may account for this slight difference in reflectance rather than being the result of intrinsic differences in surface properties. No evidence for bedrock outcrops could be found on Phobos or Deimos. It appears that both satellites of Mars have thin regoliths and are probably similar to one another in terms of surface properties, if not composition. R. E. Arvisdon and C. Hohenberg (Washington Univ.) reported on the calibration of martian surface dynamics by analysis of cosmic ray effects in returned samples.

Additional studies reported in the abstract volume include martian surface processes (J. Cutts, Planetary Sci. Inst.), and the influence of the martian scarp on wind circulation (R. Arvidson, Washington Univ.).

Volcanism - Planetary volcanism is a complex and volumetrically significant process in the history of the terrestrial planets and research is underway on various aspects of this process. W. Elston, J. Aubele, L. Crumpler, and D. Eppler reported on rates of erosion for terrestrial basaltic landforms and relating rates to scarp retreat on Earth. The authors noted that while scarp retreat may be very rapid, downward cutting of lava flows is comparatively slow. They presented an analysis of different basalt flows of known ages in which there is progressive erosion downward through different textural devisions of basalt flows, beginning with a glassy surface layer, underlain by a frothy layer, a vesicular layer, and a massive unit.

On Earth, after about two and one-half million years of weathering, only the massive zone is preserved. R. Tilling, R. Holcomb, P. Lipman and J. Lockwood (USGS, Hawaiian Volcano Observatory) presented a study of the effects of rapid events (earthquakes, eruptions, etc.) in the evolution of Hawaiian volcanoes. Of the three main processes in developing terrestrial volcanic terrains --- volcanism, faulting, and erosion --- only erosion is gradual and relatively slow. Recent activity in Hawaii involving faulting and volcanism show the essential catastrophic nature of these processes. They reported that the events of November 29, 1975, resulting from a 7.2 magnitude earthquake, generated a small tsunami, a minor sumit eruption at Kilauea, and massive subsidence of the south flank of the Kilauea shield. Eruptions in Hawaii are generated by both short bursts of relatively high volumes of lava, such as the eruption of Mauna Loa in 1975, or they may be in the form of persistent activity, as that generated during the five year interval 1969-1974 at Mauna Ulu. The presently observed magma supply rate (about 0.1 km^3 per year for Kilauea over the last twenty-five years) is an order of magnitude greater than the average supply rate for the total volume of shield volcanoes of the Hawaiian chain. Thus, the present appears to be a period of higher than average magma generation and eruption.

Other research on terrestrial volcanic processes reported in the abstract volume included reports on volcanic features and fracture sets of the south central Snake River Plain, Idaho (J. King, SUNY Buffalo and R. Greeley, Univ. Santa Clara), and the dependence of topography on volcanic processes within the eastern Snake River Plain (J. Karlo and J. King , SUNY Buffalo).

M. Carr (USGS) presented an analysis of martian volcanoes and showed a general correlation between the elevation of the constructs and their age, in which old volcanoes are generally lower. Carr pointed out that while there are several problems in determining the elevation of martian volcanoes and their relative ages based primarily on crater counts, the correlation appears to be valid for relatively unambiguous cases. In the abstract volume, R. Greeley (Univ. Santa Clara) summarized various volcanic studies relating to planetology and P. Schultz (U. Santa Clara) presented an analysis of floor-fractured craters on the Moon, Mars and Mercury, showing that impact craters provide paths for surface volcanism.

Cratering - C. Chapman (Planetary Science Institute) reported on recent analyses of small crater populations studies for a variety of Martian units. He found in general that the density of small craters is very low, indicating obliteration rates one to two orders of magnitude greater than production rates. Exceptions include secondary crater fields and unusual clusters of small circular craters. Although these craters do show a wide spectrum of morphologies, a high degree of episodicity is inferred from the large fraction of fresh craters and a general lack of a steady-state morphology spectrum. Chapman has applied these studies to the Ismenius Lacus area (Quadrangle MC-5) and found indications of episodic deposition, episodic cratering, episodic exhumation of craters and fields of secondaries. Studies such as these should prove important in untangling the recent history of the martian surface as they focus directly on time scales and styles of recently active martian surface processes.

G. Neukum and B. Konig (Max Planck Institute fur Kernphysik) also reported on studies of small craters (generally less than 10 km diameters) and compared size-frequency distributions for Mercury, the Moon and Mars. They confirmed results of previous investigators, showing that between 1 and 10 km the slope of the cumulative diameter frequency plot is much steeper than the slope at larger diameters (10-100 km) on all three planets. The curve for Mars, however, is slightly less steep than those of Mercury or the Moon in this size range. They attribute this difference to lower impact velocity at Mars.

M. Fulchignoni (University of Rome) presented an update on the planetary crater library being developed at the University of Rome. About 5000 Mercurian craters have been morphologically classified. Preliminary comparison of the distribution of different morphologic classes may suggest separable regions in which different processes and intensities have been involved in subsequent degradation.

D. Gault (NASA Ames), J. Guest (Univ. London Observatory) and P. Schultz (Univ. Santa Clara) reported on a study of large (greater than 5 km diameter) crater populations on Mercury. They repeated counts made earlier by the Mariner 10 Television Team in three regions. They divided these counting regions into three units (cratered terrain, smooth plains, and "weird" terrain) and included morphological classifications of craters for each. The general results were found in good agreement with those of the Mariner 10 team including a change in slope near 50 km diameter. By subtracting the population of craters formed on the Caloris plains from that on the cratered terrain, the authors derived a pre-plains crater density/ morphology distribution. All fresh craters (classes 1 and 2) in the size range 20-30 km postdate the Caloris filling. They conclude that the "kink" in the crater density curve near 50 km (for the cratered terrains) is therefore a reflection of some processes which obliterated smaller class 1 and 2 craters prior to emplacement of the Caloris plains.

M. Cintala, J. Head and T. Mutch (Brown Univ.) described a comparison of the depth/diameter characteristics of lunar and Mercurian craters. They note that the lunar and Mercurian populations are very similar: both show an inflection in the depth/diameter curve near 7 km although Mercurian craters are generally a factor of two shallower. By contrast this inflection occurs in the Martian populations near 15 km. It is concluded that the position of inflection is not directly related to surface gravity (Mars and Mercury have nearly identical surface gravity) but must involve other variables: target character or impact velocity, for example.

A. Woronow (Univ. Arizona) presented results of a Monte Carlo simulation of crater saturation and equilibrium. Saturation is defined as steady-state resulting from crater annihilation by overlap equilibrium is defined to include overlap and superposition of ejecta blankets. Woronow found that generally the steady-state slope was less than the production slope for three cases (production slopes of -3, -2, -15). Inclusion of ejecta blanketing only reduced the overall density but did not change the form of the distribution.

R. Strom and E. Whitaker (Univ. Arizona) reported on studies of the size/morphological frequency of large craters on Mercury, Mars and the Moon. By subtracting populations formed on old mare surfaces from those on basin ejecta blankets, and subtracting basin ejecta blankets from uplands, they have been able to extract the form of the crater production functions for different early episodes. They find that the production function has changed in form through these episodes. They infer two populations of bodies (A and B) characterized by -1 and -2 distribution functions respectively.

Additonal research included a comparative planetological analysis of cratering and geomorphological processes (C. Chapman, Planetary Sci. Inst.), depth-diameter relations for large martian craters determined from Mariner 9 UVS altimetry (J. Burt, J. Veverka, and K. Cook, Cornell), and the effects of surface gravity on the occurrence of central peaks in martian, lunar and mercurian craters (E. Smith, Univ. Wisconsin-Parkside).

Channels - H. Masursky (USGS) provided a new analysis of Martian channels which broadly catagorized different channel types. Channels were dated by innovative methods using both a degradation index and a roughness index as well as by comparisons of the crater count age of enclosing plains materials. The analysis was tied to a broad interpretation of the apparent constancy or lack of variation of Martian climate with time. Ages of oldest channels determined by cross-correlation of techniques is more than 2.5 billion years; the youngest are so young that they cannot be dated by these techniques.

Other papers on channels presented in the abstract volume included interdisciplinary ramifications of Mars channel studies (W. Hartmann, Planetary Sci. Inst.), preliminary investigations of the physics of martian channels (C. Sagan, Cornell), martian source craters (R. Stockman, Brown Univ.), and studies of the channeled scabland of Washington

State as a terrestrial analog to the channeled terrain of Mars (E. Ingerson and V. Baker, Univ. Texas - Austin).

Eolian Processes - R. Greeley (Univ. Santa Clara) reported on experiments in the NASA Ames low pressure (5mb) wind tunnel. Threshold speeds are being determined for particles of varied size and density over a range of atmospheric pressures down to 4 mb. Boundary layer characteristics determine which particles will move, one of the most important factors being surface roughness. Continuing investigations will evaluate the influence of roughness, interparticle forces, lift coefficients, particle shape, and other factors on threshold conditions. Also continuing are low-pressure wind tunnel studies of wind tunnel models (raised-rim craters, rimless craters with flat floors, and rimless craters with bowl-shaped floors), saltation trajectories, and rates of erosion of various materials.

Combined with the above report was a description of the study of the eolian regime at Amboy Crater, San Bernodino County, California where the prevailing NW wind blows over smooth plains onto the rough lava rock. Three 50-ft towers, each equipped with an array of cup anemometers and a vent vane, are arranged such that one is located upwind of the crater on smooth plains, a second upwind of the crater on lava flow rock, and the third, in the wake of the crater. Two four-meter craters were dug and time-lapse photography used to study the influence of the craters on eolian erosion and deposition of sand.

The development and modification of barchans in unidirectional wind is being studied by A. Howard, M. Gad-el-Hak, J. Morton, and

D. Pierce (Univ. Virginia). The size and shape of the barchan are functionally related to the mean wind velocity, the size and grading of sediment in transport, the upwind velocity profile, the gravitational force, and atmospheric density. They reported on efforts to define these relationships by wind tunnel studies of air movement over barchanoid models, by computer modelling of airflow regimes, and by field studies of barchan dune fields in the Salton Sea area. In determining the relationships between rate of sand transport surface slope, and the configuration of near-surface wind they have budgeted the transport of sand over the dune and recorded the results of variation of wind direction, sand size and other factors on the pattern of erosion and deposition. Their ultimate aim is to scale the processes affecting barchans to martian conditions. A.S. Cotera and C. McCauley (Northern Arizona Univ.) reported on four dune fields northeast of Flagstaff which have been studied to see if statistical analysis of grain-size data can be used to discriminate between samples collected on different parts of the dunes, and to discriminate between the different dune fields. Statistical parameters determined were: mean grain size, sorting, skewness, and kurtosis; skewness seems to be the most discriminating parameter. Size studies are being accompanied by study of the wind regime through the use of three portable weather stations and by the study of surface processes by time-lapse photography. The authors hope to determine the precise size boundaries of the various eolian environments and to discriminate precisely the conditions of transport and grain size characteristics which control dune morphology.

J. F. McCauley and M. Grolier (USGS) reported on the spectacular yardangs of the Ica Valley (Peru). Individual yardangs range from a hundred meters up to several kilometers in length --- maximum heights are about 100 meters. Length - width ratios are 3:1 to 10:1. In the lower parts of the valley the very streamlined yardangs are covered with fine in situ detritus presumably derived by chemical and mechanical weathering of the bedrock. In a unidirectional wind regime when precipitation and vegetation are scarce more or less perfectly streamlined forms will be produced that are adapted to the local wind regime and individually offer minimum resistance to it. Once well streamlined, the dimensions of the yardang will decrease with time, but its overall shape will not change. Grolier, A. W. Ward, and McCauley (USGS) also reported on comparisons of wind regimes in Peru and on Mars. Mariner 9 B-frames were used to record, planet-wide, the presence and orientations of a variety of erosional and depositional features do not everywhere coincide, suggesting that they may originate under different wind regimes. The results of interplay between local and regional wind are seen on Mars as they are in the Ica Valley (Peru).

C. Breed (USGS) discussed terrestrial analogs of the martian Hellespontus dunes, as viewed from aerial and spacecraft imagery. Dune length, width, and wave length of the Hellespontus dunes were measured and compared with measurements of these parameters of terrestrial dunes. Ratios derived from measured mean dune widths, lengths, and wave-lengths are similar in all sample terrestrial sand seas, regardless of large differences in sizes of the dunes and in shapes and geographic locations of the dune fields. Mean dune width/length ratio for all sampled terrestrial crescentic dune ridges is 1.65, vs. 1.74 for the Hellespontus dunes. Mean width/wavelength ratio for the terrestrial dunes is 1.27, vs. 1.15 for the Hellespontus dunes. Thus the Hellespontus dunes are considered geomorphically similar, in planimetric aspect, to typical terrestrial dunes of a very common type. The closest terrestrial analog to the Hellespontus dunes, based on quantitative comparisons, are the Badan-Jarang dunes of the Alashan Desert, China, rather than the oft-suggested Algedones dunes of southern California.

E. A. King (Univ. Houston) contrasted grain-size characteristics and surface morphologies of finer particles of the regolith of Earth and Moon and related these characteristics to the origin and mode of transport of the particles. He concluded that from a very small sample of martian surface regolith one should be able to establish the relative importance of impact and aeolian processes in the recent past in the vicinity of the collection site.

K. Cook and J. Veverka (Cornell) presented data on crater-related wind streaks in the north equatorial zone of Mars. Light-tone streaks occur preferentially in heavily cratered plains, and are preferentially associated with fresh craters. Craters 2-3 km in diameter show significantly more light streaks than larger craters and no evidence for a separate dependence of the density of light tone streaks on altitude emerges. A significant latitude effect does emerge: the density of light tone streaks peaks near 12°N, and drops off appreciably both towards the equator and towards higher latitudes. The mean angular width of light streaks is about 20^{o}; long light streaks are significantly narrower than short ones. Streak length/crater diameter ratio is typically less than 5. The light streak directions conform closely to the wind regime expected at the season of global dust storms (southern summer).

The results for dark and mixed tone streaks in the northern equatorial zone, although statistically less significant, are similar. But the following possible exceptions exist: 1)Dark streaks may show a slight preference to form at higher altitudes, and may be slightly wider on average than light and mixed tone streaks; 2)Mixed tone streaks do not share the preference for fresh craters exhibited by light and dark streaks; 3)The pattern outlined by dark and mixed tone streaks does not conform to the general circulation pattern expected at the season of global dust storms.

Other eolian process studies included the role of cold density currents as triggering mechanisms for martian dust storms (P. Woiceshyn, JPL), the Proctor dune field of Mars (J. Peterson, Univ. Colorado), the significance of bright spots observed during the 1971 martian dust storm (R. D'Alli, Brown Univ.), longterm evolution of the martian atmosphere and climatic change, and a numerical circulation model with topography for the martian southern hemisphere (C. Sagan, Cornell).

Tectonics - D. Dzurisin (CalTech), in a collaborative program of geologic mapping of the Discovery quadrangle of Mercury, recognizes three distinct groups of lineaments: 1) features defining two lineament directions showing no lateral offset, 2) escarpments within intercrater plains, and 3) linear to arcuate escarpments within smooth plains of large craters. Although examination of scarps and lineaments is based on a non-genetic classification, Dzurisin believes that some scarps may represent flow fronts.

A. Stromquist and G. McGill (Univ. Mass.) compared martian canyonlands graben to structures in the U.S. Four Corners area. They note that the size and spacing of graben and blocks in the Four Corners area are regular, and they interpret these in terms of a unique combination of variable strengths of rock strata, local structural patterns, and consideration of competency of rock. Field analyses are combined with comparisons of experimentally determined strengths for sedimentary rock to derive a general model of graben formation in the canyonlands. Such analyses will be useful for interpreting planetary structural patterns.

P. Masson (Univ. Paris-Sud) presented a general analysis of structural patterns in the west end of Valles Marineris. The analysis involved optical filtering methods to enhance the Mariner 9 images to bring out structural detail. Although there do not appear to be specific age-correlated intervals of tectonism, there nonetheless seems to be repeated structural deformations in the area.

R. Phillips (JPL) reviewed the Tharsis region in terms of the evolution and present state of the martian interior. Phillips showed that there is approximately 3 km of uncompensated relief in the Tharsis Plateau. He argued that this topography and the associated huge gravity anomaly must arise from viscous forces connected with the upwelling part of a convection cell in the martian mantle. If Carr's dating of uplift and vulcanism are accepted, this implies that the uncompensated topography is a "fossil" bulge now sustained by the strength of the martian mantle. Study of the age of Tharsis volcanism through crater counting suggests that the activity of the major volcanoes may have continued at a steady rate until the present time. If so, the Tharsis uplift may be sustained by still-active convection. R. S. Saunders (JPL) presented an analysis of compensated regions of Mars. He showed that, except for the Tharsis Plateau, the planet generally is in isostatic equilibrium. Minimum values for mean crustal thickness can be set by assuming a constant density contrast between the martian crust and the martian mantle and the condition that the thickness of the crust can nowhere be negative. Saunders obtained a mean crustal thickness for cratered terrain of about 50 km. Clearly the crust underlying the cratered terrain was developed early in the history of Mars. The major question is when and how the crust of the northern part of Mars formed.

Geomorphology - B. Lucchitta (USGS) outlined various erosional forms on Mars and noted that resistance to erosion varies; debris mantles and ejecta blankets are most readily modified by erosional processes, crater rims are less readily modified, and volcanic flow materials least modified. D. Nummedal (Univ. South Carolina) and J. Boothroyd (Univ. Rhode Island) discussed a comparison between the Washington scablands, alluvial fans, and various erosional landforms on Mars, using a fourier analysis method. They note that alluvial fans and glacial bursts have similar geometrics - both producing diamond shaped, braided patterns. In the case of alluvial fans, great quantities of water are not required to produce these forms. Scablands of Washington also produce diamond shaped positive features that resulted from plucking of basaltic rocks to produce isolated hills capped with loess. By comparing these features with similar appearing structures on Mars and analyzing both analogs using the first twenty harmonics of the fourier analysis, the authors conclude that gross shape may not be best for discrimination of features but that more refined analyses are required in order to characterize landforms involved. In the abstract volume, J. Guest, R. Greeley, and P. Butterworth (Univ. London Observatory) presented a study of the martian knobby terrain and M. Malin (JPL) outlined several geomorphologic studies of Mercury.

General Planetary Geophysics

S. Peale (University of California, Santa Barbara) showed that the size of the Mercurian liquid core could be determined from a combination of observations of a Mercury orbiter and ranging to a surface station. From the orbiter observations, C_{20} and C_{22} can be obtained, which yields C/MR^2 for the whole planet and also C. C_m is obtained by ranging to a transponder or reflector or several such devices on the surface; C_m is for the solid fraction of the Mercurian interior. Thus C/C_m and the extent of the fluid core can be found. G. Schubert (Univ. Calif. Los Angeles) has calculated temperatures for three of the terrestrial planets and the moon, on the basis of limiting conditions for convection. Although the results are extremely model dependent, it is important to attempt to connect temperature gradient and viscosity to realistic models of rheology and geochemistry. C. Sonnett, F. Herbert, and M. Wiskerchen (Univ. Arizona) reported on mixed electrical and accretional heating and the "zero age" lunar thermal profile. The calculations show that there are important interactions between accretion and both the transverse magnetic and transverse electrical modes of conductive heating. Inductive heating calculations must take into account the accretional history and, in turn, the importance of inductive heating in the thermal evolution of the planets, asteroids and meteorite parent bodies should not be underestimated. The abstract volume contained discussions by M. Gilbert (Virginia Polytechnic Inst.) on chemical equilibria relevant to the construction of planetary models for Mars and Mercury and by S. J. Peale (Univ. Calif. Santa Barbara) on excitation and relaxation of the wobble, precession, and libration of the Moon.

Future Exploration: Techniques and Instrument Development

A series of studies are underway on techniques and instrument development for future planetary missions, including scientific rationale and feasibility of developing a planetary scanning electron microscope with an energy dispersive X-ray analyzer (A. Albee, J. Anderson, and A. Chodos, CalTech); alpha/X-ray analysis using solid-state detectors (E. Franzgrote, JPL); measurement of small-scale terrain roughness, a bonus from airborne or spacecraft-borne side-looking imaging radar systems (G. Schaber, USGS); imaging radar for planetary studies (R. Saunders, M. Daily, and C. Elachi, JPL); an alpha, proton, and X-ray modes for planetary chemical analyses (T. Economou and A. Turkevich, Univ. Chicago); multispectral capability of the Viking lander imaging system (R. Arvidson, Washington Univ., F. Huck, S. Wall, NASA Langley, and W. Patterson, Brown Univ.); calibration of martian surface dynamics by analysis of cosmic ray effects in returned sample (R. Arvidson and C. Hohenberg, Washington Univ.); UV contrast reversal on Mars and a study of the UV reflectance characteristics of possible martian surface materials (J. Veverka, J. Burt, and J. Goguen, Cornell).

R. Greeley (Univ. of Santa Clara) presented a discussion on Mars penetrator mission studies. Instruments are being developed for post-Viking missions to the planet and will be deployed by orbiting spacecraft to impact selected target areas. Penetrators will be connected by an umbilicus to an afterbody containing imaging and meteorological instruments. Seismometers and instruments for elemental or mineral analysis, water detection, etc. will be housed in the forebody.

Education

P. Schultz (Lunar Science Institute) described a short course in planetary geology being offered to selected high-school teachers during the Spring of 1976. Unlike most universities and colleges, high schools have only limited access to current information and photographs obtained from the planetary missions. The course is designed to give teachers a clear understanding of the developing science of planetary geology. This new field has evolved from the basic principles of terrestrial geology but also includes many other disciplines. The three-day course focuses on the primodial planets, the evolving planets, and planetary atmospheres. Photointerpretation and geologic mapping exercises are included.

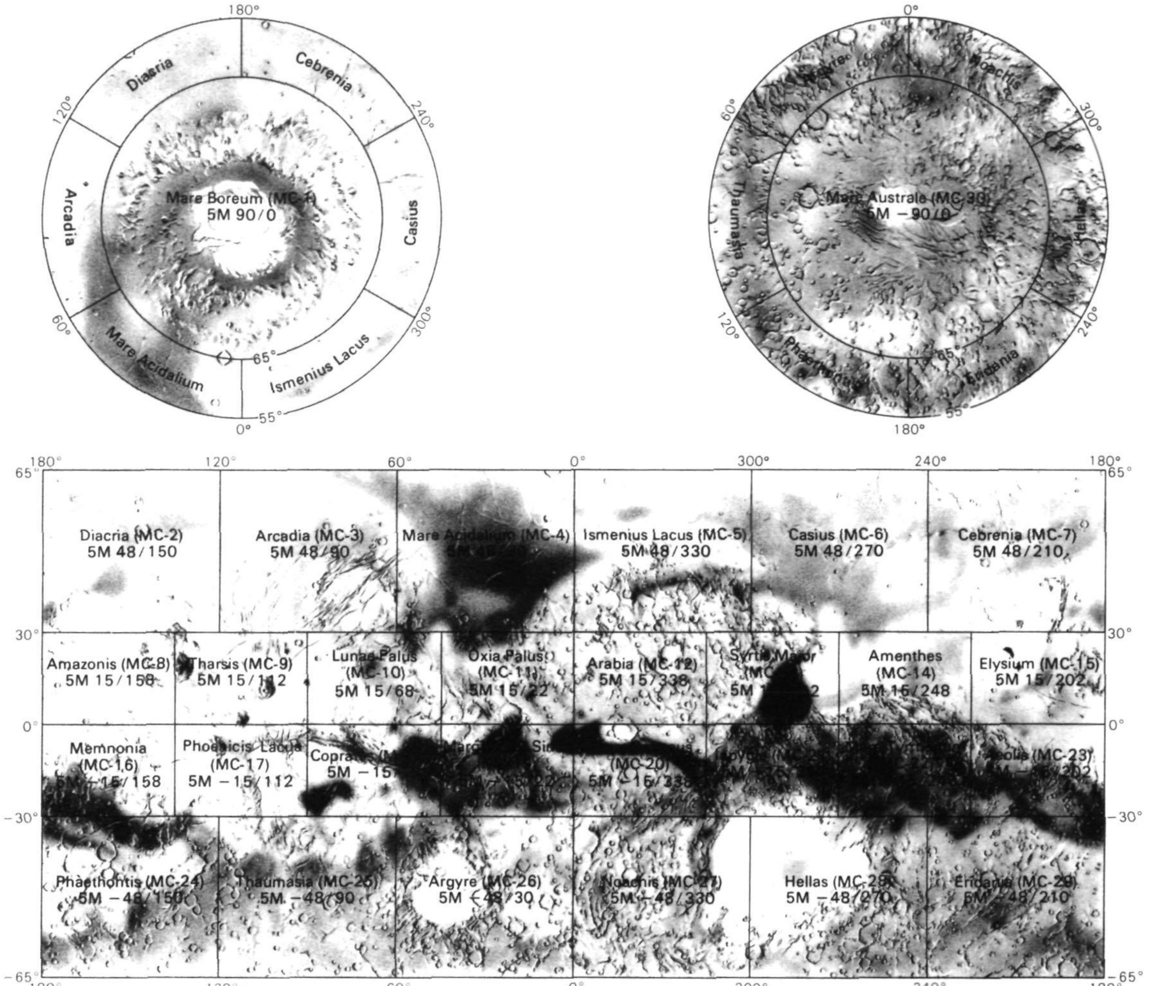
Table 1

1:5,000,000 Scale Geologic Maps

of Mars

MAP	AUTHOR	STATUS
MC-1 Mare Boreum	L.A. Soderblom & Harold Masursky	Preliminary map
MC-2 Diacria	K. Howard	In Preparation
MC-3 Arcadia	D. U. Wise	In Preparation
MC-4 Acidalium	J. R. Underwood, Jr. & N. J. Trask	In Review
MC-5 Ismenius Lacus	B. K. Lucchitta	In Review
MC-6 Casius	Ronald Greeley & J.E. Guest	In Review
MC-7 Cebrenia	Wolfgang Elston	In Preparation
MC-8 Amazonis	E.C. Morris & S.E. Dwornik	In Preparation
MC-9 Tharsis	M.H. Carr	Published (I-893)
MC-10 Lunae Palus	D.J. Milton	Published (I-894)
MC-11 Oxia Palus	D.E. Wilhelms	Published (I-895)
MC-12 Arabia	J.S. King	In Press
MC-13 Syrtis Major	J.D. Meyer & M.J. Grolier	In Press
MC-14 Amenthes	K. H. Hellar	In Preparation
MC-15 Elysium	D.H. Scott & J.W. Allingham	Published (I-935)
MC-16 Memnonia	T.A. Mutch	In Preparation
MC-17 Phoenicis Lacus	Harold Masursky	In Preparation
MC-18 Coprates	J.F. McCauley	In Preparation
MC-19 Margaritifer Sinus	R.S. Saunders	In Preparation
MC-20 Sinus Sabaeus	H.J. Moore	In Preparation
MC-21 Iapygia	G.G. Schaber	In Press
MC-23 Aeolis	D.H. Scott & E.C. Morris	In Preparation
MC-24 Phaethontis	H. Howard & J. Woodruff	In Preparation
MC-25 Thaumasia	G.E. McGill	In Preparation
MC-26 Argyre	C.A. Hodges	In Preparation
MC-27 Noachis	J.E. Peterson	In Press
MC-28 Hellas	D.B. Potter	In Press
MC-29 Eridania	R.A. DeHon	In Press
MC-30 Mare Australe	C.D. Condit & L.A. Soderblom	In Preparation
1:25,000,000 Scale Geologic Map of Mars		Published

Published maps available at $1.00 each from U.S. Geological Survey, Distribution Section, 1200 S. Eads St., Arlington, VA 22202



Albedo features from International Planetary Patrol photographs. Lowell Observatory, Flagstaff, Ariz.

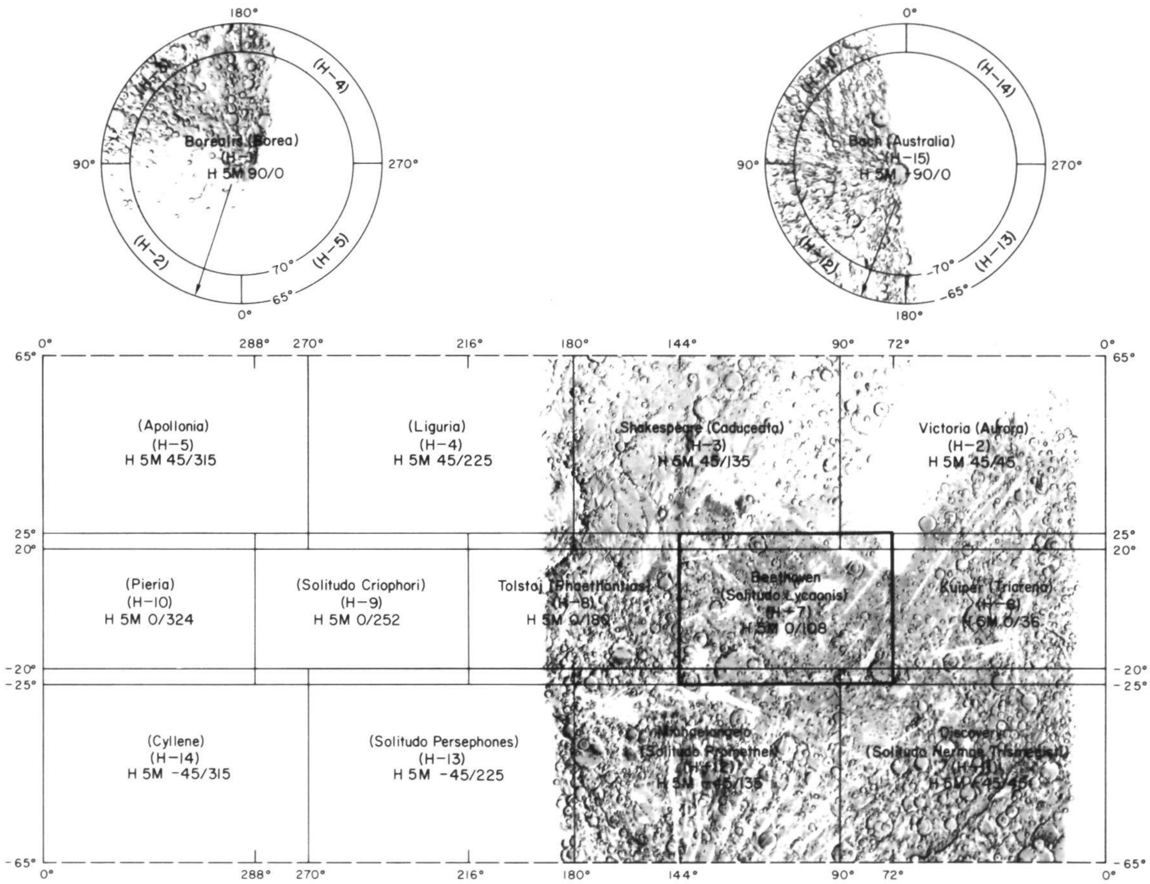
QUADRANGLE LOCATION

Table 2

1:5,000,000 Scale Geologic Maps of Mercury

MAP	AUTHOR	STATUS
H-1 Borealis (N. Pole)	M. Grolier & J. Boyce	In Preparation
H-2 Victoria	G. McGill & E. King	In Preparation
H-3 Shakespeare	R. Greeley, J. Guest & D. Gault	In Preparation
H-4	Data not available	
H-5	Data not available	
H-6 Kuiper	J. Underwood, D. Scott & R. DeHon	In Preparation
H-7 Beethoven	J. King & H. Holt	In Preparation
H-8 Tolstoj	J. McCauley & G. Schaber	In Preparation
H-9	Data not available	
H-10	Data not available	
H-11 Discovery	N. Trask, D. Dzurisin & J. Dunne	In Preparation
H-12 Michaelangelo	H. Holt, H. Masursky & K. Blasius	In Preparation
H-13	Data not available	
H-14	Data not available	
H-15 Bach (S. Pole)	R. Strom & M. Malin	In Preparation

Reference Mosaic of Mercury ($0.75) Published (I-903)



ARRANGEMENT OF MAP SHEETS ON MERCURY

The provisional name "Goethe" was changed to "Borealis," and the provisional name "Tir" was changed to "Tolstoj" by the International Astronomical Union in 1976 (IAU, 1977). The provisional names appeared on earlier editions of this index map as well as on the Tolstoj (H-8) quadrangle of Mercury.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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