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Significant Achievements in the Planetary Geology Program, 1981

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INTRODUCTION

The purpose of this publication is to summarize the research conducted by NASA's Planetary Geology Program Principal Investigators (PGPI) and Mars Data Analysis Program (MDAP) Geology Principal Investigators. The summaries in this document are based on presentations at the twelfth PGPI meeting held at Louisiana State University, January 5-10, 1981. Important developments are summarized under the broad headings as listed in the Table of Contents. A more detailed summary can be found in the 1981 meeting abstract document (Reports of the Planetary Geology Program - 1980, NASA TM 82385, 550p).

The accomplishments of any science program are a reflection of the people who take part in it. The contents of this document are a testimony to the PGPI's who have produced significant advances in the exploration of our Solar System. They represent a group of people dedicated to advancing the frontiers of geology past the traditional limitations of the planet earth.

This document is partly based on summaries prepared by some session chairmen at the annual meeting. These contributing authors are listed below.

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GALILEAN SATELLITES AND SMALL BODIES

Theoretical studies of possible thermal evolutions of the Galilean satellites were outlined by R. Reynolds (Ames Research Center (ARC)) and coworkers. At Io tidal heating is the dominant heat source and the predicted amount of tidal heating is consistent with the observed IR heat flux. But the IR heat flux implies a Q for Io that is incompatible with the Q derived from considerations of Io's orbital evolution. It was suggested that a silicate melt zone occurs within 50 km of the surface. Shallower contacts between a silicate magma intrusion and the overlying sulfur layer could produce volcanic plumes driven by high temperature sulfur vapor.

In the case of Europa, very special conditions are necessary to prevent the total freezing of an ice crust by tidal heating. Europa's geologically active phase lasted longer than for Ganymede and Callisto due to a higher radioactive content and tidal heating. Accretional heating of Ganymede and Callisto caused some internal differentiation but Ganymede's active phase lasted longer than Callisto's due in part to a longer radioactive heat source because of its greater mass.

Evolution of Io's volatiles was discussed by J. Pollack (ARC). Terrestrial analogue quantities of water, nitrogen, and rare gases could have been entirely eliminated from Io by the present time due to a combination of loss processes including interactions of the Iovian magnetosphere with atmosphere gases, plume particles and surface ices. In the case of water, extensive recycling through the melt zone between the upper and lower parts of the crust would also result in partial dissociation into hydrogen and oxygen, with the hydrogen released into the atmosphere. Sulfur volatiles are still present on Io due to its larger percentage of the planet's total mass ($S \sim 10\%$ Si) enabling them to sustain the large loss rate to the present epoch.

F. Fanale (University of Hawaii) constructed a quantitative model for the history of SO_2 molecules from the time they are supplied to Io's surface/atmosphere environment by volcanism to the time they are lost, linking Io's surface, atmosphere and magnetosphere. Given the model, he investigated whether SO_2 condensation during eclipse and sublimation on emergence could account for Io's sometimes reported post-eclipse brightening. Fanale concluded that the vapor pressure of SO_2 is such that Io's atmosphere could hold enough SO_2 (10^{-3} to 10^{-3} g/cm^2) over much of the dayside (if saturated) so that SO_2 condensation/sublimation can explain the brightening ($\leq$ 15%) and the half time ($\sim$15 minutes). Variation in the quantity of SO_2 atmosphere available (from volcanism) would result in the long term variability of Io's post-eclipse brightening.

Transient, directional features in the Io sodium cloud were described by C. Pilcher (University of Hawaii). The unusual characteristics of these features include: (1) They are generally present, usually extending toward the north and away from Jupiter; (2) The characteristic dimension of directional features projected onto the plane of the sky is about 2 Rj (140,000 km); (3) The potential energy of some sodium atoms in the features requires ejection velocities relative to Io of at least 4-5 km/sec; (4) Preliminary model studies indicate that if the sodium is jetting from the surface of Io, then ejection velocities are about 10 km/sec; (5) The directionality of the features indicates a local source in Io's northern hemisphere; and (6) The transient nature of the features requires changes in the source, sink, or both on a timescale of hours to one day.

Monte-Carlo simulations of ballistic models of Io's eruption plumes by R. Strom (University of Arizona) have led to certain constraints on the dynamics of Plumes 1 (Pele) and 3 (Prometheus). These models varied the vent geometry, limits on ejection angles, angle/frequency distribution. The best fit to Plume 3 brightness distribution and envelope shape was a model in which the material was ejected at 0.5 km/sec isotropically from a point source into a cone from 0° to 55° from the vertical. This simulation suggests that for Plume 3 the ejection velocity is not highly dependent on angle, the velocity dispersion is small, the ejection angle/frequency distribution is nearly isotropic and the limiting ejection angle is larger than 45° from the vertical. No ballistic simulation was able to reproduce the bright outer envelope seen in Plume 1. Therefore, a shock front model may best explain this feature which may be due to the concentration of particles at a shock front.

Gerald Schaber (U.S. Geological Survey (USGS)) described the size and spatial distribution of 170 volcanic vents and the trends of 15 ft lineaments longer than 50 km within an area representing 26 percent of the surface of Io. The spatial distribution of volcanic vents larger than 14 km diameter showed that the equatorial zone has about twice the number of vents as the mid-latitude zone and six times the concentration of south polar region vents. Mean vent size appears to increase steadily from the equatorial zone (48 km dia) to the south polar zone (65 km dia). The latitudinal variation in vent sizes could be related to the concentration of tidal stress. Io exhibits numerous lineaments and grabens despite a very young surface age. Normal (tensional) faults appear to predominate but there is some evidence of strike-slip movement in the equatorial zone. Both grabens and lineaments trend dominantly northwest and northeast, exhibiting a planetary grid pattern characteristic of virtually all silicate bodies observed thus far in the solar system.

A model of thermal evolution for Europa which will produce surface cracking was described by A. Finnerty (Jet Propulsion Laboratory (JPL)). The total amount of water required to dilute the density of a lunar or Io type body (3.3-3.5) to Europa's density (3.0-3.1) is about 5 wt. percent. If all the water is concentrated in a 100 percent hydrated layer, it would extend from the surface to 270 km depth. A variety of thermal models suggests that temperatures below the dehydration temperature will exist in a thermal boundary layer extending to 100-300 km depth, above a convecting interior. There is no need to invoke a thick H_2O layer (ice or liquid) on Europa, and it is likely that the ice layer is less than 24 km thick. Assuming a cool accretion model with hydrated minerals initially uniformly distributed, a dehydration front moves from the deep interior toward the surface resulting in an increase of volume. This volume increase would create tensile stress in overlying rocks which can initiate fracturing of the crust.

Europa has a unique ratio of water to anhydrous components so that thermal evolution will lead to formation of a layer of 100 percent hydration that becomes saturated with water upon further dehydration. The presence of free water effects a drastic weakening of the rocks and the hydrated lithosphere is readily fractured. If the planetary water-anhydrous component ratio were greater, a thick surface ice layer would form and mask the fracturing of the underlying hydrated silicate crust. Alternately, if the water-anhydrous component ratios were less, the hydrated silicate crust would never become saturated with water, and thus, would not be weakened and so subject to fracturing. The increase in volume with dehydration is the mechanism for forming the global scale fracturing.

The density and size-frequency distribution of craters on the dark terrain of Ganymede were described by J. Plescia (JPL). The crater densities over the dark terrain vary by a factor of 5-6, similar to the variation in crater densities across the grooved terrain. Areas of lightly cratered dark terrain have a crater density similar to the most heavily cratered grooved terrain. The dark terrain cumulative crater curves often exhibit a "bump" at about 20 km diameter, indicating a deficiency of smaller craters. This appears to result from burial of small craters by some ejecta from palimpsests. The variation in crater densities across the dark terrain can be explained by a model proposed by E. Shoemaker and R. Wolfe (USGS) which predicts the ratio of the cratering rate at the apex to the antapex of orbital motion on Ganymede is about 10X. Thus, for a surface of uniform crater retention age, the crater density at the apex areas would be about 10 times greater than over the antapex areas.

A model for the origin of the grooved terrain on Ganymede was presented by S. Squyres (Cornell). The brighter appearing grooved terrain has undergone resurfacing, but there are bands and broad areas of bright resurfaced material which are free of grooves. Thus, two processes must be involved: one that creates bright bands and a subsequent process that creates grooves. The resurfacing process that creates the bright bands may occur when crustal extension creates broad downdropped rift zones that are then flooded with bright clear ice deposits. Grooves may form when continued extension causes fracturing in the cleaner and weaker ice deposits, either as extension fractures or as grabens. The apparent contemporaneity of the resurfacing and groove formation processes supports the model that requires both result from the same tectonic regime: global extension for a brief period early in Ganymede's history.

D. Davis (Planetary Science Institute) reported on a surprising result from Monte Carlo numerical modeling of asteroidal evolution through oblique impacts. Consideration of both angular momentum and energy in asteroid collisions suggests that binary and/or mutiple asteroids can be formed as one outcome of collisions. Large, gravitationally bound asteroids are thought to be structurally weak bodies due to impacts that fracture but cannot disperse the target body. Such weak bodies tend to relax to equilibrium figures under repeated jostling by continued impacts. Occasional large impacts impart more angular momentum than can be accommodated in a single equilibrium figure, leading to the formation of binary and/or multiple asteroids. Preliminary collisional models of binaries indicate that between one percent and 10 percent of large gravitationally bound asteriods are binaries.

Spin-period determinations for 45 comets were reported by F. Whipple (Smithsonian Astrophysical Observatory). The reasonably well determined rotation periods range from 7.8 hours to 81 hours with an average period of 15 hours. Sublimation-induced spinup may be a significant factor in comet evolution. The initial spin period develops at time of comet formation which suggests formation in a very low velocity region of space. New comets are more uniform on their surfaces than older comets, but tend to concentrate their activity in single areas.

VENUS

Simulation of Pioneer-Venus (PV) radar altimetry was demonstrated by R. Arvidson (Washington University). Qualitative simulation of the effect of the PV footprint size (about 100 km x 100 km) and spacing shows that many geologic features common to Earth would be missing or badly undersampled. Features larger in wavelength than 100 km would be reproduced. Features between about 100 km and 200 km would appear as broader and more subdued features. Ocean trenches and rises are in this smaller category, so the presence or absence of comparable evidence for plate tectonics on Venus is uncertain.

A digital bathymetry map of the North Pacific ocean floor was resampled to simulate what the PV radar system would reveal of the ocean floor structures. All major volcanotectonic provinces (rises, trenches, transforms, seamounts and the Hawaiian moat and swell) are present and discernible. Such resolution is due in large part to the favorable systematic distribution of the features. Many features become broader and more subdued, i.e., the Marianas Trench is reduced in depth by a factor of two. The PV radar altimetry of Venus reveals blockier rolling plains on a 500 km to 1000 km wavelength and an Earth-like plate tectonic signature cannot be discerned.

Evidence for continental-style rifting across the Beta region of Venus was presented by G. McGill (University of Massachusetts). Beta Regio is a broad elevated region, about 1500 x 2000 km across and 3 to 3.5 km high, that is bisected by a north-south trending trough. Beta Regio and the associated trough compare closely in size with the East African rift and associated Ethiopian and Kenyan domes. Smaller topographic features, such as flanking uplifts, en-echelon offsets and variable depths are similar in scale. The East African rift has been the site of much basaltic volcanism, so the discovery of basaltic like rocks on the flank of Beta by Veneras 9 and 10 is consistent with the analogy. Thus, it is possible that Beta Regio is a structural uplift rather than a volcanic construct as previously inferred. Because continental rifts on Earth result from modest amounts of spreading, the existence of an analagous feature on Venus does not require significant amounts of lateral plate motion.

The geomorphology of Venus and Earth were compared by M. Malin (Arizona State University) through analysis of topographic data at the same scale and resolution. Based on a general global comparison, he feels Venus is not unlike the Earth. Terrestrial morphology shows rugged lowlands (sea-floor) and relatively smooth, flat-topped plateaus (continents). Ishtar Terra is interpreted to be the only true continent on Venus; Aphrodite and Beta Regio appear to be uplifted crust with extrusion along their major axes. The many small mountains suggest Venus is still geologically active, but "sea-floor spreading" may be defeated by the absence of a more fluid portion of the lithosphere. In this interpretation, most of Venus is covered by "oceanic type crust", presumably basaltic; Ishtar Terra is probably underlain by granitic "continental crust".

The ridge and trench systems of Venus were compared with global rift valleys on Earth by G. Schaber (USGS). Analysis of Pioneer-Venus radar data has resulted in recognition of three pervasive linear zones of surface disruption trending NE, NW, and N in the equatorial and mid-latitude regions of Venus. These zones extend for distances along great circles of 21,000 km (halfway around Venus) between southern Aphrodite Terra and Beta Regio (area A), of 15,000 km northwest from Themis Regio (area B), and of 5,000 km south through Beta Regio (area C). The area A and B disruption zones appear to intersect at an isolated elevated terrain of probably volcanic origin centered at latitude 0° and longitude 200°. Zones A and C are dominated by rugged, well developed ridge-and-trough topography associated with low platforms or elongated domal ridges. The troughs south and east of Aphrodite Terra and running south through Beta Regio average about 165 km in width, with a range between 125 km and 240 km. The equatorial and mid-latitude disruption zones on Venus are similar in scale to global terrestrial plate tectonic rifts. The ridge-and-trough features are best compared to extensional continental rifting (e.g. East African rifts, Rio Grande rift, and the Rhine Graben) resulting from mantle convection or other subcrustal perturbations operating beneath sialic crust.

The suggestion of aeolian processes occurring on Venus was advanced by R. Greeley (Arizona State University) from the combination of measurements of windspeeds on the surface, observation of small particles in the Venera images, and predictions of threshold windspeeds for the Cytherian environment. Aeolian features (dunes, ripples, etc.) that could be detected by radar systems in Venus orbit may have different geometries (and different radar signal characteristics) in response to the venusian environment. For example, numerical simulations suggest that saltation trajectories may be one-tenth those on Earth for similar basic conditions (windspeeds just above threshold); thus aeolian bedforms such as ripples may similarly be different. To address the general question of the physics of windblown particles on Venus, a windtunnel is currently being fabricated to simulate aeolian processes under venusian conditions.

GEOCHEMISTRY AND REGOLITH

Evidence that there are several near-equatorial regions on Mars that contain damp briny soils was presented by R. L. Huguenin (University of Massachusetts). He proposed that much of the salt in the regolith possibly could be aerosol deposits derived from evaporation processes in these "oases". With estimates that 10^{13}g of salts may be produced annually by evaporation from the oases and be distributed as aerosol deposits around the planet, it is therefore possible that much of the salt detected at the two Viking lander sites may have been deposited during dust storms. A variety of implications need to be addressed: metal ions (Fe^{2+}, Fe^{3+}, etc.) in the salts, for example, could produce absorption bands that have not been previously considered in the interpretation of reflectance spectra. Source rock interpretation of the Viking XRF also may need modification. A variety of atmospheric effects also are possible including enhanced catalysts of $CO + \frac{1}{2}O_2$ recombination reactions, nucleation/precipitation processes, and scattering effects.

J. L. Gooding (JPL) reported on studies of soils and sediments derived from basalts on the Kilauea and Mauna Kea volcanoes, Hawaii, in order to provide information on the properties to be expected among Martian soils and sediments that may have been derived from similar rocks. It is found that:

(1) Mineralogy may vary significantly with particle size, with weathering products ("allophane," smectities, hematite, etc.) concentrated strongly into silt- and clay-fractions.

(2) Alteration of glass (by fumarolic reactions or surficial weathering of vitric ash or flow surfaces) may dominate immature soils. Such alteration products may yield VIS/NIR reflectance spectra that closely resemble those of clay minerals and may be almost totally amorphous.

(3) Most immature soils contain relatively small ($\lesssim$ 5%) fractions of particles which are comparable in size to those deduced for Martian surface fines ($\lesssim$ 100 μm) and the best nominal Viking lander camera resolution ($\sim$ 2.5 mm) is inadequate to distinguish between volcanogenic soils with different evolutionary histories. Gooding concluded that sample returns from Mars are needed to answer key soil genesis questions.

Analysis of backhoe touchdown, surface bearing test, and trenching operations performed by the Surface Samplers of Landers 1 and 2 by H. Moore (USGS) and co-workers has provided improved estimates of cohesions and angles of internal friction of surface materials at the landing sites. The estimates for the four types of surface materials are listed below in order of increasing strength:

Material	Site	Cohesion	Angle of Internal Friction
1. Drift	Lander 1	1-3	10 ± 5
2. Crusty to cloddy	Lander 2	4-8	30 ± 10
3. Blocky	Lander 1	10-12	25 ± 5
4. Rocks	Landers 1 and 2	20	- - - -

Derived cohesions and angles of internal friction for Lander 1 are compatible with the previously unresolved problem of forces exerted on footpads 2 and 3 and their corresponding penetrations into drift material (footpad 2) and blocky material (footpad 3) during landing.

Failure of some natural slopes and some trench walls in drift material suggest that the cohesion between local planes of weakness (bedding planes) in drift material is substantially less than 1-3 kPa in the range of 0.01-0.1 kPa.

R. V. Morris (Johnson Spaceflight Center (JSC)) and H. V. Lauer, Jr. (Lockheed) described various lines of evidence suggesting ferric oxyhydroxides (FeOOH polymorphs) might be present in Martian surficial material. The geochemistry of the ferric oxyhydroxides is an important consideration when evaluating the likelihood of occurrence of significant amounts of these minerals on Mars. The authors have examined by laboratory experiments the stability of ferric oxhydroxides to dehydration in the presence of ultra-violet (UV) radiation. Dehydration of the ferric oxyhydroxides was observed when the intensity of the incident radiation was sufficient to thermally dehydrate the ferric oxyhydroxides by radiant heating; the intensity of this radiation was much greater than that of solar radiation incident on Mars. No perceptible dehydration of the ferric oxhydroxides was observed when radiation with an intense UV component, but weak visible and infrared components, was employed. The temperature in these experiments was lower than the thermal oxidation threshold of the ferric oxyhydroxides. The longest duration of irradiation flux used in experiments scales to about 15 Martian years of irradiation at the Martian flux. There is as yet no experimental basis for inferring that UV photodehydration of ferric oxyhydroxides occurs naturally on the surface of Mars as an efficient weathering process on a time scale of at least 15 Martian years.

The Dry Valleys of Antarctica represent the best terrestrial analog to the surface of Mars. During the austral summer of 1979-80, E. K. Gibson (JSC) visited the Dry Valleys to study the weathering processes operating in cold environments which may be analogous to those on Mars. The weathering processes in the Dry Valleys are related to the Martian surface in the following manner: low temperatures (mean -17°C) and humidities, diurnal freeze-thaw cycles (even during day-light hours), low annual precipitations, desiccating winds, high sublimation and evaporation rates resulting in salt formations, oxidizing environment and the absence of higher and lower life forms.

Soil samples from a 1-meter deep trench in the Prospect Mesa Formation, Wright Valley, Antarctica were analyzed for their carbon, sulfur, water and water-soluble cations and anions along with secondary mineralogy. Evaporite salts were found to be enriched in the soils from the active zone immediately above the frozen zone (e.g. 40 cm level). Total sulfur and chlorine abundance were similar to those reported at the Viking 1 and 2 sites. No "exotic" sulfur- or chlorine-rich parent rocks are required to produce the sulfur and chlorine-rich soils. In the cold-environment weathering process of Antarctica the sulfur- and chlorine-rich soils are produced by alteration of Beacon sandstone and Ferrar dolerite, neither of which are enriched in sulfur or chlorine.

VOLCANIC PROCESSES AND LANDFORMS

Five papers were presented in this session reflecting studies as diverse as lava flow erosion rates and the pyroclastic origin for the aureole deposits of Olympus Mons. W. Elston (University of New Mexico) reported on erosion rates in pahoehoe basalt flows in arid/semi-arid climates which would provide an analogy for martian flows. The vertical erosion rate in such settings on earth is about 1 m/10^6 years based on observations of characteristic zonation in flows less than 10 m in thickness. This value provides a minimum figure for erosion rates on Mars. Zoning in lava flows is defined by vesicles which move to the cooling fronts. A complete flow is characterized by an upper and a lower vesicular zone separated by a central massive zone. The authors have observed that (1) the upper vesicular zone makes up approximately half of the total thickness of the flow; (2) that there also exists a vertical joint zonation in which the spacing of the joints is approximately equal to their depth of penetration and the joints become deeper and more widely spaced as the solidification zone advances upward; (3) that the spacing of the vertical joints at the top of an eroded flow is approximately equal to the thickness of the material eroded; and (4) that the diameter of the largest block preserved in the lag deposits approximates the thickness of the flows.

R. Greeley (Arizona State University) presented a paper which dealt with the physical modeling of lava flows to give insights into both the style of volcanism and the location of vents. It was pointed out that laboratory simulations have an advantage in that eruptive conditions can be controlled. The major disadvantage of such simulations is that of scale difference between model and full-size conditions. In spite of this disadvantage, it is believed that the models do provide significant insights and a specific study involving a series of experiments was reported on which simulated the filling of a multi-ringed impact basin. From the resulting morphologies, it was pointed out that the cases which best approximate lunar maria involved very high rates of effusion (greater than 400,000 m^3/sec) of very fluid lavas from linear vents located at the base of the rings. It was concluded that the experiments carried out demonstrated the feasibility of simulating lava flows and provided the basis for the study of even more complicated systems.

H. Moore (USGS) reported on some of the less spectacular martian volcanic centers. Eight of these centers were illustrated as follows: (1) Syria Planum, (2) just north of Olympus Mons, (3) Ceraunius Fossae, (4) just north of Uranius Patera, (5) Mareotis-Tempe Fossae, (6) Chyrse Planitia, (7) in Arsia Mons, and (8) near the crater Lassell. It was pointed out that the importance of these and other similar volcanic centers in the volcanic evolution of Mars is still unclear. None of these centers attain the elevations corresponding to the so-called "hydrostatic" head represented by the tops of Olympus Mons and Elysium Mons.

R. J. Pike (USGS) considered the quantitative morphology of volcanoes using multivariant analysis to compare the geometry of 740 volcanoes on the Earth, Moon and Mars. He pointed out systematic relationships between the large martian volcanoes which differ markedly from tholi (small isolated domical hills) and paterae (irregular complex craters with scalloped edges believed to be volcanic in origin). The large martian shield volcanoes have much the same shape as caldera-bearing terrestrial shields although they do not resemble Hawaiian shields in gross geometry. Tholi and paterae do not have the same geometry as any class of terrestrial shields but this observation was qualified by pointing out that this could reflect partial burial by younger plains materials. It was also pointed out that terrestrial cratered seamounts are different in form from almost all terrestrial shield volcanoes and overlap only a few martian tholi and montes.

Elliott Morris (USGS) discussed a pyroclastic origin for the aureole deposits around Olympus Mons. This has been and remains a controversial topic among different investigators. The author indicated that all of the proposed origins for the aureole of grooved terrain around Olympus Mons fail to explain several points: (1) the emplacement of such a great volume of material; (2) the overlapping relations of the deposits; (3) the formation of the ridge and valley structure of the aureole; (4) the very low crater density of the aureole and; (5) the strong gravity anomaly associated with the aureole. In the opinion of the author, a pyroclastic origin for the aureole explains these points. By comparison, the largest volcanic deposits on earth in terms of volume and areal distribution are pyroclastic flows which develop in thick overlapping sheets that cover hundreds of square kilometers. Furthermore the valley and ridge structure of the aureole is analogized to similar-appearing pressure ridges that form on flowing viscous material. Although pyroclastic flows are initially very fluid, when the volatiles which cause fluidization are depleted, the mass settles from suspension. However momentum of the solid particles causes the mass to flow as a viscous material for a short distance. The author believes that viscous flow in the martian atmosphere would continue through a longer period during which viscosity would tend to increase resulting in the ridges which characterize the aureole--pressure ridges oriented normal to flow direction. It was further pointed out that the material of the aureole is readily erodable based on the low number of craters and the development of secondary yardangs. Finally it was pointed out that the gravity anomaly, which is associated with the aureole deposits and is the largest on Mars, may be related to a near-surface magma chamber from which the pyroclastic deposits were derived.

AEOLIAN PROCESSES AND LANDFORMS

Work related to understanding aeolian processes and the evolution of aeolian landforms centered about three areas (1) the origin of the Martian north polar deposits, both the layered deposits of dust and ice, and the great circumpolar dune field, (2) Earth-analog studies, mainly in the Egyptian desert, designed to provide indicators for how aeolian processes may have modified the surface of Mars, and (3) experimental studies of aeolian processes.

A. Ward and co-workers (USGS) have generated a global digital map of Martian aeolian features, including streaks, dunes, pits, yardangs, and sand sheets. Included in the data set, which is now part of the Mars consortium data base, are the location and orientation of features, and the subsolar longitude at which a given feature was observed. Data were acquired from Viking Orbiter photography.

J. Veverka (Cornell) provided a model for the formation of bright and dark streaks on Mars, based on the stability of the atmosphere. When the atmosphere is stable, such as during periods of high dust loading, flow is blocked by positive topographic obstacles, such as craters. Thus regions downwind of craters become "quiet" zones that could accumulate sediment. When the atmosphere is relatively clear of dust, the atmosphere becomes relatively unstable and positive obstacles cannot block wind flow. Rather, wind velocities would be accelerated downwind of obstacles, leading to scoring. The first situation would be conducive to formation of bright streaks, while the latter would be conducive to formation of dark streaks.

P. Thomas (Cornell), presented data on streak patterns for the polar regions of Mars. His data imply that most circumpolar transport by wind takes place during the winter season for the northern cap and during the summer season for the southern cap. J. Pollack (ARC) showed, through use of a 2-dimensional numerical model of the Martian atmosphere, that winds are greatly enhanced in the 50° to 70° N. Lat. region during times of heavy atmospheric dust loading. Such periods occur during the northern winter, perhaps explaining P. Thomas' observations. J. Pollack concluded that the reason the north polar region has a dune field is related to the enhancement of winds in the 50° to 70° N. Lat. region.

A great deal of effort has been expended in analysis of the hyperarid western desert of Egypt. F. El-Baz and associates (Smithsonian) examined bright and dark streaks extending from knobs and craters in Egypt and compared their forms to streaks on Mars. The Egyptian streaks were found to be much more streamlined (e.g. width/length smaller) than streaks on Mars. These workers also compared knobs in the western desert to knobs in the Cerberus region on Mars. The knobs are erosional outlines or remnants adjacent to escarpments. They found that knobs on the two planets have the same shapes, even though the Martian knobs were kilometers in width and the Egyptian knobs were meters in width. In another study, these workers found that dune forms in the Farafra depression in Egypt were not aligned with regional winds, mainly because the dunes were associated with local topographic obstacles that modified wind flow directions. C. Herzig (Dickenson College) examined the properties of dune sands collected from the western desert and concluded that color differences were related to stains of iron oxides and clay minerals. D. McKay (JSC) used an electron microscope to examine grains from Egypt. He concluded that the stains on the grains averaged about 1.0 micrometer in thickness, that the major elements within the stain material were Si, Al, and Fe, and that the stains were composed of interlocking platelets composed of clay minerals and iron oxides.

J. McCauley (USGS) compared the Gilf Kebir region of Egypt with the north polar erg of Mars. Based on observations of sand sheet transport in Egypt, he suggested that the source of sediment for the Martian erg may have been the fretted terrain that borders the heavily cratered uplands. Massive amounts of debris may have been transported from the fretted areas to the north sometime in the past. C. Breed (USGS) continued the comparison by noting that the knobs of inselbergs in Egypt originally were formed by water erosion, but that they are currently being modified by wind. The same may be true for fretted regions on Mars. Finally, this group presented information on climbing and falling dunes in the painted desert of Arizona, which are possible analogs to topographically controlled dunes on Mars.

R. Saunders and colleagues (JPL) discussed an unexpected phenomena that was encountered when experimentally modeling adsorption and desorption of carbon dioxide by clay-rich soils. They found that clay-rich soils, subjected to diurnal temperature fluctuations common to Mars, could catastrophically release CO_2, producing vertical channels in the soil and eruptions of minature dust clouds. Greeley and colleagues (Arizona State University) experimentally determined that wind blown saltating particles on Mars (or at 6.6 mb pressure) only reach about 20 percent of the wind velocity, in marked contrast to the case on Earth, where saltating particles are essentially traveling at the same velocity as the wind. Greeley also found that the saltation length for particles on Venus is a factor of 10 less than the length on Earth, and predicts that the transport rate of saltating grains should be 3×10^{-4} times less than the typical rate for Earth.

D. Krinsely (Arizona State University) found, through compression testing, that electrostatically-clumped aggregates are resistant to penetration. He concludes that such materials on Mars would inhibit transport by saltation by absorbing the incident energy. Finally, R. Craig (Smithsonian) discussed using autocorrelation techniques to identify periodic structure within dunes and other landforms. Their intent was to use autocorrelograms as a landform classifier.

FLUVIAL AND PERIGLACIAL PROCESSES

Studies of the Martian hydrological system have shown significant convergence in ideas and interpretations, owing principally to the effective exchanges that have occurred under the auspices of the Mars Channel Workshops. Although each investigator retains a unique perspective, common themes are now emerging, providing directions for future endeavors. Among the most prominent directions are: Relationships between Valleys and Groundwater; Planimetric and Morphologic Constraints on Channel Forming Processes; Hillslope Processes; and Exploitation of new Viking Orbiter observations.

M. Carr (USGS) presented the results of an investigation of Martian channels, which he summarized in six points:

1) Over 99 percent of Martian runoff channels are in the old cratered terrain, although occasional runoff channels occur elsewhere such as in Alba Patera and on the walls of Valles Marineris.
2) Within the cratered terrain, the channels occur preferentially in high areas, with low blue-red color ratios, and intermediate thermal inertia.
3) The dissection pattern is immature with small drainage basins, large undissected areas between basins and between tributaries within the basin.
4) Most runoff channels are old and date from close after the drop-off in cratering rate, 3.9 billion years ago.
5) Outflow channels in contrast have a wide range in age, with scoured areas ranging from 650-3,000 craters > 1 $km/10^6\ km^2$.
6) Fretted channels form by enlargement of other channels by mass wasting.

V. Baker (University of Texas) discussed his recent study of Nirgal Vallis, which he feels illustrates a Martian valley system that probably developed a sapping process involving ground-water flow. Sapping by spring head retreat is a self-enhancing process that proceeds until achieving an optimum drainage density. Nirgal Vallis appears to have not achieved this optimum density, perhaps because the Martian ground-water flow system was not as effectively recharged as terrestrial systems. The immature theater-headed valleys on younger Hawaiian shield volcanoes display some analogies to the type of sapping envisioned for Nirgal Vallis.

D. Pieri (JPL) reported on the most recent application of ideas developed during his intensive study of Martian valleys. He found that Martian valley patterns are notable by the absence of dendritic patterns. Parallel and digitate networks predominate, suggesting restricted headward source regions. This combined with cliff-walled, theater-headed morphology, suggests formation by sapping and/or seepage fed runoff. He also believes that fluvial networks can evolve in time since junction angles depend on relative slopes of intersecting tributaries and relative slope depends on the individual stream longitudinal profiles. As longitudinal profiles evolve, so will network pattern. Factors which interfere with this process will show up as structural, lithologic, or topographic controls.

J. Laity (JPL) also has investigated ground water sapping in a terrestrial analog to the Martian valleys. Aerial photographs of tributary canyons to the Colorado River formed in the Navajo Sandstone in the Glen Canyon region show several key features directly analogous to some of the Martian small valleys. These features include theater terminations of first order tributaries, large scale similar network pattern, common structural control, a relatively constant valley width from headwall to mouth, frequent hanging valleys, and high and steep valley sidewalls. Field study shows many factors influence sapping on Earth including fortuitous lithologic, stratigraphic and structural interrelationships, and suggest that similar multiple factors would most likely operate on Mars to form the valleys.

H. Masursky (USGS) has, with A. Dial and M. Strobell, examined the age relationships of the Martian valleys and channels. He reported re-evaluation of these ages based on new Viking high resolution images. The new pictures show clear evidence in some channels of secondary modification by wind as well as landslides and debris flows. Other channels are relatively unmodified and the new pictures allow crater counts with more statistical significance. These counts show that the old lava flows of the intercrater plains are older than the oldest channels. The youngest lava flows of the Arsia and Olympus Mons summit calderas are younger than the youngest channels. The channels apparently were formed over a considerable period concommitant with several episodes of volcanic activity. The large channels head in areas of collapsed terrain due to collapse of ice-supported ground, possibly by melting due to volcanic heat. The intermediate sized channels and small channel networks start in "theatre-headed valleys" typically formed on Earth by sub-surface flow or spring sapping. Melt water from precipitation (snow and/or rain), may have fed these streams.

Data for the meandering geometry of terrestrial rivers have been reexamined by P. Komer (Oregon State University). These data serve as the basis for empirical relations between meander wave length and flow discharge. Such equations have been applied to an analysis of Nirgal Vallis, using measured "meander" wave length to infer a discharge on the order of that of the Mississippi River ($\sim$16,000 m^3/sec). But the question is whether these equations from Earth rivers can be applied to Martian channels where the gravity field is different. Dimensional analysis and instability analysis reveal the importance of gravity and indicate that any discharge estimate for Martian channels must be decreased by a factor $(372/981)^{1/4} = 0.78$. Due to the scatter of the terrestrial river data upon which the relationships are based, estimates of discharge from measured meander lengths are highly uncertain (for example, a discharge estimate for Nirgal Vallis could be as low as 6,000 m^3/sec or as high as 35,000 m^3/sec).

B. K. Lucchitta (USGS) discussed her study of grooves on the floors of Martian outflow channels. She believes she can rule out catastrophic flood, water, and wind as likely erosional agents for the grooves because of difficulties with size and shape, and proposes an origin by ice because of morphologic similarities with glacially fluted terrain on Earth. Grooves on Mars are much deeper than glacial flutes on Earth, perhaps due to multiple erosion by ice flows on Mars, but the widths of Martian grooves fall within the range of terrestrial glacial flute widths, suggesting that sculpturing by ice may have taken place. Craters on the channel floors with grooved ejecta blankets and pristine rims are common and difficult to explain by erosion with fluids that tend to become turbulent, but they could be explained by erosion with thin ice sheets that may mold poorly consolidated ejecta but not resistant crater rims. The origin of flutes on Earth is generally considered to be both erosional and depositional, as flutes occur in bedrock and in till. They also generally occur near the ice margin, where the gradient is low, the ice is thin, wet, fast, and loaded with debris. On Martian channel floors low gradients occur and thin ice sheets may have been present. The condition of wet, fast ice loaded with debris is approximated in ice-charged mudflows. It is envisioned that liquefaction mudflows emerged from the chaotic terrain, became charged with ice in their course downstream, and eventually consolidated into wet glacier-like masses that slowly crept through the channel floors and gave them some of the sculpture which is characteristic of terrestrial glacial terrain.

J. Boothroyd (University of Rhode Island) reported on landscape evolution on the Central Arctic Slope in Alaska, an outflow channel analog study undertaken with B. Timson. He presented five main conclusions:

1) The landscape was generated primarily by fluvial processes during Quaternary time.
2) Remnants consist of partially exhumed tertiary fluvial surfaces.
3) Remnant and valley generating fluvial processes are largely inactive at present; primary activity occurred during times of deglaciation when discharge was greatest.
4) There has been extensive secondary modification of valley floors by aeolian and cryogenic processes, and of remnant and terrace slopes by an interaction of cryogenic and debris-flow activity.

5) The Alaskan landscape compares well to a mapped Martian proximal outflow channel, a portion of Capri Chasma, in regard to:

a) lateral scale (but not vertical) or remnants and valleys,

b) multiple flow episodes with terraces,

c) secondary modification of valley and remnant walls and valley and terrace floors.

D. Prior (Louisiana State University) presented evidence on enormous terrestrial submarine landslides, and discussed how these features compared favorably, in scale, morphology, and pattern, to Martian outflow channels. Owing to the buoyancy of sediments in the submarine environment (due to inclusion of water in debris), these materials move as if under reduced gravitational acceleration, again, suggesting close analogy to Martian conditions for material transport and deposition.

Several questions on the formation and motion of lobate debris aprons in regions of fretted terrain in northern mid-latitudes on Mars have motivated a field program and modeling analysis by D. Thompson (JPL) of flow and debris transport by rock glaciers. He feels that it is important to understand 1) the amount of interstitial ice necessary to charge debris to allow it to flow over long distances as continuum, and 2) the changes in debris production rates necessary to allow sufficient transport as well as rejuvenation of scarps. The field program consists of monitoring motion on a 52 station strain net and changes in longitudinal profile on the surface of a 2 km long rock glacier in the Sierra Nevada. Velocity changes in the net allow calculation of surface strain rates, and this coupled with depth allows development of a flow and stress field throughout the rock glacier. Modeling analysis is done in terms of development of flow and stress fields for a rock glacier under compressing flow. The rock glacier is characterized by density and viscosity stratifications representative of basal ice, a surface debris layer, and a middle transition region. Variation of parameters such as density and viscosity distributions including explicit strain-rate dependent viscosity, layer thickness, and laminar to compressing flow regimes provides understanding of changes in flow and stress fields depending on percent ice content and of the growth of surface compression features.

P. Patton (Wesleyan University) presented work performed on hillslope modification and evolution of the Valles Marineris wall scarps. He noted five main conclusions:

1) Hillslope models derived for slope retreat on earth may be useful in providing constraints for the evolution of wall scarps in Valles Marineris.

2) In Valles Marineris, relatively smooth straight slopes in tributary troughs and along landslide headscarps indicate that there is little or no removal of slope debris at the slope base. These slopes may be rejuvenated only by head scarp slumping.

3) Conversely, spur and gully topography is strongly correlated with basal slope scarps. These basal fault scarps allow debris to drain from the slope system. Spur and gully topography can be traced though a sequential evolution that reflects structural processes.

4) Mapping and analysis of the morphometry of Valles Marineris wall scarps may provide insight into the structural history of the troughs.

5) Pressure release processes most easily explain the hillslope forms observed in these canyons.

J. Underwood (University of Kansas) discussed the initial results of his study of the Martian "mottled" plains. These poorly understood plains lying mostly between latitude 50°-70°N, are characterized in Mc-4 quadrangle by:

1) Distinctly textured, uneven surface.

2) High albedo ejecta blankets extending outward, on the average, 2-4 crater diameters.

3) Low albedo inter-crater areas.

4) Scattered but scarce knobs.

5) Polygonal fracture patterns.

6) Superposed aeolian grain, with wind streaks whose orientation changes dramatically.

7) Albedo boundary that does not, in most places, coincide with a topographic feature of boundary.

Two preliminary geologic maps have been made in the southeastern part of MC-4 where early Viking photo-mosaics were available. The recently available

1:2,000,000 photo mosaics (five sheets) covering all the MC-4 quadrangle should permit mapping the subdivisions of the mottled plains. When these photo-mosaics are available for the northern tier of quadrangles and the north polar quadrangles, a planet-wide geologic map may be made of the northern plains, including the mottled plains and subdivisions.

N. Evans (JPL) reported on her search for Martian patterned ground. Although patterned ground was found, most occurrences were seen in poor quality data--the data usually overlooked in computer sort procedures and often not mosaicked. There is an apparent absence of polygonal patterns in the southern hemisphere, perhaps reflecting chemical or compositional differences from the north.

L. Rossbacker (Princeton University) presented her preliminary analysis of energy in the Martian geomorphic system, work done with S. Judson (Princeton University). This paper presents the first attempt to make a quantitative assessment of the geomorphical energy budget on Mars. Solar radiation provides 99.98 percent of all the energy available at the Martian surface (2.175×10^{16}W). Most of this is expended in sensible heat; only a very small percentage of this contributes to geomorphic work, primarily aeolian activity. The average annual aeolian erosion rate is probably very low, on the order of 1 micron/year, because of the low atmospheric density and associated high threshold wind velocities. The geomorphic energy budget varies through time (for example, global dust storms may absorb more than 50 percent of the incoming solar radiation). The budget must have been far more complex earlier in the planet's history, with the presence of liquid water, internal differentiation, higher cratering rates, and volcanic activity.

PLANETARY IMPACT CRATERING

The session on impact cratering covered a variety of research topics which can be grouped into: (1) Terrestrial field and laboratory impact and explosion cratering studies; (2) Martian cratering, ejecta and crater age dating studies; (3) Tectonic effects on Mercury from the Caloris impact; and

(4) Lunar impact basin and cratering studies. Some of the reports treated new research efforts, especially the theoretical and laboratory studies, while others summarized ongoing programs.

In terrestrial field studies, D. J. Milton (USGS) described preliminary results from mapping at Goat Paddock, a 5.1 km diameter impact crater in western Australia. This young flat-floored crater, about 340 m deep, does not exhibit a central peak but it appears to be near the transition size from simple bowl-shaped to complex shape and structure for craters in sedimentary rocks. A rim fault suggests early terrace-like development. This well preserved impact crater should provide critical data for studies of the simple to complex transition range for impacts into layered sedimentary targets.

Field studies of selected large explosion craters were described by D. J. Roddy (USGS) as generalized impact analogs. The results emphasized the range of potential cratering effects on Mars and other planets as a function of different specific initial impact conditions. In particular, the formational processes of flat-floored explosion craters with central uplifts or with multiring structures is notably sensitive to charge yield (impact energy), charge configuration (shape of impacting body), height/depth of burst (impact energy coupling) and relative strengths of layered target media. Application of the explosion cratering data to impact conditions strongly suggests that the energy coupled by impacting bodies at or near the target surface are critical to the formation of central uplifts and multiring craters. The general implications of the explosion analog data are that low-density, low-strength impacting bodies are instrumental in forming flat-floored craters with central peaks or multirings. In addition, layered targets with fluid-like strength properties should greatly enhance central uplift and multiring structure. The complexity of these conditions, including the roles of impact energy, impacting body types, layers, material responses of both target and impacter, gravity and other initial cratering parameters, indicates that numerical code work is essential for studies of the formation of large impact features.

Laboratory simulations of central pit craters, performed to test the hypothesis that different crater morphologies on the Galilean satellites reflect differences in crustal structure, were described by Jon Fink (Arizona State University). The results of 64 impact cratering experiments performed at the NASA Ames Vertical Gun Facility suggest that central pit craters can form by a multitude of processes. Factors which seem to influence the pit morphology include volatile content of the target materials, impact velocity, and relative strengths of target layers; i.e., results similar to those reported by D. J. Roddy (USGS) from much larger explosion cratering experiments. J. Fink also suggested that volatiles exsolved during impact into multilayered targets may cause explosive venting through the crater floor to form a central pit. He suggested that scaling of the strength and thickness of layered target materials may be useful in estimating crustal thickness on Ganymede. Additional experiments are underway to quantify the qualitative models of pit formation.

Experimental studies by K. H. Wohletz and M. F. Sheridan (Arizona State University) support the hypothesis that water and ice within the surface layers of Mars interact with impact melt production during crater formation to alter ballistic ejection and to form rampart ejecta deposits. Their experiments with thermite melt and water mixture indicate that the water-melt ratio determines the degree of vapor, expansion and the size of melt fragmentation particles. The movement of quasi-fluidized vapor-rich ejection clouds follows a predictable path of viscous flow decreasing in energy and fluidization to form rampart ejecta morphologies under inertial flow (grain flow) regimes. Their experimental model offers an explanation for the ejecta morphologies observed on Mars for both rampart and pedestal impact craters.

The results from some recent hypervelocity impact experiments conducted at the Detonics Centre of the SNIA VISCOSA - Colleferro, Italy were discussed by Marcello Coradini. Experiments have been completed in the impact velocity range between 8 and 10 km/sec using shaped charges. An IMACON fast-image framing camera is being used to provide data up to 5 million frames per second. The formation and time evolution of the dense hot plasma formed by impact is studied and associated with magnetic changes in the target materials. In addition, the formation of the craters throughout their evolution is recorded which permits studies of crater morphologies as a function of changing velocity and mass of impacting projectiles, and the angular distribution, velocity and spectra of ejecta. The collisions of plasma jets formed by shaped charges are being studied as examples of various astrophysical conditions.

An interpretation of global patterns of primary crater ejecta morphology on Mars was summarized by K. Blasius (Planetary Science Institute) in a systematic survey over the entire surface of the planet. Their data base comprises 2196 craters, which have been classified from examination of 162 mosaics covering 49% of the surface area on Mars. Preliminary analysis of 1,457 craters is underway to verify computer interpretation of the large data base. The preliminary analysis corresponds, in part, with the results of L. A. Johansen (JPL) that indicate rampart-type crater ejecta is more common at low latitudes and that pedestal-type ejecta is more common at high latitudes. The results also confirm the findings of P.J. Mouginis-Mark (Brown University) that ejecta deposits are, on the average, broader at high latitudes for similar size craters.

Radar studies of 131 large impact craters (20 km to 500 km diameter) within a narrow subequatorial belt on Mars were described by L. A. Roth (JPL). Depths of these craters were determined with a varying degree of confidence. These measurements confirm the overall shallowness of martian craters. Interpretation of areas on Mars scanned by the Goldstone radar show that the low-albedo markings are associated with elevation differences, but the converse is not true. Doming of crater floors observed on the moon is absent, but considerable local relief is present, but not as prominent as in lunar craters of comparable size. On Mars, there appears to be a class of craters with notable tilt of the floors. He raised an important point in suggesting that the depths of large martian craters may be only a weak function of diameter, and suggests the depth/diameter curve may have another inflection point for the larger craters. He concluded, on the basis of the shallow depths of the large craters, that there has been substantially more modification of the martian craters as compared to their lunar counterparts.

Studies of large martian craters and basin deposits were summarized by B. Hawke, (University of Hawaii) in terms of the distributions, nature, origins, and modes of emplacement of interior and exterior crater deposits in the diameter range of 50 to 250 km. In particular, the basins, Lyot and Lowell (∿200 km across) and the craters Curie (∿119 km across) and Bamberg (∿55 km across) were compared in detail. He pointed out that in craters larger than 15 km diameter, there is an increasing variation of interior morphology. Larger crater sizes exhibit a wide variety of well-developed exterior features, such as secondary crater fields and flow-type ejecta morphology. The basin studies indicate that ballistic ejecta emplacement is important at these largest sizes, but radial surface flow has played an equally important role in final emplacement of martian basin continuous ejecta deposits.

The latitudinal distributions of martian craters with different flow-ejecta morphologies were re-examined by R. Sanders and L. A. Johansen (JPL). Their data included size, ejecta types, and latitude of craters on a single terrain type: the ridged plains. The ridged plains were selected because they occur over a wide range of latitudes and appear to have similar rheological characteristics. Their preliminary conclusions, based on 371 craters, indicate that distal-ridge craters are more common at 20°S than 60°S but tend to be larger at 60°S (greater than 20 km diameter) than at 20°S (less than 10 km across). Mound craters are far more prevalent at 60°S than at 20°S and most are less than 10 km across in both areas. Their interpretation of this data is that the abundance and nature of subsurface volatiles, i.e., water, controls the ejecta morphology. The equatorial regions contain less water in the subsurface and craters tend to have distal-ridge morphology. Nearer the poles, more water is present, most likely as ice, and mound-type ejecta is prevalent.

The relative ages of aureole materials on Olympus Mons were discussed by K. Hiller (Institut fur Allgemeine und Angewandte Geologie, Ludwig-Maximilians-Universitat, Munchen, FRG) in terms of new data derived from standard crater counting techniques. The statistics include crater counts from the surrounding plains, Olympus Mons shield, and its caldera floor. The aureole material is interpreted as a series of landslides originating mostly from the main scarp of the shield. Previous crater counts gave Olympus Mons an age of between 3.0×10^9 and 0.5×10^9 yrs, i.e. an old feature on the order of the age of the northern plains lavas. Their current results bracket the age of the aureole material as between 3.2×10^9 and 0.5 to 1.5×10^9 yrs (more likely near the latter). Interaureole materials show crater counts of 200-300, the flows making up the surface of the shield show 100-200, and the caldera floor about 100. Crater counts on the plateau ridge tops indicate major crater destruction on the aureole surface terminated about 0.5 to 1.5×10^9 yrs ago, corresponding to the peak in activity on Olympus Mons. Erosion, however, continued until about 0.2×10^9 yrs ago in the inter-ridge regions, ending about the time of the youngest lava extrusion in the summit caldera. It is possible that the erosion of aureole craters is related to periods of volcanic activity, perhaps caused by seismicity effects on poorly consolidated material on steep slopes in the aureole.

Studies of the Caloris impact on Mercury, presented by Phillippe Masson (Universite Paris-Sud, France) suggest that this major impact event strongly influenced the structural evolution of the planet. The presence of numerous extensional tectonic structures, i.e. fractures in the Caloris basin internal plains, suggests that lack of mass inside the basin caused an isostatic readjustment which produced a wide terrain bulge surrounded by a topographic low. This is consistent with the general interpretation of thin elastic plate deformation within an elastic lithosphere about 150 km thick. The Mariner 10 images also show a global pattern of lobate scarps that are interpreted as thrust faults, or reversal faults, which resulted from global contraction of the planet. Mapping of the scarps shows a global constriction parallel to a submeridian great circle, and the Caloris basin is nearly perpendicular to the center of this constriction circle. Masson interpreted this to indicate that after the Caloris impact, isostatic adjustment produced an elongation of the planet between Caloris and its antipode, and a resulting constricture occurred perpendicular to this elongation. This global impact effect, combined with planet cooling, would appear to explain the statistical prevalence of many structural directions on Mercury.

The evolution of multiringed basins on the planets was discussed by S. Solomon (Massassachutts Institute of Technology) in terms of theoretical calculations of cooling, thermal stress, and topographic relaxation. He noted that several major endogenic processes appear to have affected the multiring basins, including, (a) viscoelastic relaxation of topographic relief (10^4-10^7 yr time-scale), (b) cooling of the initial heat of the basin formation (0-10^8 plus yr time-scale), and (c) volcanic filling and associated subsidence and tectonics (<10^8-10^9 yr time-scale). Comparisons of topographic profiles for young (Orientale) and older (Tranquillitatis) lunar basins indicate that visoelastic relaxation of the topographically-produced stresses may have been an important contributor to the degradation of the topographic relief and to the poor preservation of ring structures. This would be most important for basins formed when shallow lunar temperatures were high and the lithosphere was thin. Solomon also modeled the loss of initial basin-related heat to test the predicted topographic subsidence and thermal stresses against the observed topography and tectonic features in comparatively unfilled basins. The initial heat includes both uplift of planet isotherm and impact-generated heat. The results of the calculations indicate that (a) thermal contraction during cooling leads to subsidence of up to several kilometers and compressive thermal stresses of up to a few kilobars, and (b) the cooling and associated strain and stress continue to be important for times in excess of 10^8 yrs. From (a) he concluded that basin-cooling had a substantial effect on the topography and tectonic features now seen in the large basins. From (b) he concluded that continued thermal subsidence and stress acted in concert with effects of loading by mare basalt to produce the observed faulting and topography.

A new technique to identify buried surfaces of major geologic units was derived by D. Scott and K. Tanaka (USGS). They note that major lava flow units in the Tharsis region are relatively thin but quite numerous and extensive. These areas are generally continuous without long time intervals between eruptive episodes. In many locations, impact craters on a buried surface project through younger flows that overlie them. The identification of buried units can be facilitated by using the frequency distribution of partly buried craters. This technique is especially useful in the Tharsis region where the stratigraphic succession of major flow units has been established by detailed mapping. The method has been successfully applied to aid in the delineation of buried geologic units and to construct a series of paleostratigraphic maps showing the sequence of major eruptive events for the Tharsis region.

A lunar study of apparent crater depths and selenographic distributions was summarized by R. DeHon (Northeast Louisiana University). The diameter/depth relationships of complex craters (>15 km) is much more varied than for simple craters. The data indicate that apparent crater depths (measured from the surrounding surface) exhibit variations which appear to be controlled by location on the lunar surface, i.e., by the surface rock type with little relationship to crater diameter. The mean apparent depth of craters, 10 to 20 km diameter, is $\sim$1.4 km and the highlands crater mean depth is $\sim$2.2 km. Regions of shallow apparent depths (<1.5 km) generally correspond to mare basins. Regions of large depths (>2.5 km) occur in topographically high regions, such as basin rims and highland terrains. These results tend to support a model of complex crater formation in which excavation is controlled by mechanical (rheological) properties of the target rocks and the thickness of the regolith. The type, distribution and number of impact craters is large enough to excavate through the base of the regolith and provide reasonable estimates of the regional thickness and lateral variations of the regolith at many locations. His contour map shows the regolith thickness varying from 1 km to 3 km with low apparent crater depths in the basins and low-relief terrain, and greater apparent crater depths in the highlands and basin rims.

PLANETARY REMOTE SENSING

Viking Lander images have documented changes in the atmospheric opacity by a factor of 2-3 over the Martian year, the presence of ground fogs at both landing sites, and evidence of a high condensate cloud at the Viking 2 site. Changes in surface detail, other than the deposition and sublimation of frost at the Lander 2 site, have been reported as very minor by S. Wall and

L. Cullen (JPL). Lander 1 is still functioning well and transmitting imaging, meteorology, and engineering data. This Lander is approaching its third northern hemisphere winter (K. Jones, JPL).

R. Terrile (JPL) and A. Cook (SAO) reported on their continuing search for evidence of sulfur dioxide condensation on the night side of Io, using Voyager 2 images of the satellite in which the dark side is faintly illuminated by Jupiter-shine. If concentrations of SO_2 gas from volcanic effluents are high enough (locally 10^{-7} to 10^{-6} bar), then condensation of SO_2 frosts should occur during night cycles. Such frosts would be observed as higher night side surface albedos. In general, large scale day-night albedo variations are not observed but local contrast decreases of about 25 percent occur during the night cycle. This contrast decrease is being investigated in terms of a calibration problem due to scattered light or possibly a real surface phenomenon near plume sources where SO_2 gas concentrations are expected to be higher.

B. Hapke and B. Rava (University of Pittsburgh) have produced color ratio maps of Mercury using orange/ultraviolet image pairs obtained by Mariner 10. Some of the color units are associated with the planet-wide system of scarps, but normally the color units do not exhibit evidence of geologic control. Hapke and Rava suggest that the smooth plains are not volcanics similar to the lunar maria. They believe that the lack of maria on Mercury is consistent with a crust and mantle low in FeO and in radioactive potassium.

Earth-based radar observations of Mars continue to provide valuable measurements of local altitude, surface roughness (rms) slope and reflectance (dielectric constant). S. Zisk (Haystack Observatory) and P. J. Mouginis-Mark (Brown University) argued that various terrain units on Mars can be identified by their distinct radar signatures. They believe that lava plains, cratered terrain and canyon regions show distinct hypsometric properties and that, in general, cluster diagrams of the different radar parameters can be used to separate distinct terrain types.

D. U. Wise (University of Massachusetts) reported on a series of experiments designed to test the reproducibility of lineament detection in radar images. The same area of Ohio covered by two distinct illumination directions of the SEASAT radar was analyzed for lineaments by six different individuals. For each image, the dominant observed lineaments were approximately 30° on either side of the illumination azimuth, but there was little correlation between the lineaments seen in the two different images of this same area. A similar experiment was run using a raised relief map of Iceland illuminated successively at 18 distinct azimuths. The results show that the observers tend to suppress real lineaments parallel to the illumination azimuth and exaggerate those about 30° from it.

PLANETARY CARTOGRAPHY

Planimetric mapping of the Galilean satellites of Jupiter (Io, Europa, Ganymede and Callisto) and four satellites of Saturn (Tethys, Dione, Rhea and Mimos) are in progress. A total of about 40 maps of these satellites is planned in two or more versions each, according to R. Batson (USGS). Mapping priorities were established on the basis of scientific interest to support geologic mapping and on data availability. Cartographic image processing includes cleanup of EDR and artifact removal (level 1), geometric and photometric correction (level 2), and mosaicking (level 3). Airbrush maps, based on level 3 processing, will be made showing relief and albedo markings (version 1) and relief only (version 2). Level 1 processing is completed for the Galilean satellites and level 2 is in progress. Level 1 processing is underway for the Saturnian satellites.

The status of VOIR photogrammetry, a research and development program for techniques to extract three-dimensional topographic information of terrain features of Venus from VOIR type stereo-radar images, was described by S. S. Wu (USGS). Solution of this complicated radar mapping problem is being approached with two processes; off-line and on-line. The off-line approach is to computer-rectify side-looking radar images from their line-scan geometry to an equivalent of point-perspective projection so that present available analytical plotters can be used for map compilation. The off-line approach has progressed to setting up stereo-models of side-looking radar images of relatively flat terrains on an analytical plotter, and compiling planimetric maps and contour lines. The layover problem in terrains of moderate to high relief has not been solved.

The on-line approach in VOIR photogrammetry is to interface a high speed digital computer to the existing radar stereoplotter so that all computations for geometric corrections can be performed in real time during map compilation. The hardware to interface a Modcomp computer to the radar stereoplotter is almost completed. The computer programs to operate the system are being developed.

Paleogeologic maps of the far side of the Moon were presented by D. E. Wilhelms (USGS). The three paleogeologic maps, entitled Pre-Nectorian, Nectorian and Lower Imbrian, were prepared as part of a larger effort to summarize lunar geologic history. The maps show the major geologic units formed on the Moon's far side during the first 0.7 aeon of its history. Each map portrays only features formed during the mapped time interval; terranes older are shown by subdued air-brush rendition of the base map while younger terranes are left blank. Crater $\geq$ 30 km are mapped and all known or suspected basins are included. The dominance of basins and craters in these early scenes is clearly evident and little area remains that could be extensively inundated by volcanic materials. Interaction with the lunar sample analysts must be maintained in support of efforts to determine the provenance of the terra samples and absolute ages of the source basins and craters.

The geodetic control networks of the Galilean satellites are being computed by M. Davies (Rand Corporation) using pictures from Voyager 1 and 2 encounters at Jupiter. Points have been identifed on the satellites and their coordinates computed by single block analytical triangulations. The systems of longitude on Europa, Ganymede, and Callisto are now defined by small craters. On Io, the IAU (1975) definition of longitude is still in use since it is doubtful that a small permanent feature can be found which will still be identifiable on future missions, considering the high rate of volcanism. The control net computations are used to measure the mean radii of the satellites, which give at this time--Io, 1815 $\pm$ 5 km; Europa, 1569 $\pm$ 5 km; Ganymede, 2631 $\pm$ 10 km; and Callisto, 2400 $\pm$ 10 km.

SPECIAL PROGRAMS

Gerhart Neukum (Geological Institute at the University of Munich, FRG) described their evolving capability for processing and evaluation of multispectral images. The basic hardware for image processing has been acquired; software suitable for processing of Viking, Voyager and future Galileo imagery is being developed in conjunction with the state at the U. S. Geological Survey at Flagstaff and two German institutions, the German Aeronautics and Space Research Institute, and the Institute for Photogrammetry and Remote Sensing. Viking images are currently being processed in an effort to map specific geologic surface units.

Jack King (State University of New York at Buffalo) reported that the Planetary Geology Undergraduate Research Program has completed another successful year. This program was initiated as a follow-up to the Viking Intern Program. Student participants in the program are chosen from among the highest ranking applicants based on demonstrated scholastic ability, motivation, referee's recommendations and their areas of competence. Every effort is made to insure that the students participate in a meaningful way in the research projects of the chosen host. Both hosts and students prepare summary reports at the conclusion of assignments. The program is clearly fulfilling its objective of bringing highly competent young students into early contact with current research in planetary geology.

Responsibility for naming planetary surface features and newly discovered smaller satellites in the solar system rests with the International Astronomical Union. The IAU's Task Group on Outer Solar System Nomenclature currently consists of Merton Davies, Harold Masursky, Tobias Owen and Bradford Smith from the U. S. in addition to three scientists from the USSR, and one each from France and Norway. Tobias Owen (State University of New York at Stony Brook) reviewed the major tasks of this group during the past year which included the selection of names for surface features on the larger satellites of Jupiter, the development of suitable sources of names for features on

Saturn's satellites, and the establishment of guidelines for naming new satellites in the outer solar system. Myths and legends from around the world have been chosen as the basic source material for names of satellite surface features. New satellites should be named consistently with the established historical tradition for each planetary system wherever possible. The actual assignment of names to features on Saturn's satellites is just getting under way and will continue through 1982.

Robert Vostreys explained the functioning, organization and services to the scientific community of the National Space Science Data Center/World Data Center A for Rockets and Satellites (NSSDC). The center now holds more than 800 planetary data sets ranging from the early Apollos to the Voyager Jupiter encounter data. The extent of NSSDC's service to the science community is demonstrated by the fact that the center processed 600 requests for data during the past year.

Nancy Evans (JPL) reported that the Viking 1 Orbiter had successfully completed two surveys of higher resolution mapping images. Survey I, conducted in mid-fall 1979, obtained images of the northern reaches of Arabia. The slant range during the survey mission varied between 1600 and 2500 km. Most of the images have been processed in the shading-corrected, rectilinear version. Survey II, conducted in the summer of 1980, included four basic blocks of coverages: Al Quahira, Ma'adim, Memnoia and Mangala. Slant range during this survey varied between 100 and 2500 km. Unfortunately, at the time of this writing, only parts of the Survey II images have been processed.

Victor Baker (University of Texas) and Dag Nummedal (Louisiana State University) reported that the second Mars channel workshop was conducted at Flagstaff, Arizona in the fall of 1980. Although many aspects of the Martian channels instill disagreements, and sometimes heated arguments, at least one major consensus was reached: groundwater-groundice played a significant role in the evolution of the Martian landscape in general, and the channels in particular. A major summary paper, presenting the arguments for a channel origin through the release of water and sediment from the subsurface, is presently being prepared.

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15. Supplementary Notes

16. Abstract

Recent developments in planetology research as reported at the 1981 NASA Planetary Geology Principal Investigators meeting are summarized. Important developments are summarized in topics ranging from solar system evolution and comparative planetology to geologic processes active on other planetary bodies.

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