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Significant Achievements in the Planetary Geology Program, 1981

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Significant Achievements in the Planetary Geology Program, 1981

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TABLE OF CONTENTS

Introduction	v
Saturnian Satellites	1
Asteroids, Comets and Galilean Satellites	5
Cratering Processes and Landform Development	11
Volcanic Processes and Landforms	18
Aeolian Processes and Landforms	22
Fluvial, Periglacial and Other Processes of Landform Development	25
Mars Polar Deposits, Volatile and Climate Change	34
Structure and Tectonics	38
Remote Sensing and Regolith Chemistry	43
Cartography, Geodesy and Geologic Mapping	51
Special Programs	56

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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), Mars Data Analysis Program (MDAP) and Jupiter Data Analysis Program (JDAP) Geology Principal Investigators. The summaries in this document are based on presentations at the thirteenth PGPI meeting held at the Jet Propulsion Laboratory, January 12-14, 1982 and are a digest of the 1982 meeting abstract document (Reports of the Planetary Geology Program-1981, NASA TM-84211). Important developments are summarized under the broad headings listed in the Table of Contents.

The accomplishments of any science program are a reflection on 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 space. They represent a group of people dedicated to advancing the frontiers of geology beyond the usual confines of planet Earth.

This document is based upon summaries prepared by session chairpersons at the annual meetings. These contributing authors are listed below.

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Saturnian Satellites

J. B. Pollack discussed some implications of the Voyager 1 and 2 results for models of the history and evolution of the Saturn system. The likely carbonaceous composition of Phoebe (deduced from its very low albedo) is consistent with other indications that this outer satellite is a captured object. Pollack suggests that the capture could have occurred by gas drag friction, in the early proto-Saturn nebula, just prior to the hydrodynamical collapse phase. The fact that not only the large satellites but probably even the ring particles are made chiefly of water ice suggests that Saturn's nebula was cooler than that of Jupiter, permitting the condensation of water at all locations. This deduction is consistent with Saturn having about 1/3 the mass of Jupiter and hence, only 1/10 the luminosity during the early portion of the late hydrostatic phase. Voyager observations show that the He/H₂ ratio in Saturn's observable atmosphere is about 1/2 that in Jupiter's, consistent with the suggestion that the metallic hydrogen region of Saturn's interior was cool enough for helium to become partially immiscible and sink towards the planet's center. The gravitational energy released by this separation could account for a significant fraction of the excess energy radiated by Saturn today.

J. B. Plescia and J. M. Boyce presented the results of their study of crater densities on the satellites of Saturn. Rhea was found to be heavily, but not uniformly cratered. Areas of the north polar region have been affected by a process which appears to have effaced large (50 km) craters. Certain equatorial regions appear to have been mantled judging from the subdued relief of large craters and the absence of small ones. In general, Mimas is as heavily cratered as Rhea, but again the density of cratering is non-uniform. Craters larger than 30 km are lacking from the south polar

region, suggesting resurfacing. There is evidence of a progressive decrease in the effectiveness of this resurfacing as one moves away from the polar area. The hemisphere of Tethys viewed by Voyager 1 showed a very heavily cratered surface. The other half of Tethys imaged by Voyager 2 showed slightly lower, but still very high crater densities. At least two episodes of resurfacing can be identified from the crater data, both of which occurred prior to 3-4 billion years ago. Iapetus' bright hemisphere was found to be uniformly and heavily cratered, indicating an age of at least 4 billion years. No crater statistics for the dark hemisphere are available. Dione exhibits the largest range of crater densities of any satellite in this study. Voyager images show units ranging from heavily cratered ancient terrains, to smooth, lightly cratered plains. This satellite has evidently undergone considerable evolution since the end of its formation stage. Enceladus is definitely the most evolved of the satellites studied. The most heavily cratered areas have crater densities comparable to those on the lightly cratered plains of Dione. Other units have significantly fewer craters, and some appear to have none. The oldest areas on Enceladus are about three billion years old; the age of the youngest is 0-1 billion years. Two types of tectonic features have been observed on Enceladus: linear fractures implying tension, and ridges implying compression. The first could have been produced during periods of expansion caused by tidal heating; the second, could have formed between periods of tidal heating, when cooling and contraction would have occurred.

G. Schubert and K. Ellsworth summarized their studies of the thermal evolution of Saturn's icy satellites. The model includes accretional and radiogenic heating, conductive and convective heat transfer, and lithospheric growth. The key issue is whether the internal thermal states predicted by the model calculations are consistent with the contrasting appearances of the surfaces of

the icy satellites. Convection was found to be important in the evolution of all four satellites studied in detail (Mimas, Tethys, Dione and Rhea). Independent of T_e (the ambient temperature during formation) Mimas and Tethys end up as cold, conductive bodies with maximum internal temperatures of about 100 K. Convection lasts no more than 100 myrs. in Mimas, and 1400 myrs. in Tethys for reasonable assumed values of T_e . Schubert and Ellsworth conclude from their models that subsolidus convection in Mimas and Tethys, if it occurred at all, was transitory and restricted to the earliest stages of the satellites' histories. On the other hand, the calculations suggest that Dione and Rhea started convecting within a few hundred million years of their formation and continue to do so today. According to the model, Dione today has a lithosphere some 270 km thick and an interior temperature of about 195 K. Rhea has a lithosphere some 225 km thick and an interior temperature of 200 K. An important implication of this work is that according to the model, radiogenic and accretional heating alone were insufficient to differentiate Mimas, Tethys, Dione or Rhea, and all four bodies should have essentially homogeneous interiors.

Veverka and co-workers reported on their analysis of the photometric data on Saturn's small satellites obtained by Voyagers 1 and 2. The observations are limited but in most cases sufficient to derive accurate values of the surface reflectance, r . The two F-Ring Shepherds have similar reflectances: 0.52 for the Inner F, and 0.60 for the Outer F. Comparable values are found for two of the "Trojans": 0.58 for the Tethys Leading Trojan, and 0.56 for the Dione (Leading) Trojan. The Tethys Trailing Trojan is significantly brighter with $r=0.85$. The reflectances of the co-orbital satellites are closely similar, but lower than any of the above values: 0.46 and 0.42 for the Leading and Trailing Co-Orbitals, respectively. The range in reflectance (from 0.42 to 0.85) as well as the very limited color data, are consis-

tent with icy surfaces with small, but variable admixtures of a dark material. For a material as dark as the surface of Phoebe ($r=0.04$) admixtures in the range of 0.1-5% are sufficient to explain the range of observed reflectances. All of these satellites have higher reflectances than Hyperion ($r=0.30$), a satellite known from Earth-based observations to have some water-ice on its surface. Combining these values of the reflectances with sizes derived from the Voyager images, the opposition magnitudes of the small icy satellites are found to range from +14.8 (Leading Co-Orbital) to +19.1 (Tethys Leading Trojan).

Asteroids, Comets and the Galilean Satellites

The evolution of small planetary bodies was studied by Davis and co-workers (Planetary Science Institute, Tucson). They considered a two-component collision model in order to allow for the likely differences in material properties associated with the C- and S-type asteroids (and possibly the inner moons of Saturn). The evolution of two mutually interacting populations having different material properties was traced for the situation where all the bodies were in orbit around a central body. Results from this simulation included predictions for the evolving asteroid size- and orbit-distributions, the frequency of catastrophic disruptions and cratering events.

A second computer simulation was also presented, this time by Fred Whipple (Smithsonian Astrophysical Observatory), on the life history of typical comets. Whipple discussed his model, with particular attention given to the consequences of wasting by sublimation on the nuclei of comets:

The evolution of the satellites of Jupiter formed the major subject of this session, however. Reynolds and coworkers (all from NASA Ames) discussed some of their recent calculations on the internal evolution of these bodies. From a consideration of the density of Ganymede, Callisto and Titan, it appears that a large mass fraction of H_2O is almost certainly present in each body. Reynolds calculated the effects that phase boundaries would have on the internal structure of the satellites for two different models of internal heat flow. Model A was based upon heat flow ($H = 3.34 \times 10^{18}$ ergs) from a core having the present day radiogenic element abundances of carbonaceous chondrites (i.e., the present day configuration). Model B had a higher heat flow ($H = 3.9 \times 10^{19}$ ergs), corresponding to an earlier time when an initially molten region in the interior had just frozen.

These models of internal heat flux were used by Reynolds to calculate the values for the conductive thermal gradients at the phase transition boundary. It was found that the thickness of the interior's convecting layer was primarily responsible for affecting the system's stability. Calculations indicate that the ice I-II, III-V, V-VI and VI-VII transitions permitted solid state convection through the phase boundaries for a wide range of superadiabatic temperature gradients. Transitions I-III, II-V and V-VI also appeared to be unstable to convection for large temperature gradients and the associated high heat flow. It was concluded by the Ames group that an initially hot icy satellite with a large outer layer of ice could have experienced convection throughout most of its mantle, and this situation may have continued until the present day.

The problem of the cratering record within the Solar System, and the information which can be gleaned from the icy satellites, was considered by Strom and Woronow (University of Arizona). From the distribution of small craters on Callisto, it was proposed that crater obliteration by viscous relaxation was not an important process on this satellite. Evidence was also presented by these workers that at least four, and most likely five, different families of objects were responsible for the crater records preserved on all of the observed bodies in the Solar System. By comparing the populations of craters on the heavily cratered terrains of Mercury, moon and Mars with those populations for the satellites of Jupiter and Saturn, a diverse set of cratering bodies was hypothesized. In particular, Strom and Woronow feel that not all of the required families of impacting bodies could have arisen from a common set of physical conditions.

New crater density measurements for Ganymede were also presented by Plescia (Jet Propulsion Lab). He showed that the originally proposed asymmetry in crater

densities between the leading and trailing hemispheres of Ganymede is much weaker than previously thought, and it appears to be overshadowed by true age and crater retention differences. Most of the variation in the density of large craters on the dark heavily cratered terrain are interpreted by Plescia to be due to differential relaxation rates, perhaps as a consequence of spatial variations in heat flow. Conversely, the grooved terrain has crater density variations which appear to result from differences in age rather than crater relaxation rates. Interestingly, the pattern of crater density presented by Plescia also indicates a latitudinal control on the age of the grooved terrain: examples of young and old grooved terrain are found at the equator, while only heavily cratered, old grooved terrain is observed at the poles.

Several investigators explored the possible mode(s) of formation of grooved terrains on Ganymede. Fink and Greeley (Arizona State University) proposed that these features formed through extensional instability within the crust, and that the spacing of the grooves gave crustal thicknesses in the range 2 - 10 km. Golombek and Allison (University of Massachusetts) attempted to deduce the sequence of brittle deformation preserved in portions of the grooved terrain. A three-stage process was outlined and found to be applicable to most of the groove systems which they studied. Primary grooves (~1000 km long) were thought to be the first to form and acted as domain boundaries for subsequent fractures. Secondary grooves (100's of km long) were next to form, followed finally by short (10's km) tertiary grooves which now make up most of the surface area of the completely grooved terrain. A more general review of the geophysical evolution of Ganymede and Callisto was also presented by McKinnon (University of Arizona).

Buratti and Veverka (Cornell University) are investigating the photometric

properties of Europa's surface using Voyager images covering phase angles 3° to 109° . They have already found excellent agreement between the spacecraft measurements and Earth-based observations. Between $3-22^\circ$, however, the phase coefficient decreases markedly with increasing wavelength. It was observed that a lunar photometric function definitely does not fit the scattering properties of Europa's surface; for example, near opposition, definite limb darkening was observed.

Meiner (University of Houston) is developing a technique which uses a ternary diagram to display the relative spectral content of the Voyager images of Europa which were acquired in three colors. A direct correlation between color distribution and geomorphology was made for certain areas of Europa using this technique. Further work is also planned, and Meiner plans to incorporate the dispersion of each color distribution field (and other parameters) into his subsequent analyses.

Considerable progress is evidently being made in understanding the unusual rheological properties of the sulphur lava flows on Io. Using the color and morphology of flows from Ra Patera, Pieri (Jet Propulsion Laboratory) and coworkers have deduced that the observed changes of the flow down its length are consistent with predominately sulphur lavas losing most of their heat by radiation. An eruption temperature of about 525 K for one of the flows was inferred, although multiple cooler eruptions (400 K) from Ra Patera also appear to have occurred. Pieri and coworkers have also calculated that the resurfacing rates on Io due to volcanic flows are much larger than for explosive eruptions: burial of the surface to a depth of 1 km would evidently be achieved by lava flows in only about 10^5 years. Experiments are also in progress at JPL to measure the thermal spectral dependence of liquid and quenched sulphur (under vacuum), as well as the observation of hot sulphur flows on a cryogenic bed under vacuum.

Fink and Greeley (Arizona State University) also analyzed the cooling of liquid sulphur flows due to both radiation and conduction. Their calculations for thin sulphur flows show that cooling is dominated by downward conduction. It therefore appears that laboratory models at least a few centimeters thick are necessary to adequately simulate sulphur flows on Io.

Two types of volcanic plumes on Io were described by Crumpler and Strom (University of Arizona). Some of the plumes are evidently associated with fractured and uplifted terrains which possess central rift-like graben, while other plumes appear to originate at the rims of caldera. Complex structures on the floors of some of the calderas were also recognized by mapping from some of the highest resolution Voyager images. Using these observations, thermal models of molten silicate-powered sulphur volcanism were proposed; vaporized sulphur plumes may be driven by simple silicate-sulphur thermal interactions, possibly for months or years which is consistent with the observed lifetimes of the plumes observed by Voyager.

Terrile (Jet Propulsion Laboratory) and coworkers have studied both short (several hours) and long (four months) time variations in volcanic activity on Io. These variations include changes in the shapes of active plumes, differences in the deposits associated with the plumes, and differences in the caldera and scarp deposits. Between the two Voyager encounters, the plume Pele (19°S, 257°W) had turned off, leaving a modified area about $9 \times 10^5 \text{ km}^2$ in extent. A new eruption site, measuring about 1000 km in diameter, appeared between the two encounters in the area north of Loki at Surt (45°N, 335°W). Short-term changes were also reported for the brightnesses of some caldera floors. It appears that these brightness changes were not due to phase function variations, suggesting that the probable cause of this contrast change was the introduction of gas or other material over the area.

Pilcher (University of Hawaii) has identified a narrow plasma source region in the Io torus using S^+ images. This source region is about $0.2 R_J$ in radial extent and is centered at $5.6-5.7 R_J$ from Jupiter (i.e., it's just inside the orbit of Io). Brightnesses of this feature were discovered to vary significantly on a time scale of days. Currently, two models are being explored by Pilcher to identify the possible mode of formation of this material: 1) Direct ejection of sodium from Io's surface; and 2) collisional sweeping of atmospheric and extended cloud sodium by the corotating heavy ion plasma.

Cratering Processes and Landform Development

Numerous interesting reports were presented this year and, while they treated a wide variety of processes and mechanisms, most concentrated on one of two specific impact landforms: basins and rampart craters. Although the term "rampart crater" normally evokes images of martian craters surrounded by ejecta that appears once to have been fluid (or "fluidized"), V. Horner and R. Greeley (Arizona State University) have studied a number of craters on Gany- mede that appear to possess ejecta deposits more than slightly reminiscent of those on Mars. They find that the extent of the observed ganymedian ejecta deposits are independent of latitude (unlike some of those on Mars) and longi- tude, but there might be a correlation between terrain type and areal extent- of the deposits relative to the area of the crater itself. Because the rela- tive freshness of the rampart craters precludes an origin by erosion or vis- cous relaxation of the target ice, the investigators suggest that liquid water might play a role in causing the relatively low energy ejecta (i.e., that em- placed near the rim) to flow after its deposition. In comparing these craters to their martian counterparts, Horner and Greeley propose that the differences in extent of these ejecta deposits result from the interplanetary differences in surface gravity, temperature, and target characteristics.

An aspect of the role of water in causing ejecta flow on Mars has been examined by A. Woronow (University of Arizona). His model of the formation of flow lobes around the craters is found to explain the following observations: (1) Flow-like ejecta deposits surround craters on all terrain types and a wide range of altitudes, indicating that the existence of these features is insen- sitive to target properties and atmospheric pressure; (2) the lobe material either ponds behind or is deflected by obstacles, implying a ground-hugging flow; (3) flow lobes closer to the crater rim have no vible effect on lobes

farther from the rim (when they occur); and (4) the area covered by these deposits is proportional to the crater diameter to the 1.5 power, which is consistent with the ejecta thickness at the crater rim being independent of the crater's size. Thus, Woronow models the generation of these ejecta deposits as the collapse of ballistically emplaced water- and clay-rich ejecta after it attains a thickness sufficient to overcome its shear strength. If deposition were to continue close to the rim after such a flow event, another slide would occur upon attainment of the same failure criteria, but because subsequent slides would travel over more nearly level terrain caused by the previous flow(s), their runout distances would be correspondingly shorter. For a 6 km crater - the smallest ones which exhibit flow features on a regular basis - the calculated shear strength is < 500 kPa ($1 \text{ kPa} = 10^{-2}$ bar) with a maximum angle of internal friction of 26 to 36 degrees. Using terrestrial clays as analogs, a range of 13 to 42 weight percent of water is implied by these values.

K. Blasius (Planetary Science Institute, Pasadena) and co-workers have garnered data for over 3000 martian fresh craters larger than 11.9 km, dispersed over 70% of the planet's surface. The data base includes information on ejecta and interior morphology, ejecta morphometry, and terrain characteristics. With these data, the investigators have performed a statistical study of craters with three different ejecta morphologies: (a) double concentric deposits, the inner with marginal scarp(s) and a marginal ridge, (b) single deposits (either simple or multilobate) with marginal ridge(s), and (c) single deposits (again, either simple or multilobate in plan) with marginal scarp(s). They find that all three types exhibit a definite latitude dependence, with some modulation by the different terrains on which they occur. They conclude that the latitude dependence is an effect of varying volatile stratigraphy with distance from the equator, while the terrain contributions

result from surface roughness and overall target stratigraphy.

Blasius et al. have also used this data compilation to examine the distribution of the radii of these three crater types as a function of latitude and terrain. Their results indicate that the double deposit craters ("a" above) are generally larger than those with single deposits and, for the large part, increase in size toward the equator. The radii of single deposit craters with ridges ("b" above) show much less latitude dependence than either the double deposit craters or those with single deposits and scarps ("c" above). Once again, the observed trends are influenced by the target terrain. These workers suggest that the different morphologies of ejecta are due at least in part to target layering, and that the different strata influencing the final ejecta morphologies are located at varying depths, again depending on the latitude and terrain type.

L. Johansen (Jet Propulsion Laboratory) has continued her statistical analyses of martian crater morphology. Study of the central peaks and ejecta of almost 1900 craters between the diameters of 700 m and 100 km yields a number of observations. Central peaks are found in smaller craters closer to the equator than near the poles. There is also a correlation between the existence of central peaks and ejecta deposits with raised distal edges, but this does not exclude other craters from possessing central peaks. When the abundance of craters with sloping terminations to their ejecta deposits is plotted versus latitude, a trend very similar to that proposed for the thickness of subsurface ice emerges. In particular, they begin to appear in significant numbers at 40°N, and increase emphatically toward the pole. Both central peaks and the sizes of craters with specific ejecta morphologies exhibit regional differences. Johansen suggests that such observations might be used to constrain surface and subsurface material properties.

Previous statistical studies of martian crater ejecta have been examined in a collective sense by V. Horner and R. Greeley. Because each individual investigation had different classification criteria, the results and interpretations of these earlier analyses have often been somewhat different. Horner and Greeley show that a correlation exists between latitude and some ejecta morphologies and, while they find that there is general agreement that ejecta morphologies can correlate with terrain, the detailed nature of the correlation is as yet unclear. There are also some hints of a dependence of ejecta type on altitude. The two Arizona State University mediators deduce that discrepancies in the results might be due to (a) methods of defining fresh craters, acceptable photographs, viewing and lighting geometries, etc., and (b) the data available to different investigators at the time of their analyses. They are encouraged that new data bases are emerging whose application might aid in resolving ambiguities; these sources of information include new Earth-based radar data, revisions of geologic map units on the basis of Viking photography, 1:2 M Viking photomosaics, and "non-imaging" data sets, such as IRTM and spectral information.

A number of unusual circular features interpreted to be the erosional remnants of impact craters have been examined by P. Davis, D. Roddy, and N. Whitbeck (U.S. Geological Survey, Flagstaff) using both photogeologic and photoclinometric techniques. They classify crater-form structures as follows: Type I - bowl-shaped with visible ejecta; Type II - flat-floored with wall terraces and visible ejecta; Type III - flat-floored, no visible ejecta, and an annular depression between the "rim" and the floor; Type IV - similar to Type III, but the floor is higher than the surrounding terrain; and Type V - faint, circular features with annular moats and flat floors topographically higher than the surrounding terrain. In their evaluation of candidate processes which might account for the features, the authors find a number of

possible difficulties with thermokarst dissolution, which include the regular shapes of the moats, their confinement near the craters' rims, and various topographic oddities inconsistent with present understanding of thermokarst development. Shallow intrusions, as suggested by other investigators, might have been responsible for liquefying an ice-rich debris mantle in the vicinity of these features, causing the observed degradation; in this scenario, the Type V features might be the result of volcanism. On the basis of explosion cratering experiments, Davis et al. offer an alternate hypothesis. Surface bursts on unconsolidated, flat-lying alluvium overlying water-saturated clays have yielded craters with morphologies that include moat-like topography on the crater floor adjacent to the crater walls surrounding a flat, centrally uplifted floor. They suggest that the martian features might have been formed by meteoroid impacts into comparable targets of low strength (such as permafrost), to be modified by subsequent erosional processes of uncertain nature.

His studies of impact basin ring-spacing on a number of planets and satellites has led R. Pike (U.S. Geological Survey, Menlo Park) to the conclusion that the $\sqrt{2}$ spacing rule espoused by earlier workers is quite general and holds for basins on all bodies treated in his analysis (Mercury, Earth, the Moon, Mars, Ganymede, Callisto, and Rhea). In addition, it seems to apply equally well for all rings, both within and outside the most prominent ring, the "topographic rim". He interprets these results to indicate that the mechanism coupling impact energy to the planetary target has a wave nature, with radial decay from the impact site accounting for the decrease in frequency of the outermost rings. Planetary layering and inhomogeneities, Pike theorizes, could account for missing and incomplete rings.

P. Spudis (U.S. Geological Survey, Flagstaff) has utilized photogeologic, orbital geochemical, Apollo site geologic, terrestrial analog, and

petrographic data in an integrated approach toward the problem of identifying lunar basin ejecta. Scrutiny of this information leads him to suggest that basin deposits consist of a coherent main sheet of relatively clast-free, ophitic to subophitic impact melt which was probably not sampled by Apollo astronauts. This sheet grades laterally into discontinuous, clast-rich melt deposits with poikilitic to aphanitic textures. Ejected melt should be aphanitic and could be relatively clast-rich or clast-poor, depending on the environment and mode of deposition. Structural uplift probably exposes pre-basin material within the massifs of the main outer basin ring (e.g., at the Apennine front). If any Imbrium ejecta were sampled at the Apollo 14 and 16 sites, Spudis contends, it would be purely clastic in nature; a basin "cryptic" component is probably present in undeterminable quantities at most highland sites, but it could be difficult to identify. The orbital geochemical data imply that heterogeneous highland provinces comprised the target for basin-forming impacts, leading to the conclusion that basin ejecta deposits are azimuthally and radially variable in composition.

The contribution of viscous relaxation to the modification of impact basin topography has been evaluated by S. Solomon, R. Comer, S. Stephens (M.I.T.) and J. Head (Brown University). Their analytic approach differs from those used previously for crater relaxation in the use of a layer of uniform viscosity, density, and thickness overlying an inviscid halfspace of greater density. They also assume that the initial topography is partially to completely compensated by corresponding relief at the base of the layer (i.e., the crust). In attempting to model the relaxation of the Tranquillitatis basin, these investigators start with an initial topography similar to that of the present Orientale basin. After correcting for the effects of mare fill and its associated tectonics, they report that their model yields results

consistent with the observed topography of the older basin. Because the more ancient South Pole-Aitken basin on the lunar farside still exhibits substantial relief, they suggest that the farside had a higher effective viscosity (by a factor of ~ 10). Therefore, a hemispherical asymmetry in mean crustal temperature, with higher nearside temperatures and a cooler farside crust, is implied for the era of Pre-Nectarian times over which these basins formed. In an interesting corollary to these results, Solomon et al. calculate that, provided the high surface temperatures have persisted since the time of heavy bombardment of the inner solar system, viscous relaxation should have reduced the relief of 3-4 b.y. old basins on Venus to negligible values. Thus they conclude that any ancient impact features large enough to qualify as a basin should have no visible topographic expression, and that any large quasi-circular depression is not likely to be of impact origin.

Volcanic Processes and Landforms

Dzurisin and Casadevall (U.S.G.S., Vancouver) reported on the morphologic evolution of the May 18th, 1980 crater at Mount St. Helens, Washington. A host of geomorphic processes are currently at work re-shaping the 2.5 km³ excavation produced by the 18 May 1980 landslide and eruption at Mount St. Helens. Subsequent eruptions of airfall tephra, pyroclastic flows, and a dacite lava dome have contributed most to crater filling. Rockfalls from steep crater walls have also been important, and may eventually dominate if eruptive activity wanes. Mudflows and gully incision have been the major processes responsible for exporting material from the inner crater. Although eolian re-distribution of fines has not been volumetrically significant, resulting thin mantles have significantly altered the appearance of the volcano as sensed remotely. Documentation of these continuing processes may shed additional light on the style and rates of crater modification on other planetary bodies.

Criswell and Elston (U. New Mexico) are also studying the deposits created during the eruptions of Mount St. Helens. They are investigating the morphology of ash-flow tuffs and pyroclastic deposits in order to establish criteria by which similar deposits can be recognized on other planetary bodies. No single morphological characteristic has yet been found that is diagnostic of pyroclastic flows (each morphological attribute could be duplicated by lava flows, mudflows or glacial deposits), a combination of observed features, together with an appropriate vent, may prove to be sufficient.

Drawing upon the work of Thorarinsson (1959 and 1968), the work of Thorarinsson and Saemundsson (1980), many years of direct field observations and study (on the ground and from the air), and review of the literature on volcanic geomorphology of Iceland, a new provisional geomorphic classification of Icelandic volcanoes has been developed by Williams and Morris, (U.S.

Geological Survey) and Thorarinsson (University of Iceland). The new geomorphic classification relates the nature of volcanic activity (effusive, mixed, or explosive); environment during formation (subaerial, subglacial, or submarine); and form of feeder conduit (short fissure/tubular conduit or long fissure) for the three primary classes of Icelandic volcanoes: basalt, rhyolite, and central; and a fourth related class, volcano-like landforms in Iceland. The "Illustrated Geomorphic Classification of Icelandic Volcanoes," a NASA Special Publication under preparation, will present each of the thirty types of volcanic landforms identified in Iceland as an illustrated text.

Hawke and Bell (University of Hawaii) reported on their new multispectral data for lunar dark-halo craters. They concluded from their observations that dark-halo craters can be formed by both volcanic as well as impact-related processes. Mare materials which originally underlayed the present surface can be recognized from their spectra at Copernicus H and in the Schickard-Schiller regions. The additional examples of dark-halo craters of pyroclastic origin that have been identified indicate that volcanic activity has been more abundant and widely distributed on the Moon than previously believed.

A model for eject transport on Mars, based on the energy-line concept, is being investigated by Wohletz (Los Alamos) and Sheridan (A. S. U.) The size and shape of ejecta particles produced in their explosion experiments are thought to be similar to those on Mars and certain examples within terrestrial pyroclastic flows and base surges. The interaction of a melt and a volatile substance (water, ice, or carbon dioxide) is being investigated and it has been found that extreme water/melt ratios (> 5) produce particles that are highly susceptible to hydration and alteration.

The problem of planetary volcanology and landform development has been approached from first principles by Wilson (U. Lancaster) and Head

(Brown U.) in an attempt to understand the important variables in the process of magma ascent and eruption. It has been found that eruption style is controlled by a combination of factors such as magma composition and temperature, magma volatiles content, tectonic setting, and the external environment (e.g. atmospheric pressure and gravity). Magma rise velocity has been modelled in terms of magma density, viscosity, yield strength, fissure width, planetary gravity and the effective density difference between the magma and its surroundings. A significant difference in volcanic eruption style is expected for the different planets.

The cooling of a basalt flow was also modelled by Aubele (U. New Mexico) and co-workers in an attempt to explain the abundance and size distribution of vesicles observed in the field. They found that the size and distribution of vesicles depends on the rate of buoyant rise, lava viscosity, and the advancement of the upper and lower solidification fronts. They proposed that if the pits observed in blocks at the Viking Lander 2 site are vesicles, then the frequency of pits suggests sampling to a depth of one-half the flow thickness.

Contrasting styles of martian volcanism were described by Mougins-Mark (Brown U.). A candidate for a well-preserved, explosively generated air-fall deposit has been found on Hecates Tholus, the northernmost of the three Elysium volcanoes. On the basis of crater counts, this unusual eruption appears to be a recent phenomenon, probably having an age of less than 300 myr. In comparison to Hecates, Viking Survey images show that the evolution of the Olympus Mons caldera was dominated by effusive activity. A tectonic origin for the ridges and graben on the caldera floor was proposed.

Independent studies of martian volcanoes by Whitford-Stark (Univ. Missouri) and Pike and Clow (U.S.G.S., Menlo Park) have addressed the probable original size of partially buried volcanoes in the Tharsis region. Using a relationship between caldera diameter and flank width, they have reconstructed

the height of each volcano by assuming a constant flank slope beneath the embaying lavas. Results indicate that the martian tholi, paterae, montes and Alba Patera are four distinct landforms. Estimates of ~ 4 km were also derived from both analyses for the maximum thickness of the post-shield lavas. The quantitative data of Pike and Clow for martian and terrestrial volcanoes (which now includes 730 volcanoes) indicate that the best Earth analogues for the martian montes are some of the oceanic island shields.

Further analysis of the thickness of martian lavas have been conducted by DeHon (N. Louisiana U.). Using partially buried craters as an indicator of flow thickness, DeHon has found that the maximum thickness of the ridged plains within Lunae Planum is about 1.5 km.

Aeolian Processes

R. Greeley (ASU) summarized work done by the NASA-Ames Aeolian Consortium. After nearly five years of wind tunnel testing, rates of abrasion can now be calculated for a wide range of conditions on both Earth and Mars. The effort has involved determining particle flux, particle velocity, susceptibility to abrasion functions, and wind frequency data for Earth and Mars. The conclusion for Mars is that eolian abrasion must involve particles that are relatively ineffective, such as aggregates of very fine grains. The Venusian wind tunnel was put into operation in the fall, 1981, at NASA-Ames, and will be used to carry out threshold studies for particle entrainment in a simulated Venusian atmosphere. High resolution IRTM and image data are being combined to develop models of martian eolian materials in dunes, streaks, and in some channel areas.

D. Krinsley (ASU) and colleagues reported results of studies of natural eolian abrasion of quartz grains, conducted to understand details of abrasion and account for the apparent low eolian abrasion rates on Mars. Samples were studied by electron microscope after two months' exposure to sand-carrying winds at Vicksburg, Arizona. The significant abrasion of edges and the slow abrasion of rounded grains suggests that self-abrasion of saltating material on the Earth and on Mars may be minimal during most of the lifetime of an eolian system. J. Marshall (ASU) reports experimental work that suggests electrostatic aggregation of dust may greatly enhance fallout of particles from martian duststorms.

Remote monitoring of desert meteorological and sediment conditions is being conducted by J. McCauley (USGS) and associates. Data collection platforms, using satellite relays, give documentation of eolian conditions in remote areas of particular geological significance. The lack of accurate

meteorological data from areas of morphologic interest has long been a major impediment to good modelling of desert eolian processes. Three stations are operating in Arizona, with two more planned to give data on wind speeds and directions, temperature, humidity, precipitation, and barometric pressure. Particle transport monitors are being added, and some abrasion experiments have been completed.

R. S. U. Smith (Texas) has compared terrestrial reversing and non-reversing transverse dunes to dune forms on Mars. Dunes formed by seasonally reversing winds form long, narrow and straight to gently curving ridges arranged parallel to one another, with local forked junctions; cross sections are nearly symmetric. Non-reversing transverse dunes are less parallel, more cusped in plan and asymmetric in cross section. The unusual linearity and parallelism of some dune ridges in the north polar region of Mars may be explainable by reversing winds, possibly on time scales longer than the reversal observed on Earth.

Work by F. El-Baz (Smithsonian) and M. Mainguet on dune forms in the Great Sand Sea of Egypt emphasized the importance of alternating wet and dry periods in the formation of terrestrial eolian features. They suggest that gently sloping whaleback dunes in Egypt are eolian erosional remnants of a thick layer of sand deposited during a period of wetter climate. During dry periods, such as the present, they lose sand to active dunes. Yardang-like features in low martian latitudes are believed to have also been formed by a similar interplay of fluvial and eolian processes. El-Baz and L. Manet also have identified large serrated-edge eolian streaks in China originating from small topographic obstacles that appear similar to some wind streaks on Mars.

P. Thomas (Cornell) has studied the relation of local streak sedimentary processes to the global pattern of eolian features. Color and

morphologic data indicate active saltation from intra-crater dunes and lack of dust fallout on dunes and sand surfaces. However, these crater dunes appear to be part of the final stages of erosion of complex dust and sand deposits from the craters, and thus indicate some parallel with the complex sediment/climate cycles in terrestrial deserts.

Fluvial, Periglacial and other Processes
of Landform Development

Studies of the Martian hydrological system show a good balance between investigations of the large outflow channels and the small valley networks. Due in part to the exchange of ideas at the Mars Channel Workshops, there has been a convergence of ideas and interpretations which in turn are providing direction for further investigations. Prominent directions of the research include refining the chronology of channel formation, definition of constraints for channel-forming processes, resolving the relationships between valleys and groundwater, hillslope processes, and the behavior of permafrost in producing Martian geomorphic features.

Investigations are underway in mapping regions containing outflow channels in an attempt to determine the chronology of emplacement of different geological units, the ages being assessed with crater counts on the different units. In such a study of Chryse Planitia, J. A. Cutts and colleagues (Planetary Science Institute) conclude that the erosion phase of outflow channel formation was limited to a comparatively narrow time span in Martian history. H. Masursky and colleagues have obtained crater counts for seven parts of five channels, inferring from their results that the large outflow channels formed over a long period of time and that in some cases there were probably several episodes of water flow with the broad widespread flows having been earlier and the confined inner channels being cut later. J. A. Cutts and colleagues also are investigating whether there has been structural control in the development of chaotic terrain, the sources of some outflow channels. Their results agree with the hypothesis that chaotic terrain is consistent with extensional tectonics within and adjacent to the Valles Marineris.

H. Masursky and colleagues have analyzed radar traverses acquired at

the Goldstone facility of the Chryse Planitia region and the canyon area to the south. Long profile slopes of outflow channels were obtained for the first time, the values for Ares (1.7 m/km), Tiu (1.7) and Simud (0.5), being on the same order as the channel slopes in the Channeled Scablands (1-4 m/km). The radar traverses also show channel depths ranging 300 m to 1.5 km below the adjacent cratered terrain. Measurements such as these are critical to further analyses of the flows which eroded the outflow channels.

B. K. Lucchitta (USGS, Flagstaff) reviewed the various processes that have been suggested to account for the origin of the outflow channels, relating these to the observed channel morphologies. A composite channel origin was proposed, with the initial conditions being mudflows emerging from the chaotic terrain area. These mudflows then became more viscous and moved more slowly when the liquid portion froze and the channels choked in a manner comparable to ice drives. The proposed outflow channels are thus hybrids formed by very viscous mudflows and debris-rich glaciers.

The longitudinal grooving observed in the Martian outflow channels has been used as an argument supporting a glacier origin for these channels. For this reason, D. E. Thompson (JPL) also has undertaken analyses to examine the development of subglacial longitudinal grooving through the development of stable secondary helicoidal flow patterns in the basal glacier ice. These analyses are being compared with patterns of glacial grooving in the Arctic Canada and Alaska as well as with those on Mars.

P. D. Komar (Oregon State Univ.) has focused his attention on the formation of streamlined islands observed in the outflow channels, the objective being to constrain the types of the flows that may have caused their erosion. It is found that the Martian streamlined islands are very similar in their geometries to streamlined islands found in terrestrial rivers and in the

Channeled Scabland. Comparisons with measurements of the drag on airfoils demonstrates that streamlined islands have achieved shapes that provide a minimum total drag. These comparisons led to the conclusion that the Martian flows must have been turbulent, thus ruling out debris flows, glaciers and low-viscosity lavas, leaving only water flows as an erosion agent consistent with the shapes of the streamlined islands.

D. Nummedal (Louisiana State Univ.) discussed the variety of channels found in the ocean and their possible relationships to the Martian channels. In terms of morphology, size and topographic relief the many channels, slumps and chaotic terrains on Mars present a suite of landforms very similar to that present on terrestrial submarine slopes. The ability to infer the correct causative process from geomorphic analysis of the Martian surface is critically dependent on the identification of an entire suite of landforms. Given the excellent correspondence between Martian instability features and those on submarine slopes one might infer that large-scale gravity-induced sediment displacement was a major process in the evolution of the Martian surface.

M. C. Malin and D. Eppler (Arizona State) are investigating the channels and deposits of catastrophic floods (jökulhlaups) in Iceland. Their field observations include cataracts, "Scabland" plucking of bedrock, streamlined islands, megaripples and depositional tails. They found no evidence of linear grooving at scales greater than 10's of meters in length. The flow discharge is estimated at $3 \times 10^5 \text{ m}^3/\text{sec}$. Comparisons with the Martian outflow channels are currently in progress.

J. C. Boothroyd (Univ. Rhode Island) is studying the Sagvanirktok River on the Arctic Slope of Alaska, a braided river which flows through a permafrost area. The study includes examinations of ice drives which sometimes

jam and redirect the river laterally onto the unoccupied part of the fluvial plain, and the morphology of the river bars. Solifluction and debris flows are significant processes on the slopes adjacent to the river. This river serves as a terrestrial analog to the Capri Chasma for which Boothroyd is preparing a geomorphic map. It is apparent that Martian terrain exhibits the same suite of erosional remnants and secondary modification features active in this permafrost environment; Capri Chasma has been subject to multiple episodes of fluvial flow, perhaps by sediment or ice-charged water or by debris flows,

D. E. Thompson (JPL) is investigating the role of kinematic waves in sediment transport during catastrophic flooding. The theoretical analysis is constrained with data gathered from the Alsek River channel in Yukon Territory, Canada, down which catastrophic floods regularly occur when the ice-dammed Lake Alsek suddenly drains. Data have been gathered on the scour and depositional interrelationships along the channel, and the hypsometry of the lake level is reconstructed from terrace distributions and lake shoreline measurements in the field. Further constraints are provided by theoretical hydrographs created for the Lake Alsek flood. The analysis is now concentrating on how initial features are modified during changes in the flood, how the flow stability is affected by changes in hydraulics and sediment concentration, and how bedforms migrate.

Deeply entrenched theatre-headed canyons are widespread on Mars and are generally believed to have been formed by sapping. J. E. Laity and R. S. Saunders (JPL) are investigating canyons developed within the Navajo Sandstone in the Glen Canyon region of the Colorado Plateau to examine feature/process relationships. A major objective is to assess the relative roles of overland flow versus groundwater flow processes in developing the observed

morphology; their conclusion is that groundwater sapping is the primary erosional mechanism as overland flow does not explain the relationships in as reasonable or consistent manner. Direct comparisons have been made with the valley networks developed on the walls of Valles Marineris. These valleys exhibit many form characteristics similar to the terrestrial examples, and are observed to grow along structural linements. However, more detailed examination presents certain anomalous conditions that are not easily explained by groundwater sapping as described for the Colorado Plateau. These include: (1) The networks may actually contain closed depressions; (2) Sapping does not always occur along stratigraphic boundaries; (3) Intricate branching patterns that are difficult to explain by a large regional groundwater flow system; and (4) Valley networks that appear to intersect one another.

A. D. Howard and C. McLane (Univ. of Virginia) are investigating the development of stream channels by groundwater sapping through a combination of process modelling and groundwater flow modelling. The result will be a simulation model of channel network development by headward growth and branching, illustrating the action of groundwater "capture". A variety of alternative models are being examined to determine their effect upon the geometry and extent of the resulting channels. An attempt is also being made to specifically model sapping in fine-grained cohesionless sediment. Preliminary experiments are being conducted in a groundwater "flume" to determine the appropriate rate laws. Later experiments will be conducted in a large sandbox.

Investigations are also underway examining the evolution of features on escarpments. Once a scarp is formed, they become extensively modified by mass wasting processes which produce considerable scarp recession. V. R. Baker and R. C. Kochel have demonstrated that the large-scale reentrants of

the escarpment along the western Kasei Vallis outflow channel appear to be structurally controlled by more or less regularly-space joints, faults and/or wrinkle ridges. Scarp retreat accounts for several kilometers of postdiluvial widening of the outflow channel, also forming an extensive tributary network. P. C. Patton (Wesleyan Univ.) is studying the spur and gully topography of the wall scarps of Valles Marineris. The morphometry of the spur networks has been mapped in several canyons, and various parameters including spur length, area, density and frequency have been measured. Regression analysis indicates that spur networks grow in width at an equal rate as they grow in length. This is accomplished by the capture of one spur network by another as unequal headward growth occurs at the scarp crest. The analyses also indicate that the density of the spur and gully topography networks can be used as relative indicators of recent fault activity at the base of the Valles Marineris scarps. Range front faults of various ages in the Basin and Range Province of California and Nevada are being analyzed to determine if the evolution of these scarps is an appropriate analogy to the Valles Marineris wall scarps.

O. L. Franke and colleagues (CUNY) have begun a survey of the slope features at the boundary between the plateau terrain and northern plains of Mars, obtaining measurements of slope heights and angles of both bedrock surfaces and debris aprons using standard photogrammetric techniques. Stabilities of the slopes are being analyzed by a variety of techniques which assume realistic failure surfaces and include the effects of seepage. It is expected that the analyses will provide constraints on values of the relevant material parameters.

B. K. Lucchitta and colleagues (USGS, Flagstaff) have made quantitative studies of some landslides in Valles Marineris. Plotting the volume of

the slide against the tangent of its slope from the head of the landslide scar to the top of the slide deposit reveals consistent differences with data from terrestrial slides. The comparisons also show that the Martian landslides had higher speeds, the one exception being the Huascarán landslide in Peru which fell from a great height and contained ice and water. Large terrestrial slides are generally dry, and the differences found between the terrestrial and Martian landslides may be due to higher water contents of the Martian slides. The data therefore, support the hypothesis that Martian landslides contain water and may have been similar to gigantic mudflows.

Liquid water, and thus mud, is unstable on the Martian surface because of the low atmospheric pressure. The mud will tend to boil and freeze, producing a vesicular icy mud. The ice may then sublime, leaving a sediment and salt residue. L. A. Johansen (JPL) has undertaken a study of this phenomenon using a vacuum chamber, employing a range of sediment sizes and compositions, varying the quantity of water and amounts of salt. The strongest clods formed so far consist of montmorillonite clay with a magnesium sulfate salt solution. These persist up to an unconfined compressive load of about 500 psi, indicating that the material is strong enough to support scarp slopes up to a height of about 70 meters. Thus it is possible that the rocks around the Viking landers are salt-cemented vesicular clods, thereby explaining the inability of the lander to sample rocks.

There is now considerable evidence for water ice on Mars, much of it in the form of permafrost. L. A. Rossbacher and S. Judson (Princeton Univ.) considered the implication of the presence of water ice to weathering and freeze-thaw mass wasting cycles on Mars, especially in the formation of the theater-headed valleys. D. M. Anderson (SUNY, Buffalo) is considering the thermodynamic relationships which govern the behavior of permafrost and frozen ground, and the implications of these processes to landforms observed on Mars

and to other bodies where water-ice may form a major constituent.

J. J. Fagan and colleagues (City College of CUNY) are examining subsidence depressions on the Martian plateau-like uplands, finding evidence for the origin of certain depressions by subsidence rather than by direct impact. In some instances these subsidence depressions are underlain by ancient impact craters that have not been uncovered because of incomplete subsidence or insufficient erosion. When the large subsidence depressions and small pits are not represented as impacts, the plateau surface takes on an aspect of being younger than it is normally assumed to be.

Exhumed landforms are topographic features that were created by surficial processes, buried by a covermass, and later uncovered to such a degree that they constitute an important part of the landscape. Exhumed topographies are common on Earth and appear to also exist on Mars. D. D. Rhodes (Whittier College) is reviewing the literature dealing with the exhumation of terrestrial features, examining the effects of depth, duration and degree of burial on the preservation of the landscape. On Earth a variety of exhumed geomorphic features are found including karst topography, cliffs, impact structures and fluvial and glacial features; no depositional aeolian forms have been found, presumably because they are too easily destroyed. Recognition of similar Martian features may be an important indicator of the geologic record of Mars.

V. R. Baker (Univ. of Arizona) is investigating various Australian analogs to geomorphic features on Mars. Because of the remarkable tectonic stability of Australia, the profusion of very ancient relict landscapes, the occasional spectacular influence of fluvial processes, and the abundant aeolian modification of structural and fluvial landforms, central Australia is an important analog to ancient conditions on Mars. The Gosses Bluff impact

structure probably formed during the early Cretaceous, and is now deeply eroded with the superposition of a drainage system from an ancient land surface. The Henbury craters are relatively young and are now undergoing active dissection by a drainage system which the impact disrupted. Analogs are also present for the influence of mare-like ridges on outflow channeling in the western Chryse Basin, for the relationship between the northern plains and heavily-cratered plateaus, and for escarpment retreat features.

Mars Polar Deposits, Volatiles and Climate Change

James Cutts and Karl Blasius (Planetary Sciences Inst.) discussed a variety of theoretical models intended to explain the physical linkage between formation of the layered terrain on Mars and climate change on that planet. Their theoretical models fall into two broad classes: Uniform deposition rate models assume that the major constituent of the layered deposits is laid down at a constant rate. Climate-modulated deposition rate models assume that the deposition rate of the major constituent is controlled by climate. Discrete layers are defined by intervals during which deposition slowed down or temporarily ceased. Conceptually they resemble models for the formation of terrestrial or ocean margin sedimentary records where there are hiatuses in deposition in association with glaciation or change of sedimentary base level. Pattern recognition techniques are being developed for distinguishing characteristics of particular models and comparing the results of theoretical models with observational data.

Alan Howard and the two previous authors continued the analysis of the stratigraphy of the layered deposits, leading to the following conclusions:

1. Layered deposits accumulate on the smooth and banded terrains on flat uplands and pole-facing trough walls, respectively. Concomittent erosion of pole-facing scarps exposes layers deposited previously. Both the deposition and the erosion have continued to the present epoch.
2. The polar topography, dominated by parallel troughs, has formed contemporaneously with layer deposition. Near the poles the trough bottoms build up as troughs migrate, but near the edge of the polar deposits the trough bottoms may lower, locally exposing underlying basement. Near the poles the erosion of equator-facing scarps has not kept pace with layer deposition; either infrequent episodes of massive erosion or basal melting could account for the youth of the layered deposits.

3. Unconformities in layered deposits indicate that deposition of several layers has been alternating with trough wall erosion. Equator-facing scarps undergo erosion during most orbital configurations, but pole-facing trough walls receive slight episodic erosion. Banded terrain is produced by minor erosion of the feather edges of layers deposited on pole-facing rough walls. Slopes that strike north-south are rare, and alternate between pronounced erosion, exposing layers, and unconformable deposition of several layers.

4. The regularity of thickness indicates that the layers have accumulated as a result of quasi-cyclical orbital variations. Individual layers may be created during the 5.1×10^4 year precessional cycle, and the alternations of erosion and deposition may be due to the 1.2×10^5 year obliquity cycle. Alternatively, layers may form during obliquity cycles and the alternations may be due to the 1.3×10^6 year modulation of the obliquity amplitude.

James Cutts reported on the highly successful workshop on Quasiperiodic Climate Change on the Earth and Mars that was held at Ames Research Center in the Spring of 1981. He pointed out that papers corresponding to the presentations at that meeting will be published soon in a special issue of *Icarus*. This highly successful meeting emphasized the comparative planetological interest arising from the many strong parallels and interesting contrasts between obliquity/orbital - driven climate change on Mars and the Earth. Formation mechanisms for the layered terrain, obliquity driven volatile exchange among the regolith, atmosphere and caps, and the relationships among atmospheric pressure, dust transport and surface temperatures were among the subject intensively treated in that meeting.

Fraser Fanale (U. Hawaii) discussed the formulation and implications of recently developed models for Mars climate change. The obliquity variation of Mars (much larger than on Earth) causes massive transfer of CO_2 among the three reservoirs of "exchangeable" or "available" CO_2 on Mars. At present,

most (>90%) of the exchangeable CO₂ is stored neither in the atmosphere nor in the very small quasipermanent surface CO₂ south cap, but in the "ocean" of adsorbed CO₂ in the regolith. Large variations in atmospheric pressure and cap mass due to changes in planetary obliquity are related to layered terrain development via the relationship between poleward dust fluxes and pressure, etc.

The latitude-thickness distribution and the mineralogy of any near surface gas-permeable "regolith" on Mars is only poorly known. However models involving a wide variety of thickness distributions and mineralogies yeild qualitatively comparable results. Some investigators have suggested Pre-Tharsis obliquity variations were substantially greater than at present, and somewhat higher "maximum" pressure (~25 mb) and lower "minimum" pressure (~.02 mb) attained in most regolith-atmosphere-cap models if driven by these greater variations. On the other hand, pressures >25 mb are almost impossible to achieve - at least in any of array of the models discussed (barring such events as a major episodic change in solar luminosity) so the regolith might be legitimately viewed as an inhibitor of atmospheric variations rather than as an alternative source of CO₂ (in the absence of a large surface CO₂ cap) that would allow them to happen.

Robert Huguenin (U. Massachusetts) discussed the detectability by MAWD of proposed enhanced soil moisture occurrences in near-equatorial regions. It was noted that during the non-dust periods detectability was unlikely, due to very low predicted outgassing rates (<<1 pr micron sol⁻¹) which are well below background levels. Several days of column accumulation would be required to reach detectable abundances, and thus would require a static atmosphere which is inconsistent with observed winds. During late spring dust storm seasons outgassing rates should be much higher (>10 pr. microns sol⁻¹) but dust masking prevents detection (opacities of as much as 8 were measured). Condensates are

the most sensitive indicators of vapor source regions, and the evidence from condensates for their existence was interpreted as being compelling.

Structure and Tectonics

The tectonic significance of histograms of planetary elevations (hypsograms) was discussed by M. C. Malin. He pointed out the problems of defining and quantifying bimodal hypsograms consisting of two gaussian distributions of elevations. For Earth, the amplitudes of these two gaussians are determined by relative proportions of two different crustal types; this separation is a function of the density difference and thickness of the crustal types; the gaussian widths are related to the relative efficiency of processes which either create or destroy the differences between the two fundamental crustal types. In other words, the gaussian widths reflect the balance of effects of tectonics versus erosion and sedimentation. Bimodality of the hypsometric curve on other planets, however, need not require the operation of plate tectonics. In particular, the slightly bimodal curve of Venus neither supports nor refutes the operation of plate tectonics on that planet.

Further implications based on the contrasting topography of Venus and Earth were presented by R. E. Arvidson. A variety of data bases were combined into shaded relief, color and grey tone images. These included Pioneer Venus altimetry data and Arecibo radar roughness measurements. Direct comparisons between Earth and Venus were possible by simulating Pioneer Venus resolution, both vertical and lateral, with degraded terrestrial data. The Earth data were further corrected for removal of the load of oceanic water and for changes in oceanic ridge height consistent with the high Venusian ambient temperatures. The result was reduction of relief of the ocean floor by 60%. However, when the corrected data were enhanced and displayed, the oceanic ridges, trenches and transforms were still visible. The fact that similar features are not visible on the Venus data with comparable resolution suggests that Earth's plate tectonic topography does

not exist at present on Venus.

The problem of the offset of the Martian center of mass from its geometric center was discussed by M. Kobrick in a paper by L. E. Roth, M. Kobrick, G. S. Downs, R. S. Saunders, and G. Schubert. Goldstone radar profiles confirm that the Martian center of mass is offset toward the western hemisphere south of the crest of Tharsis. This is in general agreement with all but one published study; the discrepancy in that study resulted from a minor error in sign convention for east and west longitude. The longitudinal offset must be determined by Tharsis much as the offset of the Earth's center of mass from its center of figure is toward its highest elevations in the Tibetan region.

Methods of lineament swarm analysis to detect paleostress trajectories on planetary surfaces was presented by D. Wise and L. Allison (U. Mass.) using a test area in southwest Wyoming. Images analogous to radar were produced by side illumination of raised relief maps. Extensive tests for reproductibility of the topographic lineaments were run by analyzing the same area with illumination from six different directions, by redoing the entire experiment a half year later, by plotting the location of lineaments recurring in all lighting directions, and by separate analysis of adjacent maps with continuation of the same lineament swarms between the maps. The methodology involves filtering of azimuth frequency histograms by gaussian fitting techniques similar to those used for deconvoluting Mossbauer spectra. These lineament analysis techniques may have considerable utility in mapping patterns of fracture porosity and permeability for hydrocarbon exploration as well as for the mapping of paleostress trajectories on other planetary surfaces.

In a pair of presentations, Maxwell and Watters described their attempts to identify a chronology for the tectonic features within the

Tharsis Province of Mars. They have mapped the distribution of ridge segments in this area and have found that a significant number are evidently not related to a single center associated with the Tharsis Bulge. Maxwell and Watters also believe that several examples of graben which post-date ridge formation can be found within Tharsis, suggesting that ridges started to form prior to the period of volcano-tectonic activity which was centered at Pavonis Mons (and, hence took place prior to the development of Valles Marineris). A pulsating sequence of uplift and/or volcanic loading, with associated long-term crustal response, was proposed for the evolution of Tharsis.

An analysis of lineament orientations in the Tharsis region of Mars was also reported by M. Fulchignoni, R. Salvatori, R. Bianchi, and M. Coradini. More than 6000 lineaments were drawn from the U.S.G.S. 2,000,000 map series, digitized, and analyzed by azimuth, length, and location with respect to the center of Tharsis. Surprisingly, a dominance of north-south lineaments appears rather than the more traditionally reported sub-radial fracture system. The difference does not appear to be a function of length of lineaments mapped, but may represent differences in prominence of development of radial systems.

A new structural interpretation of the basal scarp of Olympus Mons was proposed by E. Morris. Radial fractures, concave and convex segments, local dips of layered material toward the volcano suggest possible radial thrust faulting for the scarp. Additional evidence is a raised rim to the scarp, ponded sediments behind the rim and apparent thrust overlap of cone materials over the adjacent plains. The relations suggest that the scarp formed late in the history of Olympus Mons, during a relatively short time interval. The scarp is interpreted as a thrust fault zone formed in

consequence of compressive forces developed by the subsidence and outward spreading of the main mass of Olympus Mons.

A slightly different form of gravitational tectonics was discussed by C. A. Baskerville as an Earth analogue of Martian chaos regions. Citing terrestrial engineering geology studies he proposed that the chaos resulted from deep gravitational creep of a plastic layer beneath a rigid, massive rock sheet. The flatter the slope, the thicker is the plastic mass needed to initiate the chaotic disruption. The plastic substrate can be squeezed up into valley floors, withdrawing support from beneath the brittle, massive cap rock of the adjacent uplands. The result is a separation, rotation, and sinking of massive blocks of the rigid material into the plastic substrate -- a fair description of Martian chaos terrain.

The interplay of gravity processes, with faulting, volcanism, and local sedimentary basins in the Valles Marineris region of Mars was discussed by B. Lucchitta. Using some of the very highest resolution late Mariner imagery, she illustrated a sequence of events starting with the development of a regional stratigraphic sequence of easily liquified rocks overlain by the volcanics of the Lunae Planum. Subsequently east-west grabens eliminated most of the volume of material missing from the Valles. These were accompanied by sapping, valley widening and general landsliding. Locally debris accumulated in the center of the troughs to form basin beds. Local dark, resistant units interbedded with the basin units suggest volcanism accompanied this stage. No calderas for this stage were detected but the basin beds may include ignimbrites and tuffs. Faulting and major landsliding continued after cessation of deposition of the basin beds. Local deposits of dark material along some of the faults suggest late stage, minor basaltic volcanism. The final stages of valley evolution have

been largely wind erosion, deflation, and deposition.

A way of reconciling the apparent conflict between the geological record of Mercury's surface and its geophysical character was proposed by M. A. Leake and co-workers. Much of the present problem stems from the time constraints that the heavy bombardment phase seems to postdate the major disruptions associated with core formation and solidification. Conventional wisdom would have this bombardment phase end about 4 b.y. ago; geophysically it is very difficult for the core tectonic events to have been completed before that time. One possible solution is the existence of vulcanoids representing a population of bodies left over from Mercury's accretion and having extremely long lifetimes due to variations in Mercury's ellipticity. These bodies would be unique to Mercury and permit the cessation of heavy bombardment to occur much later on Mercury than the ~ 4 b.y. date for the Moon. The research group has searched without success for such bodies presently in Mercurian orbits with a resolution limit of 50 km. The authors therefore suggest caution in too rigorous an application of comparative planetology: Mercury might have a unique cratering record and a much younger surface history than the Moon.

Remote Sensing and Regolith Chemistry

Radar studies of planetary surfaces have continued by using Pioneer Venus data to understand the roughness of the Venusian surface, along with using earth-based radar studies of Mars to study selected regions in greater detail. Gerald G. Schaber (U.S.G.S.) presented the latest Pioneer Venus radar data sets (altimetry, rms slopes, and fresnel radar reflectivity), along with color composite and gray-tone ratio maps (rms slopes/altitude, reflectivity/altitude, and reflectivity/rms slopes) of the Venusian surface. To date, 129 areas on Venus have been digitized and statistics on altimetry, rms slopes and reflectivity have been obtained. Cluster diagrams have also been obtained for all combinations of altimetry, rms slopes and reflectivity. Schaber noted the final processing of the PV radar data sets has permitted initiation of quantitative geologic and morphologic analysis of the Venusian surface.

Schaber reported that Maxwell Montes, high massifs of Aphrodite Terra (Ovida, Themis, Atla Regios) and Theia Mons (in Beta Regio) are characterized by high altitude (up to 11 km), high rms slopes (7° to greater than 10°) and high ($27f_0$) reflectivity. The foothills of Istrau Terra, Aphronite Terra and the areas of Tellus and Alpha Regios are anomalously low in reflectivity (by 6 to $7f_0$) but are characterized by moderately high ($5-7^\circ$) rms slopes and 1-4 km relief. Schaber reported a possible 400 km diameter crater-like feature detected in the PV rms slope/altitude ratio map located northeast of Beta Regio at latitude 32°N and longitude of 295° . Schaber has also postulated global scale linear disruption zones (of probable tectonic origin). These linears (20,000 km, 14,000 km and 5,000 km in length) are called the Aphrodite-Beta linear, the Theris-Atla Linear and the Beta-Phoebe linear trend NW, NE and NS respectively. The Ridged-Trough features on Venus are attributed to uplift, extension and rifting of a 40-65 km thick continental-style crust

along ancient lithospheric zones of weakness.

Radar mapping of selected regions on Mars is continuing. R. A. Simpson (Stanford University) and colleagues have been studying the polar regions of Mars. They reported that radar data taken near Mars' north pole may be associated with the plains units because of the low rms surface roughness measurements. Intermediate values ($2-3.5^\circ$) correlate with the permanent polar cap, while the highest values ($3.5-7^\circ$) are found in dune fields. The effect of anisotropic surface structure (such as the transverse dune fields) on the echoes has been considered, but no distinctive signatures have been identified in the data. If the polar dunes are sparse (relatively low and/or containing a low volume) of material, then the $5-6^\circ$ rms roughness observed must be small scale structure superimposed on the visible dunes. If the dunes have trough to crest heights on the order of 50 meters (over wavelengths of around 1 km), then no small scale roughness is needed to explain the observations.

New radar data from Syrtis Major prompted a combined remote sensing analysis of that region by R. A. Simpson and G. L. Tyler of Sanford, J. K. Harmon of Arecibo Observatory, and A. R. Peterfreund of Arizona State Univ. By using albedo (for dust distribution), infrared (sand), radar roughness (decimeter to dekameter undulations), and radar ranging (topography) it was possible to derive a self-consistent (albeit non-unique) model for the surface around Syrtis Major. Their data suggest that Syrtis Major is a relatively young plain flooded region of low viscosity basalts which have issued from concentric vents ringing Isidis Planitia. Their data are contrary to published U.S.G.S. maps and show that the center of Syrtis Major is a local topographic high; one or more calderas near its center have probably been the source of the most recent flows. Aeolian processes have dominated erosion/deposition since those vents became inactive. A field of dark dunes is located near the calderas.

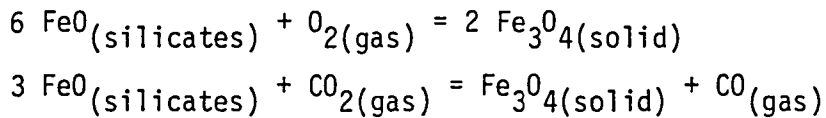
A new topographic map of the equatorial belt of Mars (23°N - 21°S) has been derived from earth-based radar measurements by G. S. Downs (Jet Propulsion Lab), P. J. Mouginis-Mark (Brown Univ.) and S. H. Zisk (NEROC Haystack Observatory). The new map is referenced to the 6.1 mb pressure surface. A number of analyses are currently being made by these authors: (1) Topography for "small" features such as impact basins is being used to help investigate the distribution of ejecta deposits; (2) Hypsometric curves for the cratered hemisphere reveal that 2 or possibly 3 distinct erosion surfaces may exist; (3) Terrain analysis (autocorrelation functions) is being applied to different geological units to recognize such things as spatial variations in the emplacement of the ridged plains materials and the degradation state of the hilly and cratered materials; (4) Hemispheric topography illustrates that the Southern Hemisphere is not always high (lows reach 1.7 km below datum) and the Northern Hemisphere is not always low (highs exceed 9 km above datum). Thus, old interpretations that this subdivision can be made by relief need revision; previous elevation estimates for Tharsis Dome and Lunae Planum have also been shown to be over estimated by 3-5 km.

R. Blom and associates at J.P.L. have been studying the radar scatterometry of sand dunes and lava flows in order to better understand the nature of radar/terrain interaction. In order to quantify the radar backscatter characteristics of geologic surfaces, a collection of multifrequency, multipolarization radar scatterometry data has been obtained over the Kelso Dune fields of California, along with the lava flows at Newberry Volcano, Oregon. Their analysis of the data indicates that a wide variety of surface configurations yield the same radar backscatter when viewed in a single image, but that the multiple radar parameter data set can resolve most of these ambiguities.

R. E. Arvidson and colleagues (Washington University) have examined the

application of Landsat multispectral scanner data for mapping of rock and soil types. They have used the data to assist in determining the limits of inter-repeatability of data returned from the Viking orbiter color data. The Meatiq Dome in Egypt was extensively studied. The dome is composed of a variety of granitic-granodioritic rocks together with quartzofeldspathic to mafic and ultramafic mylonites. They found that principal components color enhancements provided optimum discrimination between the trinitoid Dome rocks and the mylonites. However, use of the Landsat data did not allow them to discriminate between the granites and the granodiorites within the Dome; e.g., soil size variations were detectable whereas subtle mineralogical variations among rock units within the Dome were not discriminable. Two lessons can be learned from their study. First, because Viking orbiter color data are typically highly correlated and consist only of three channels, subtle color variations, such as those between various dark regions, may be difficult to discern. Secondly, it was concluded that incorporation of more independent data, such as thermal inertia or radar, would be very helpful in increasing the capabilities of this technique. E. L. Strickland (Washington University) used color enhancements of Viking orbiter approach and orbital color mosaics to map color/albedo provinces in the west central equatorial regions of Mars. The data were examined in light of the Mars consortium data. Color/albedo markings were shown to be due to sand and dust eolian deposits that obscure bedrock. Two suites of materials were found from the color enhancements: intermediate to high albedo "red" units of similar color, and intermediate to low albedo "blue" units of diverse color. Strickland concluded that the recognition of color variations around units is severely hindered by the cameras' 7-bit data, overlap of color filters, and the subtle color variations of Mars.

Rock weathering on Venus was examined by James L. Gooding (NASA, JSC). Equilibrium thermodynamic calculations indicate that primary minerals which are likely to occur in igneous rocks on Venus should react with the prevailing hot, high-pressure CO₂ atmosphere to form a variety of secondary minerals. However, the present study appears to be the first attempt to experimentally simulate such weathering processes. Exploratory experiments subjected two standard rock powders (andesite and basalt) to 100 atm. of CO₂ at 350°C (approximately 100° below ambient Venus surface temperature due to experimental limitations) and found evidence for significant alteration of both rock powders after times as short as four days. Although identification of the alteration products requires further work, it is hypothesized that the following reactions were involved:



It was noted that in the experiments, O₂ was a trace contaminant in the CO₂ (as is essentially the case on Venus). Thermodynamic calculations indicate that both reactions are favorable on Venus. The most obvious consequence of the experimental alterations was darkening of both rock powders. The altered andesite yielded reflectance spectra which were nearly identical to those of basalt over the wavelength range of 0.35-0.8µm. Furthermore, the spectra were rather flat and featureless, and possessed some similarity to the spectra of the Venusian surface which were interpolated from Venera 9 and 10 wideband photometer measurements. Thus, the low albedo of the Venusian surface might, in part, be due to rock/CO₂ reactions.

The Dry Valleys of Antarctica probably represent the best terrestrial analog of the Martian surface. E. K. Gibson (NASA, JSC) has been studying

a suite of soils and core samples returned from the Dry Valleys. The investigations have produced an idealized soil profile for the regolith which is very applicable to the Martian regolith. The soil profile is composed of five basic zones: an aeolian zone, a salt formation zone, an active zone, a seasonally frozen zone, and a permanently frozen zone. The observed condensates in the Solis Lacus and Noachis-Hellespontus regions could easily be accounted for by this soil profile model. The movement of moisture through the regolith with subsequent loss to the atmosphere would leave behind those anions and cations which favor salt formation. The seasonal cycling of moisture from the regolith would result in salt-rich deposits near the surface similar to those observed at the Viking sites.

D. S. McKay (NASA, JSC) and Sue Wentworth (Lockheed) reported on studies of a sequence of ten samples from an 80 cm deep soil pit in Wright Valley, Antarctica. The soil samples are being studied in order to determine the processes and effects of weathering in cold, arid climates, with possible application to Mars. Petrographic model data (20-250 M fraction) indicate that chemical activity and alteration occur throughout the soil column, even in the permanently frozen zone (below 40 cm). Evidence includes an increase in the total abundance of fresh ferromagnesian minerals and a decrease in altered ferromagnesian minerals (iron hydroxides) with depth. Similar processes are possible on Mars: subsurface H₂O ice or even groundwater may be present, the temperature range would allow ionic migration by means of unfrozen liquid films, and the mafic rocks would be prone to alteration. Thus, simple mineralogical models for the Martian regolith are probably unrealistic. The authigenic zeolites in the soil pit may also have implications for Mars. If present in the Martian regolith, zeolites could serve as a CO₂ reservoir and their gas exchange properties could affect atmosphere-regolith interactions.

R. V. Morris (NASA, JSC) and H. V. Lauer, Jr. (Lockheed) have investigated the structural states intermediate between goethite (α -FeOOH) and lepidocrocite (γ -FeOOH) and anhydrous forms by reflectance spectroscopy, X-ray diffraction, and water analysis. Their objective was to establish if these forms had optical and/or sorptive properties that are characteristic of the observational data on Mars and thus model their likelihood of occurrence there. Some aspects of the optical properties of the end members do not match the observational data for Mars, and they do not have a large sorptive capacity. In agreement with previous work, they found that the intermediate states were disordered forms in which the oxide ions ordered to the crystal structure of the anhydrous forms before the ferric ions did. Spectrally, the disordered forms closely resembled the crystalline anhydrous equivalents so it would be difficult to distinguish between the two in the reflectance spectra of Mars. Relative to the ordered forms, the disordered forms had a significantly higher concentration of absorbed water indicating a very high effective surface area. Their work opens the possibility that disordered forms of iron oxides may be involved in the storage and exchange of volatiles on Mars.

The strength of absorption bands in reflectance spectroscopy has been examined by Bruce Hapke (Univ. of Pittsburgh). Using the new reflectance theory of Hapke [J.G.R. 86, 3039 (1981)], a series of artificial reflectance spectra was calculated for regoliths having absorption bands. The relation between reflectance and absorption coefficients is highly non-linear. Nevertheless, it is shown that, with care, it is possible to recover an absorbance spectrum from a reflectance spectrum. A complication in interpretation is the occurrence of minima in the reflectance spectrum on either side of a strong absorption peak when $\alpha \sim \lambda^{-1}$. The theory is illustrated using the measured reflectance and absorbance spectra of water frost. In addition, Hapke examined the effects of macroscopic roughness on the reflectance of surfaces. An

analytical expression was derived by which an arbitrary smooth-surface reflectance function may be corrected for effects of macroscopic roughness. The correction is applicable to a surface with any albedo. Hapke's theory may be applied to planetary observations to deduce mean slope angles (on a centimeter scale) on the surfaces of planets.

Cartography, Geodesy, and Geologic Mapping

A highlight of the cartography program was the production and distribution of planetary globes. R. M. Batson and colleagues reported that globes of Mercury, Venus, and Earth were manufactured by Replogle Globes, Inc. of Chicago and distributed to planetary program principal investigators during FY81. Globes of the Moon and Mars are nearly complete and are being distributed as they are received from the manufacturer. All globes have nominal scales of 1:32 million.

Preliminary maps of the Galilean and Saturnian satellites were completed, and the 1:5 million maps of the Galilean satellites are in preparation: work has progressed through the level 1 stage (radiometric and cosmetic corrections) for most Voyager images and the level 2 stage (map projection) of a large number of images. The Europa Je 3 quadrangle is ready for use by geologic mappers, and 11 other maps are scheduled for completion during FY82.

Batson and colleagues are also involved in a number of products on Mars. A catalog of Viking Orbiter pictures, processed prior to December 1978, is in press. This catalog consists of 198 "subquad" mosaics, originally compiled at a scale of 1:1,250,000. Compilation of a series of 140 controlled photomosaics of Mars at a scale of 1:2 million is continuing. To date, a total of 71 mosaics have been published, 29 mosaics are in press, and 18 mosaics are in preparation. A 1:15 million scale airbrushed albedo map of Mars is in progress and several of the 1:5 million-scale maps of Mars, originally compiled from Mariner 9 pictures, are being upgraded by adding details from Viking Orbiter pictures to the original airbrush drawings. Of these, five quadrangles have been published or are in press, four are in revision.

Four special Mars maps were completed and published or submitted for publication during FY81. These are: 1) a shaded relief map of the Chryse

Planitia region of Mars, 2) an orthophotomosaic of the Arsia Mons region of Mars, 3) a controlled photomosaic of the Olympus Mons region of Mars, and 4) a shaded relief map of the Coprates Northwest quadrangle of Mars. A series of controlled mosaics of high-resolution Viking pictures is being developed for mapping selected areas at scales of 1:500,000.

Special techniques for 3-dimensional transformations of Viking Orbiter pictures have been developed. The techniques are now sufficiently refined to allow their routine use in compiling orthophotomosaics and 3-dimensional illustrations. Their use has been demonstrated for the Arsia Mons region in the preparation of an orthophotomosaic, and monoscopic and stereoscopic oblique presentations of the mountain.

Merton E. Davies refined control nets for Mars and computed nets for the satellites of Jupiter and Saturn. The planet-wide control net of Mars has been strengthened by adding strips of Viking mapping frames to the existing data set. The horizontal coordinates of the control points on Mars have been updated with a single-block planet-wide analytical triangulation computed in September 1981. Geodetic control networks for the large satellites of Jupiter and many of the satellites of Saturn are based on pictures of the Voyager 1 and 2 encounters. Points have been identified on the satellites and the coordinates computed by single-block analytical triangulations. The coordinate systems have been established assuming that all the satellites are in synchronous rotation and that their spin axes are normal to their orbital plains.

Photogrammetric techniques are being used by Sherman S. C. Wu and colleagues to compile topographic maps of the planets. For Mars, a planet-wide control network is being prepared. The network uses more than 900 high-altitude Viking orbital photographs and includes Goldstone Radar Data. The existing global map at a scale of 1:25 million is being revised. Thirteen 1:2 million-scale subquads and special maps of Olympus Mons and Arsia Mons

have been distributed to PGPis. For Venus, the global topographic contour map has been completed. VOIR radargrammetry is undergoing measurement tests on the radar stereo plotter, the hardware is completed and the software is being developed.

For the Moon, a topographic datum was defined and published. The datum uses the gravity field of the Moon described in terms of 6 order spherical harmonics; the radius of the mean sphere is 1,738 km. Control networks derived by the Defense Mapping Agency and Schmid-Doyle were converted to the new datum. Topographic information was derived from Apollo and Lunar Orbiter photographs, laser-altimetry, radar sounder data, and earth observations. The new global topographic map will contain three shades and will be in Mercator and polar stereographic projections. It will have a scale of 1:5 million and a contour interval of 500 meters. Wu and colleagues are also compiling contour maps at scales of 1:2,750,000 based on Apollo metric photographs. The reliability of the contours is better than 150 meters.

Geologic mapping continued on Mars and the Galilean satellites. Dave H. Scott reports that the 1:15 million geologic mapping of Mars in the western hemisphere has disclosed new interesting relationships: 1) The new work has allowed detailed subdivisions of lava flow units in the Tharsis region. 2) An ignimbrite province of several million square kilometers has been provisionally identified along the highland-lowland boundary in the Amazonis region of Mars. 3) A new volcanic province has been discovered in the southern highlands and large ring-structures associated with volcanic edifices in the Tempe Terra highlands. 4) The stratigraphic relationships between Tharsis flows, Kasei Vallis channeling, and the Lunae Planum surface were resolved.

The Mare Acidalium area was mapped by Nanci E. Witbeck and James R. Underwood. The map is compiled on 1:2 million photomosaics and will eventually be transferred to the 1:5 million quadrangle MC-4. Eight geologic subdivisions were found within the lowland plains; particularly the unit previously known

as mottled plains has been reassigned to 5 new units. The plains materials represent a complex history of depositional and erosional events that involve volcanic, fluvial, aeolian, and glacial processes.

More restricted geologic mapping on Mars concentrated on channel features. Ellen Stofan and associates investigated Mangala Vallis. They proposed that flood material, probably in the form of viscous mudflows, ponded behind structural ridges that acted as temporary barriers to the flood. The mudflows partially dewatered and, upon breaking through, created a complex of terraces and channels. Counts of crater densities on various parts of the channel do not show any age differences.

D. C. Pieri and T. Parker mapped the region including Nirgal Vallis and the Uzboi-Ladon-Holden Valles complex. Preliminary findings include 1) a range of ages for the nearby Lunae Planum, 2) location of both upper and lower Nirgal Vallis in a specific unit, and 2) strong structural control by an old, 600-km diameter basin in Margitifer Sinus that dictates part of the alignment of the Uzboi-Ladon-Holden valleys. High-resolution pictures of Nirgal Vallis show the expression of wrinkle ridge structures in the valley walls, structured debris deposits on the valley floors, possible Thalweg features in some valley reaches, and a small chaotic deposit associated with the mouth of the Nirgal at its debouchment into Holden Vallis.

Preliminary geologic maps based on the 1:25 million version of the Galilean satellites were prepared for Io, Europa, and Ganymede. The maps are being published in a book on the Galilean satellites by D. Morrison. For Europa, B. K. Lucchitta and L. A. Soderblom reported that it differs from the terrestrial planets in lacking evidence for a horizontally stratified crust. Rather, Europa's geology appears characterized by disruptions of the crust and intrusions of ice-rock breccia. They proposed that the depth of the ice-layer to a silicate subcrust is probably no more than a few tens of

kilometers and they generally favor a thin-ice model, where ice overlies a hydrated lithosphere.

A program of geological mapping of the Galilean satellites at scales of 1:5 million involves about 40 investigators from universities research institutes, and government offices in the USA, England, Germany, and Italy. Data packages containing all good-quality high-resolution pictures of Io, Europa, and Ganymede have been mailed to the investigators in order to enable them to gain an overview of the geology of the satellites. Preliminary mapping is in progress.

Special Programs

Seven papers were presented in this section, most of which provided progress reports on many of the special programs.

King reported on the Planetary Geology Undergraduate Research Program (PGURP). A brief history of the program from its inception following the Viking Mission in 1976 was presented along with the objectives of the program. It was indicated that announcements of this program are sent each year to all geoscience departments listed in the Directory of the American Geological Institute usually in late September. Some perennial problems involving posting of these announcements by the recipient departments have occurred whereby some potential applicants do not hear of the program sufficiently early to apply. Some effort is being directed to resolve this problem. Selections of successful applicants are made by a selection committee and every attempt is made by this committee to match skills and interests of the undergraduate researcher with the proposed project of the host. An appeal was made for new hosts to become involved in the program. The undergraduate research program has been well-received by both selected applicants and the hosts. 1982 will be the 6th year of this program and a preliminary review of the applications and the hosting institutions and projects indicates that it will be as successful this year as in the past.

Greeley presented a progress report on the Planetary Geology Speakers Bureau. He indicated that the Speakers Bureau went into operation in the spring of 1981. Fliers were sent to all geoscience departments in the United States and Canada and the program was announced in Geotimes and EOS. The bureau consists of 18 Principal Investigators who can speak on a wide range of Planetary Geology topics. To date each of

the 18 speakers has averaged two speaking engagements. In most cases, at each host institution, speakers gave both a general talk with a wide interest appeal plus a specialized seminar. The announcement of this program will be reprinted in 1982 for a second distribution.

Wall and Pieri discussed the third Mars year of imaging after the Mutch Memorial Station. They indicated that the Viking Lander Monitor Mission is continuing into its fourth Mars year with the Viking I lander, now designated as the Mutch Memorial Station. The lander is in excellent health with the exception of two of the four batteries which are 60% degraded. Software changes are currently being implemented to attempt recovery of these batteries' capacity and to provide for automatic downlink should the lander command receiver fail. Image processing is continuing and product deliveries are on schedule. The scene at the lander site is slowly being modified by aeolian redistribution of fines both during dust storms and at other times. Both removal and deposition has occurred, but removal dominates and has generally brightened the scene albedo and reduced surface contrast. Two small slumps have been observed, one of which may be being covered during the third year by settling fine material. Imaging and meteorology data indicate that a local dust storm may have occurred near sol 1750 ($L_S = 335^\circ$).

Henry Moore reported on some observation of changes which occurred at both Viking Landers. He described how conical piles of surface materials constructed by the Viking lander surface samplers have retained their form and relief for more than one martian year. Their survival is largely the result of large wind-threshold velocities that are required to entrain the fine-grained cohesive materials and wind gusts with speeds of 35 m/s and less. Materials deposited in the footpads have

changed in dramatic ways, undramatic ways and hardly at all. Of particular importance is a miniature "landslide" in footpad 3 of Lander I which constrains the adhesion of metal and "soil" to a value of 5 to 9 Pa.

Further characteristics of the lander sites were reported by Moore. Natural landslides at the Lander I site appear to occur in the late summer (L_S 148). The landslides are located on planes of weakness and probably are initiated by positive pore pressure generated by desorption of CO_2 from soil surfaces when the atmospheric pressure is at minimum, average temperatures are a maximum, and the diurnal variation of temperature is a maximum.

"Soil" temperatures measured by the surface samplers about 5-6 cm below the surface during the winter time at the Lander 2 site are higher than the CO_2 - CO_2 water clathrate temperatures throughout most of the day and they are always larger during the springtime. These temperatures show that the winter "snow fall" is composed largely of water-ice.

Arvidson discussed storage of digital data on videotapes and videodisks. He explained that problems exist with acquiring digital data from national facilities because of the costs of copying and distributing magnetic tapes. Videodisks using laser technology have an intrinsic high density for storage of analog data including encoded digital data. For instance, it is theoretically possible to store data from 100 to 200 magnetic tapes (2400 feet, 1600 BPI) on one videodisk. Arvidson indicated that they are pursuing a test disk with all Viking Lander image data stored on it as encoded digital data. They are employing a SONY pulse code modulation scheme. Test data has been successfully encoded, stored, and converted back to digital data. The bit error rate is about 10^{-6} , which is fine for most image data. It is hoped to have a test disk ready and to

have demonstrated the feasibility of the system next year.

Vostreys gave a progress report on planetary data at the NSSDC. He explained the functioning, organization, and services that the National Space Science Data Center/World Data Center A for Rockets and Satellites (NSSDC/WDC-A-R&S) provides to the scientific community. He indicated that 479 data sets from 177 planetary probe experiments are available for additional research and analysis by investigators. In 1981, NSSDC provided data to 1,788 investigators of whom 465 were lunar and planetary researchers. Data from the early lunar missions through the recent Voyager encounter with Saturn is currently being provided for continuing scientific studies.

Smith gave the final presentation of this session for Tobias Owen. This was a progress report on the nomenclature of the outer solar system. He indicated the origin of names as follows: Mimas (the Legend of King Arthur); Tethys (the Odyssey - with the largest crater Odysseus); Dione (the Aenead); Rhea (creation myths with Asian emphasis). It was also indicated that the names of satellite discoverers will be commemorated on one of the satellites they discovered. The assignment of names for Saturn was deferred until April of 1982. The name for Pluto's satellite (Charon) has been accepted but assignment deferred awaiting clarification of the orbit and the body's uniqueness. The letter designations (A,B,C,D,E, and F) will be retained for the rings of Saturn and fine structures in the rings will be identified by distance measured from the planet's center. Two division names (Encke and Cassini) are retained but no further gap or division names have been accepted. It has been proposed that newly discovered rings will be classified with a letter designation indicating the planet, the ring number and the year of discovery; i.e. the first Uranus ring discovered in 1981 = UR1-81; NR10-81 = the tenth Neptune ring discovered in 1981. Future work will consider names for surface features of Enceladus and Iapetus among others.

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16 Abstract Recent developments in planetology research as reported at the 1982 NASA Planetary Geology 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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