NASA Technical Memorandum 4428

Directory of Research Projects

Planetary Geology and Geophysics Program

Henry Holt, *Editor*
NASA Office of Space Science and Applications
Washington, D.C.

(NASA-TM-4428) DIRECTORY OF RESEARCH PROJECTS: PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM (Office of Space Science and Applications) 152 p

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H1/91 0136139

National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program
1992

INTRODUCTION

This directory of Research Projects provides information about the scientific investigations funded by the NASA Planetary Geology and Geophysics (PG&G) program during fiscal year (FY) 92. The Directory consists of the summary sheets from the proposals that were selected by NASA for funding in FY 92. Each summary sheet indicates the title, principal investigator, and institution of the investigation and information related to the objectives, past accomplishments, and the research activities proposed for FY 92.

The Directory is intended to provide the science community with an overview of the research projects supported recently by the PG&G program. A supplementary purpose of this Directory is to provide general information regarding the types of research proposals that have been successful in obtaining support under the NASA PG&G program.

Research projects funded under the PG&G program cover a broad range of topics including: the nature and origin of planetary surface features, theoretical and analytical studies of lithospheres, planetary interiors, the dynamics of rings and satellite systems, geologic mapping, remote sensing, comets and asteroids, and terrestrial analog studies of geologic features and processes thought to occur on the other planets and satellites in the solar system. In addition, this program supports several research facilities for the common benefit of researchers within the science community.

Research activities identified in this Directory were selected for funding in FY 92 on the basis of the scientific peer review conducted annually by the Lunar and Planetary Geosciences Review Panel. Statistical information about the FY 92 program is enclosed. A total of nine research investigations were selected for new funding in FY 92. These investigations are also identified on the following pages.

For additional information about the PG&G program, contact one of the persons below:

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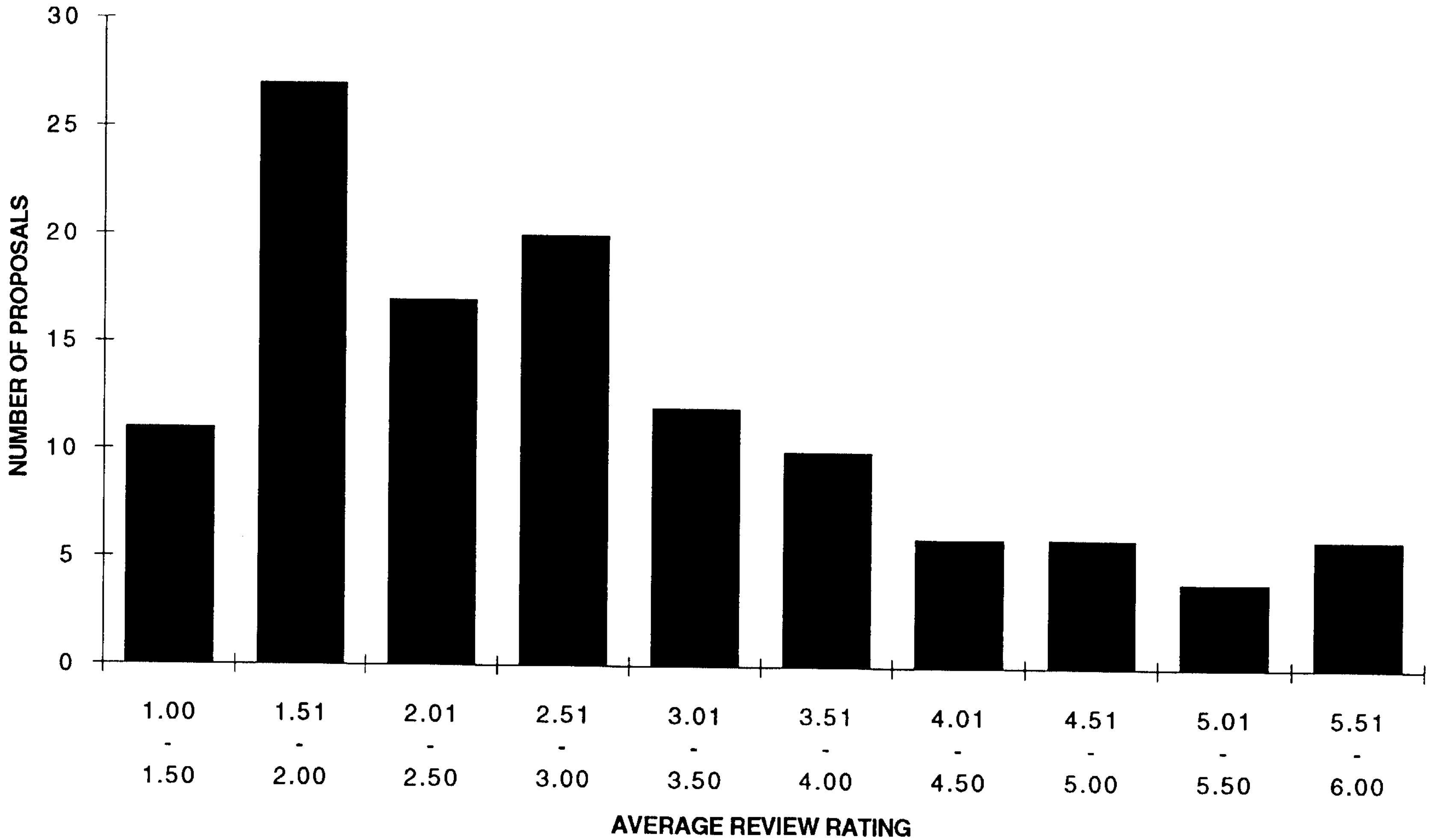
RATINGS SUMMARY FOR PG&G PROPOSALS (FY 92)



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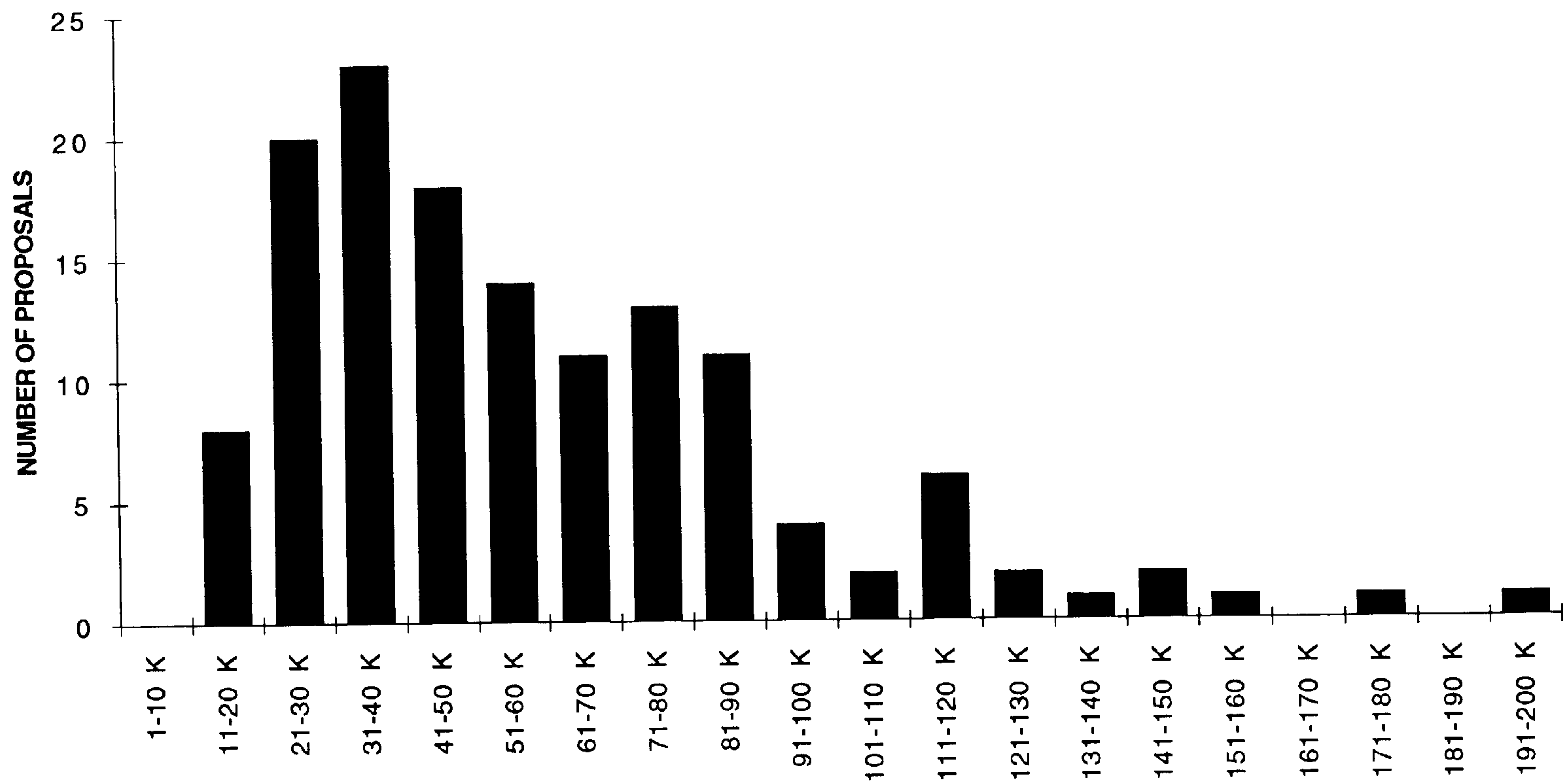
PG&G FUNDING - FY 92



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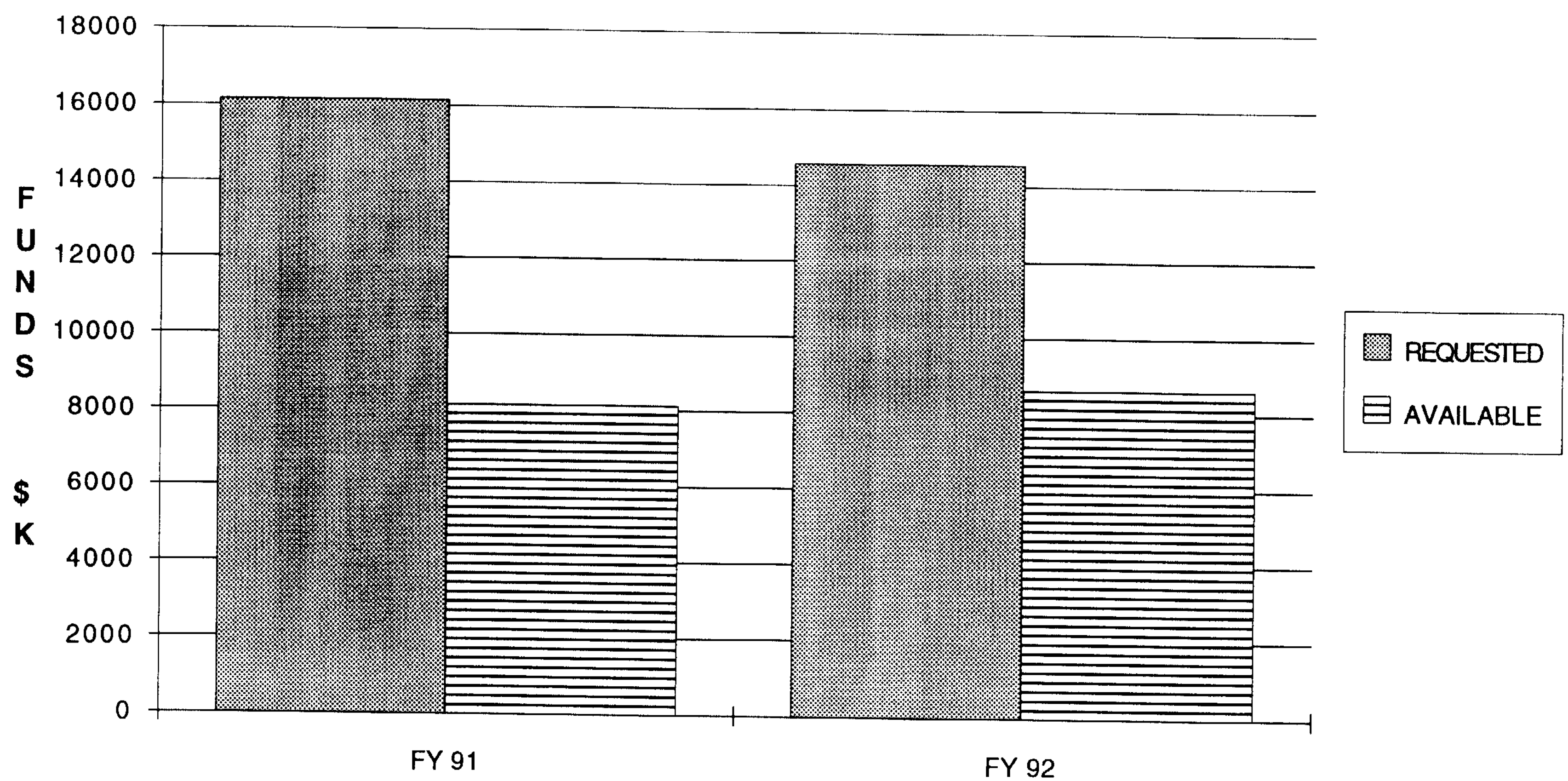
PG&G RESEARCH FUNDS REQUESTED VS. AVAILABLE



9/28/92

NEW PG&G INVESTIGATIONS FUNDED IN FY-92

Principal Investigator	Institution	Title
A'Hearn, Michael/ Schaefer, Martha	Univ. of Maryland	Aqueous Geochemistry & Sedimentary Processes on Early Mars
Alvarez, Walter	UC Berkeley	Study of Impact-Wave Deposits Near the Proposed K/T Boundary Impact Crater in Yucatan
Hansen, Vicki L.	SMU	Structural, Kinematic, & Strain History of Ishtar Terra Deformed Belts, Venus
Herkenhoff, Kenneth	JPL	Geology of the South Polar Layered Deposits on Mars
Kohlstedt, David L.	Univ. of Minnesota	Physical Properties of Partially Molten Ammonia Water Ice
Muhleman, Duane O.	CalTech	Analysis of Synthetic Aperture Radar Images of Mars, Venus, and Mercury
Pearl, John C.	NASA/GSFC	Compositional & Surface Properties of Io from Analysis of its Thermal Spectrum
Stewart, Glen R.	Univ. of Colorado	Kinetic Theory Models of Planetary Rings
Whitford-Stark, J.L.	Sul Ross Univ.	Correlation of Eruption Conditions and Composition of Lunar Lavas

10/5/92

PROPOSAL SUMMARY

ADMINISTRATIVE PRINCIPAL INVESTIGATOR:

Michael A'hearn, Astronomy Program, University of Maryland

CO-INVESTIGATOR: Martha W. Schaefer

Code 921, Goddard Space Flight Center

Greenbelt, MD 20771

(301) 286-7026

PROPOSAL TITLE: Aqueous Geochemistry and Sedimentary Processes on Early Mars

ABSTRACT:

a. Basic objective: obtain a better understanding of the processes that have modified the Martian surface and atmosphere through time, specifically how the atmosphere, hydrosphere, and regolith of early Mars interacted. Such an understanding is valuable for its relevance to the interpretation of present-day Martian geomorphology, and therefore the determination of the geologic history of Mars. Specific questions to be addressed: Can the depletion of the postulated ancient, dense CO_2 atmosphere be explained simply by the formation of carbonate deposits in bodies of water, or are more complicated mechanisms necessary? How is the chemistry of the primary igneous rocks likely to be reflected in the chemistry of the sedimentary deposits formed? How might a proposed primordial Martian ocean evolve over time to produce the sedimentary deposits of the northern plains seen today? b. New Proposal c. A preliminary computer model will be improved in several ways: it will be changed from steady-state to quasi-static, and the ability to model the removal of carbonate from the system over time will be added, enabling a clearer insight both into the evolution of the atmosphere over time, and into the partitioning between atmosphere and regolith of the CO_2 budget of the planet; a greater number of chemical species will be added, in particular, magnesium- and iron-bearing species (to form magnesium and iron carbonates), sulfur-bearing species, and iron oxides; corrections for the effects of salinity will be added. d. Karst on Mars? The thumbprint terrain, M. W. Schaefer, Icarus 83, 244-247 (1990); Geochemical evolution of the northern plains of Mars: Early hydrosphere, carbonate development, and present morphology, M. W. Schaefer, JGR, 95, 14291-14300 (1990).

PROPOSAL SUMMARY / ABSTRACT

PRINCIPAL INVESTIGATOR — John B. Adams
Dept. of Geological Sciences AJ-20
University of Washington
Seattle, WA 98195
(206)543-6221

CO-INVESTIGATORS — Milton O. Smith

PROPOSAL TITLE — Spectral Reflectance of Planetary Surfaces

ABSTRACT

a. Our overall research objective is to provide new information on the chemistry, mineralgy and geology of planetary surfaces using multispectral images and reflectance spectra in the visible and near-infrared wavelength region. The approach is to interpret the remotely sensed data in terms of laboratory reference spectra, and to use spectral mixing models to quantify mineral phase-abundances.

b. We developed spectral calibration and spatial registration procedures for telescopic CCD images of Mars in collaboration with P. Pinet and J. Bell. We found that registration of CCD images taken at different times during which Mars had rotated could be optimized by minimizing the fraction errors in a spectral mixture analysis. We studied multiple Viking Orbiter images of the Apollinaris Patera region, and demonstrated that an area on the surface changes significantly in the fraction of bright dust with time. We found a new spectral analog of Martian bright dust in a Hawaiian palagonitic tephra that was formed by contact heating of tephra by a basalt dike.

c. In the coming year we propose to complete a paper on a comprehensive evaluation of ways to calibrate spectral data of Mars. We will present an assessment of all major kinds of spectral reflectivity data, and evaluate these data in terms of the compositional heterogeneity of the surface of Mars and the detectability of surface materials.

d.

Robinson M.S., Smith M.O., and Adams J.B., Time variable spectral feature at Apollinaris Patera, Mars, Lunar and Planet. Sci. Conf. XXII, March 1991.

Bell J.F. III, Morris R.V., and Adams J.B., Thermally altered palagonitic tephra as a Martian soil analog, Lunar and Planet. Sci. Conf. XXII, March 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Thomas J. Ahrens
Seismological Laboratory
California Institute of Technology
Pasadena, CA 91125 818/356-6906

CO-INVESTIGATOR(S):

TITLE: Impact Cratering Calculations

ABSTRACT:

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a. Objectives:

To describe and understand the physics of impact cratering, both normal and oblique, on planetary surfaces and impacts of similar sized objects composed of solid silicates, ices, and their regoliths, as well as impacts into planetary atmospheres and proto-atmospheres and into the ocean. On a larger scale we expect to constrain impact conditions for partial and complete loss of atmospheres as well as whole planet, devolatilization melting and/or disruption. This includes determining energy partitioning and ejecta distributions (with regard to size, velocity, energy content, and sorting). We also expect to study the interaction of planetary atmospheres with the cratering process.

b. Accomplishments:

1) In the process of studying the effects of planetary crustal strength and gravity on crater formation, depth of penetration, and depth of melting, we discovered the onset of crater (diameter) growth via a surface-wave driven by the collapse of the crater lip. During growth of crater diameter, via this mechanism, the floor of the crater is also rebounding and material on the crater lip moves upwards and outwards similar to the particle motion of a surface wave. Thus, the final crater diameter in this regime is unrelated to what has been previously identified as the transient bowl-shaped crater.

2) We have written a fully 3-dimensional Smoothed Particle Hydrodynamics (SPH) code and have applied it to study energy partitioning and shock-induced melt and vapor production as a function of impactor and target size, impact velocity, and geometry of impact. For example, for normal impact at 20 km/sec on a 1700 km radius silicate planet, 17% of the target is shock melted and 4% is vaporized; for a similar impact on a 6000 km radius planet, the corresponding figures are 38 and 6%.

3) We have written a 2-dimensional code for calculating the interaction of inclined bolide shocks and waves in the Venus atmosphere with the planetary surface in 3 dimensions and examined the conditions for mobilization, via gas entrainment of different-sized surface granular materials. We have also studied the "refraction" effect of the Venus atmosphere on the trajectory of incoming bolides. This is an important problem to study because unlike the Moon or even Mars, evidence for oblique impact is better preserved in the ejecta pattern (because of atmospheric entrainment) on Venus.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Thomas J. Ahrens
Seismological Laboratory
California Institute of Technology
Pasadena, CA 91125 818/356-6906

CO-INVESTIGATOR(S):

TITLE: Impact and Collisional Processes in the Solar System

ABSTRACT:

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a. Objectives:

We are carrying out experimental research on mechanical and thermodynamic aspects of shock and impact cratering and accretionary processes on solid planets, and their atmospheres and satellites. Experiments are being conducted to understand impact induced melting and vaporization of minerals on the terrestrial planets, their satellites and the icy satellites. Recent theories of the impact origin of the Moon and impact devolatilization of Mercury need to be tested with these data.

We measure the shock pressure, and hence, infer corresponding impact velocities of infalling planetesimals during planetary accretion which are required to induce melting and vaporization of planetary materials. We are studying the release of volatiles by impact on water-, carbon dioxide-, sulfur-bearing minerals, and hydrocarbons because this process is believed to underlie the accretion of planetary atmospheres. Studies of noble gas devolatilization are conducted to constrain theories of atmospheric evolution. We combine experimental data on shock-induced melting and vaporization and theories of planetary atmospheric growth to understand the chemistry of interaction of hot proto-planetary surfaces with proto-atmospheres. To understand impact production of melt and vapor from silicates and formation of magma oceans on the Earth, Moon, and Venus, we are studying shock temperatures in the minerals of planetary crusts and mantles. We are conducting shock loading experiments on rocks in order to understand and be able to describe their mechanical response which gives rise to the observed negative Bouguer gravity anomalies observed over impact craters on the Earth and Moon, and the seismic velocity deficits beneath impact and explosion craters. Oblique impact experiments are being studied to both understand the transfer of angular momentum in oblique collisions in the solar system as well as to provide fundamental data on the state, velocity and mass of jetted material upon large body impact.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Walter Alvarez
(Name, Address, Telephone Number) Dept. Geology and Geophysics
Univ. California, Berkeley CA 94720
415-642-2602 415-642-9299

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Study of impact-wave deposits near the proposed KT boundary impact crater in Yucatan

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

Throughout the 1980s evidence accumulated in support of a large bolide impact as the cause of the paleontological mass extinction at the Cretaceous-Tertiary (KT) boundary, 65 Myr ago. It was disappointing, however, that the crater could not be identified. This situation has changed in the last year with the proposal that a circular, 100-200 km diameter subsurface structure on the north coast of Yucatan may be the KT impact site. This hypothesis predicts that nearby KT boundary localities should contain proximal ejecta and show stratigraphic evidence for impact-generated megawaves.

In recent work we have located two proximal localities which do in fact agree with these predictions. (1) We have restudied DSDP sites 536 and 540, recognizing current-bedded, altered-glass sand dating precisely from the KT boundary and containing the iridium anomaly characteristic of the KT boundary impact horizon elsewhere. (2) In February, we discovered a superbly exposed outcrop in NE Mexico containing the altered microtektites typical of other proximal sites, and sedimentologically recording a series of major wave/current events precisely at the KT boundary. This is probably the best outcrop yet discovered for inferring the nature of the KT boundary impact event.

We propose three lines of research which should contribute to understanding of the proposed KT impact event in Yucatan: (1) detailed study of data and samples we collected from our new site in Mexico, (2) field work aimed at finding and studying other proximal sites in Mexico, and (3) theoretical consideration of the results of impact in Yucatan and how these results would be recorded in proximal stratigraphic sections.

The work proposed here should produce a significant increase in understanding of the largest known impact event on Earth. It will both benefit from and contribute to understanding of impact as a geological process on other solar-system bodies.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Raymond E. Arvidson
McDonnell Center for the Space Sciences
Dept. of Earth and Planetary Sciences
Washington University, Campus Box 1169
St. Louis, Missouri 63130

Co-INVESTIGATORS: (Name Only)
Edward A. Guinness

PROPOSAL TITLE: EVOLUTION OF PLAINS ON VENUS AND MARS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Geological evolution of plains on Mars and Venus, based on analysis of compositional and textural maps generated from Earth-based and spaceborne data sets. Ground truth tests using similar data for terrestrial targets. DBMS systems for RPIFs.

(b) Pre-Magellan papers summarizing Goldstone observations, likelihood of aeolian activity, and preferred model for Venusian resurfacing history. Compilation of 5 Gbyte archive for PG&G-funded Geologic Remote Sensing Field Experiment (GRSFE). Initial GRSFE data analyses of multi-emission angle playa and lava flow observations.

(c) GRSFE field and airborne observations for Lunar Lake playa, lava flows, and ash deposits to test models for compositional and textural mapping. Initial work on compositional mapping of Coprates and Phoenicis Lacus quadrangles, Mars. Tests of hypotheses for timing of plains resurfacing on Venus. Generation of Magellan data product catalog for RPIFs.

(d) Arvidson et al., 1990, GRL, 17, 1385-1388; Plaut et al., 1990, GRL, 17, 1357-1360; Greeley and Arvidson, 1990, Earth, Moon, Planet., 50, 127-157; GRSFE 8 CD-ROM data set collection.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Victor R. Baker
Department of Geosciences, University of Arizona
Tucson, AZ 85721 (602) 621-6003

Co-INVESTIGATORS: (Name Only)

William D. Sellers (Task 1)
Valentina I. Sumin (Task 2)

PROPOSAL TITLE: Planetary Geomorphology

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. **Objective:** Task 1 - Understand the processes and history of paleohydrological and hydroclimatological change on Mars. Specific mechanisms of hydrological cycling will be evaluated by modeling of dynamical processes and by geomorphological study of various channels, valleys, and related hydrogeomorphological features. Task 2 - Develop the procedure of morphostructural analysis to analyze the role of endogenetic processes (hot spots, mantle convection) on the surfaces of Mars and Venus.

B. **Progress:** (1) Discovery of ocean-land-atmosphere interactions as an explanatory system for interrelated volcanic, glacial, periglacial, and fluvial landforms on Mars, (2) Development of the hydrothermal model to explain valley development on Mars (e.g. Gulick and Baker, 1990), (3) Geomorphological mapping of valleys associated with impact craters and volcanoes on Mars, (4) Development of hydraulic procedures for analyzing discharges of Martian outflow channels, (5) Development of explanations for valley formation based on terrestrial studies of ground-water sapping processes, (6) Discovery of the sequence of valley formation on Mars in relation to volcanic terrains.

C. **Proposed Work:** Task 1 - Continue mapping, morphometric studies, photointerpretation, and theoretical analysis of channels and valley networks on Mars. The new global model of ocean-land-atmosphere interactions through Martian history will be evaluated against the observational base and through quantitative modeling. Groundwater modeling will be used to analyze outflow processes and ocean inception. Climatological implications will be analyzed with a quasi-three-dimensional global climate model. Model simulations and geomorphological work will be closely integrated. Task 2 - Initiate morphostructural analysis of Venus and Mars, using topographic data (Pioneer, Venera, Viking) and imagery. Compare planetary morphostructures to known earth structures. Select geophysical models appropriate to geological constraints.

D. **Publications:**

Baker, et al., in press, Channels and valley networks, in Mars (H.H. Kieffer, B. Jakosky, and C. Snyder, editors): Univ. of Arizona Press, Tucson.

Gulick, V.C., and Baker, V.R., 1990, Origin and evolution of valleys on Martian volcanoes: Jour. Geophys. Res., v. 95, no. B9, p. 14,325-14,344.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Stephen Baloga
Jet Propulsion Laboratory
MS. 183-501, 4800 Oak Grove Dr.
Pasadena CA, 91109
(818) 354-2219

CO-INVESTIGATORS: Joy A. Crisp

PROPOSAL TITLE: QUANTITATIVE STUDIES IN PLANETARY VOLCANISM

OBJECTIVES: The objective of this research is to improve the quantitative understanding of physical processes in volcanism on Mars, Io, and the Earth. Specific objectives are: 1) To develop quantitative methods for assessing the relative influence of topographic and rheological controls on the emplacement of planetary flows and apply the results to selected volcanoes on Mars, 2) To develop new energy balances for explosive eruption columns that incorporate radiation, latent heat release and particle losses and investigate the large scale fumarolic activity for selected surface features on Mars, and 3) To establish eruption and compositional constraints on volcanological processes with models that have been calibrated using terrestrial analogues.

PROGRESS: Two papers co-authored with Dr. J. A. Crisp on thermal processes (radiation and conduction) in terrestrial and planetary lava flows were published. This model has been extended by the P.I. to include the effect of flowbed heating by a lava flow. The methodology for modeling the conservation of lava flow volume was submitted and is under revision. A three-dimensional model for an unconfined lava flow over arbitrary topography was formulated, solved, and applied to terrestrial basalts and dacites. Progress was achieved on the effects of latent heating and particle fallout on the rise of buoyant volcanic plumes and fumaroles.

PROPOSED WORK: Research on thermal processes in lava flows will be completed with a paper comparing radiative effects with flowbed heating and the results applied to revise eruption rates of flows on Mars shields, paterae, and plains and the lobate flows on Io. New theoretical results for the influence of topographic versus rheologic controls on lava flows with be applied to Mars data. Volatile dispersal by large scale fumarolic activity on Mars will be completed.

SUMMARY BIBLIOGRAPHY : Crisp, J. and S. Baloga, (1990) Lava flows with two thermal components, JGR, 95, 1255-1270; Crisp, J. and S. Baloga, (1990) A method for estimating eruption rates of Planetary lava flows, Icarus 85, 512-515; Baloga, S., Inversion of volume conservation laws for mass movements (submitted and under revision); Other drafts in preparation are presented in Appendices.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: W. Bruce Banerdt
Jet Propulsion Laboratory, MS 183-501
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-5413 (FTS) 792-5413

CO-INVESTIGATORS: None

TITLE: Planetary Tectonics

ABSTRACT

A. The broad objective is to better understand the mechanical behavior, structure, and history of the crusts and upper mantles of the solid planets and satellites.

B. During the past year we have: (i) continued the investigation of mechanical and petrological constraints on the evolution of Tharsis, combined with information derived from geological observations; (ii) initiated an investigation of the historical and inferred current seismicity of Mars based on its faulting history; (iii) examined the effects of vertical loads on the horizontal state of stress in planetary lithospheres.

C. In the remaining year of this proposal I plan to work on the following tasks: (i) continue the work underway using stress predictions, petrological constraints, and tectonic observations to test various models for the thermal and tectonic history of the Tharsis region of Mars, and develop a general modelling framework for further extending these studies; (ii) complete the study of martian seismicity based on faulting history; (iii) complete the derivation of rational bounds on the state of stress in a lithosphere due to vertical tectonics; and (iv) investigate tectonic deformation processes and subsurface structure on Io using realistic rheological assumptions and broad-scale topographic data

D. Selected References:

Banerdt, W. B., M. P. Golombek, and K. L. Tanaka, Stress and Tectonics on Mars, in *Mars*, H. Kieffer, B. Jakosky, and C. Snyder, eds., University of Arizona Press, Tucson, Arizona, in press, 1991.

Tanaka, K. L., M. P. Golombek, and W. B. Banerdt, Mars Tharsis region: Reconciling stress and structural histories, *J. Geophys. Res.*, in press, 1991.

Golombek, M. P., Tanaka, K. L., W. B. Banerdt, and D. Tralli, Mars seismicity through time from surface faulting, *Lunar Planet. Sci. XXII*, in press, 1991.

Banerdt, W. B., Horizontal stresses induced by vertical changes in the lithospheric column, *EOS Trans. Am. Geophys. Un.*, 71, 1623, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Jeffrey Bell
Planetary Geosciences, Dept. Geology & Geophysics
2525 Correa Rd. Honolulu, HI 96822 (808)956-3136

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Spectral Studies of Possible Asteroid Materials

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The objective of the proposed work is to improve our understanding of the surface mineralogy of asteroids, and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be targets of future NASA missions. The methodology to be employed is: 1) prepare simulated asteroid regolith material by pulverizing meteorite samples or constructing artificial mineral mixtures corresponding to hypothetical asteroid compositions, 2) obtain IR (0.3-5.0μm) reflection spectra of the simulated regolith, 3) analyze the lab spectra for systematic changes with composition, 4) use the knowledge obtained in the lab to analyze asteroid spectra obtained telescopically and develop mineralogical interpretations of the surfaces of selected objects, and 5) integrate the mineralogical information with other astronomical data, orbital dynamics, and meteorite studies to reconstruct the condensational, thermal, and collisional history of the asteroids and their parent planetesimals.

b. compared asteroid and meteorite spectra via principal component analysis; studied mineralogy of S asteroids including Galileo flyby candidates; examined new asteroid family lists of Zappala *et al.* for mineralogical consistency.

c. Obtain lab spectra of rare and newly discovered chondrite classes; continue to study asteroid families for clues to interior structure of parent bodies; study unusual stony-iron meteorites thought to be S asteroid analogs.

d. Cruikshank, D. P., D. J. Tholen, W. K. Hartmann, J. F. Bell, and R. H. Brown, Three basaltic asteroids and the souirce of the basaltic achondrite meteorites. *Icarus* 89, 1-13 (1991). Bell, J. F., D. Davis, W. K. Hartmann, and M. J. Gaffey, Asteroids: The Big Picture. In ASTEROIDS II, (University of Arizona Press, 1989), pp. 921-945. Bell, J. F., Mineralogical Clues to the Origins of Asteroid Dynamical Families. *Icarus* 78, 426-440 (1989).

Proposal Summary

Principal Investigator: Alan P. Boss

Department of Terrestrial Magnetism
Carnegie Institution of Washington
5241 Broad Branch Road N.W.
Washington, D.C. 20015
(202)686-4402

Proposal Title: Three Dimensional Evolution of the Solar Nebula

Abstract

(a) *Objective*: This proposal seeks continued support for a research program devoted to a theoretical investigation of the solar nebula. Using finite difference solutions of the three dimensional equations of hydrodynamics, gravitation, and radiative transfer, the collapse of dense molecular clouds can be followed through to the formation of the protosun and the solar nebula. The numerical models yield physical properties of key importance for planetesimal accumulation and chemistry, such as surface density and midplane temperature profiles. Three dimensional models allow the study of global processes such as nonaxisymmetric structures that lead to angular momentum transport by gravitational torques, a process that may have controlled the dynamical evolution of the solar nebula.

(b) *Progress*: New proposal.

(c) *Proposed work*: The primary aim is to improve significantly upon the previous study of three dimensional solar nebula formation (Boss 1989, see below) through the use of more accurate numerical methods and more likely initial conditions. The goal is to learn whether or not the detailed results of the previous study (such as relatively high temperatures in the inner solar nebula; Boss 1990, see below) are correct. A new numerical code has been developed during the previous grant period, including second-order accurate hydrodynamical fluxes as well as many other improvements, and this new code will be used to calculate a suite of models of the formation of the solar nebula in two and three spatial dimensions. The new models will focus on collapse starting from centrally condensed density profiles that characterize dense cloud cores and are thought to lead to single star formation. A separate proposal to the *Origins of Solar Systems* program requests an augmentation to this proposed research through support of a postdoctoral fellow. The fellow will study mixing and transport processes in the solar nebula models in the context of meteoritical evidence for homogeneity and heterogeneity of certain elements and isotopes.

(d) *Relevant recent publications:*

A. P. Boss (1989), Evolution of the Solar Nebula. I. Nonaxisymmetric Structure during Nebula Formation, *Astrophysical Journal*, 345, 554-571.

A. P. Boss (1990), 3D Solar Nebula Models: Implications for Earth Origin, in *Origin of the Earth*, J. Jones and H. E. Newsom, eds. (Houston: Lunar and Planetary Institute), pp. 3-15.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Dr. Frank Bridges, Physics Board
University of California, 1156 High Street, Santa Cruz, CA 95064 (408) 459-2938

Co-INVESTIGATORS: (Name Only) Dr. Douglas Lin

PROPOSAL TITLE: Structure of Saturn's Rings: The Dynamics and Agregation of Water Ice Particles

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

We propose two series of experiments that simulate the environment in Saturn's rings, and which likely have a more general significance in the development of planetesimals in dust clouds. The first series of experiments will measure the coefficient of restitution in glancing angle collisions using our recently developed 2-D pendulum system. Such collisions likely play an important role in the dynamics of ring particle collisions and may be the dominating influence in areas of the rings with a large optical depth. The second set of experiments address the question -- what holds small clusters together? We have found that water frost provides a large sticking force at low temperatures for collisions below a critical velocity, and think that many other frosts would also result in a large sticking force. We will expand our measurements to include a wide range of materials and also make some sticking measurements at much lower temperatures (down to 4.2K using a liquid helium cryostat system) for gases such as oxygen and nitrogen.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert H. Brown
Jet Propulsion Laboratory
M.S. 183-501
4800 Oak Grove Dr.
Pasadena, Ca. 91109

CO-INVESTIGATORS: Dennis L. Matson, Jacklyn R. Green

PROPOSAL TITLE: Observations and Theory of Solid-State Greenhouses on Icy Satellites

ABSTRACT:

a) OBJECTIVES: Our main objective is to modify and apply our existing solid-state greenhouse models to the solid-state greenhouse effect on icy satellites, in particular to Triton and its geyser-like plumes. Prior work on the solid-state greenhouse effect for icy satellites around Jupiter and Saturn has shown that recognition of and understanding the nature and scope of the solid-state greenhouse effect can be important to understanding icy-satellite thermal histories and their geological evolution.

b) PROGRESS: In the past year we have applied our model to a preliminary analysis of the energy sources of Triton's geyser-like plumes. We found that the solid-state greenhouse effect can indeed provide the energy required, and that at present this model is the best explanation for the location, distribution and scale of Triton's plumes. We have also collaborated with Dr. Randy Kirk at the USGS in Flagstaff on a model of the for how the energy to drive Triton's plumes is collected and stored, as well as how that energy is delivered to the plume vents via latent heat transfer. The bulk of that preliminary work appeared in a *Science* special issue on Triton which the PI organized and which appeared on October 19, 1990.

c) PROPOSED WORK: We have several directions in which we are proceeding this year. The first consists of studying models of the internal heat transfer within Triton as it interacts with the extensive cover of solid nitrogen on Triton's south pole. Preliminary models indicate that Triton's internal heat has a substantial effect on Triton's global temperature and atmospheric pressure (paper appeared in *Science* on 3/18/91), and we are pursuing those ideas with more detailed models of the coupling of the internal temperature distribution and heatflow on Triton with Triton's south polar cap material. We are also initiating laboratory experiments to measure the absorption coefficient of solid N_2 over a wide range of temperature and wavelength to more strongly constrain the propagation scale length for sunlight in N_2 ice as well as to constrain the range of possible sizes for the ice crystals on Triton's surface.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bonnie J. Buratti
(Name, Address, JPL 183-501
Telephone Number) (818) 354-7427

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Surface Properties of the Satellites of the Outer Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. OVERALL OBJECTIVES: 1) Study the importance of various exogenic alteration processes in the outer Solar System. 2) Characterize short-term (~day) outbursts on the asteroid/comet 2060 Chiron. The study of these outbursts will lead to a better understanding of the nature of volatile release in Chiron and other comets. 3) Determine the physical validity of photometric models such as that of Hapke by initiating a program of laboratory measurements and modeling of a range of planetary surface analogues.

b. **ACCOMPLISHMENTS OF FY 1991:** 1) Published multispectral maps of the five major airless Saturnian and Uranian satellites; 2) Finished an analysis of the exogenic alteration processes in the Jovian system; 3) Analyzed a rapid decrease in the brightness of 2060 Chiron's coma; and 4) Modeled the IUE phase curve of Oberon.

c. **PLANNED ACCOMPLISHMENTS FY 1992:** 1) Attempt to detect short term changes in the coma of Chiron and changes in its lightcurve to understand volatile release in comets; 2) Construct a low resolution UV map of Oberon from Voyager images to better understand the importance of exogenic alteration processes on its surface; 3) Create (from astronomical observations) and model the first visual phase curve of Ariel and Umbriel to understand their surface properties and geologic evolution; 4) Compare the albedo patterns on the Saturnian satellites with those expected from meteoritic erosion; and 5) Obtain laboratory measurements of the phase curves of a set of planetary surface analogues to determine the range of validity of photometric theories such as that of Hapke, and develop a library of such data.

D. **TWO RELEVANT RECENT PUBLICATIONS:** 1) B. Buratti et al. (1990) Albedo and color maps of the Saturnian satellites, Icarus 87, p. 339-357. 2) B. Buratti and R. S. Dunbar (1991). Observation of a rapid decrease in the brighness of 2060 Chiron. Ap. J. Lett. 366, L47-49.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Professor Joseph A. Burns
CRSR, 328 Space Sciences Bldg., Cornell Univ
Ithaca, NY 14853-6801 ; 607/255-7186/6909

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Physical Processes in Planetary Rings

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives. We wish to understand the processes that govern planetary rings, particularly narrow ones and faint ones, since they are affected by a different suite of physical processes than dense planetary rings. By considering slightly different situations from the dense rings, we hope to isolate the relevant physics in both circumstances. Since the processes that act on planetary rings have counterparts in the dynamics that occurred in the solar nebula and the circumplanetary disks out of which planets and satellites, respectively, grew, our studies may be relevant to the birth of the solar system.

b) Progress. Our study of narrow perturbed rings included a systematic search of Saturn's F ring for periodic signals due to satellite perturbations, a numerical scheme for simulating the true 3-D problem and a code for incorporating collisions. The following faint ring problems were considered: physics of circumplanetary dust, orbital resonances associated with passage of dust through planetary shadows, and dynamics of E ring particles. We also studied the nature of the region surrounding an asteroid in which material might be trapped.

c) Plans. We will complete our study of narrow perturbed rings, including the influence of collisions; and we will apply our understanding of the F ring to the Encke ringlet and to the Keeler gap. We will write up our finished research about the physics of circumplanetary dust (electrical charging; orbital evolution; and passage through Lorentz resonances). We will investigate electromagnetic effects on various ring topics (spokes; corotational Lorentz resonances and Neptunian rings; asymmetrical coating of satellites, such as Iapetus and Rhea, by dust). We will model the generation and evolution of faint rings, including Saturn's E ring and the Uranian dust sheet.

d) J. A. Burns (1991). Physical processes on circumplanetary dust. In Origin and Evolution of Interplanetary Dust, (A. -C. Levasseur-Rigourd and T. Mukai, eds.), D. Reidel, Dordrecht, in press.

M. Horanyi, J. A. Burns, M. Tatrallyay and J. G. Luhmann (1990). On the fate of dust lost from the Martian satellites. Geophys. Res. Ltrs. 17, 853-856.

R. A. Kolvoord, J. A. Burns and M. R. Showalter (1990). Periodic features in Saturn's F ring: Evidence for nearby moonlets. Nature 345, 695-697.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Roger George Burns
54-816 Dept. of EAPS M.I.T. Cambridge, MA.02139
(617)253-1906

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Electronic Spectra of Materials Simulating Planetary Surfaces: Mars & Venus

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives. When basaltic magma extrudes onto the surface of a terrestrial planet, the crystallizing ferromagnesian silicates may interact with the atmosphere as the minerals cool down causing changes of oxidation state and mineralogy of iron. Since iron cations in surface-exposed minerals on planets contribute significantly to their remote-sensed reflectance spectra, particularly in the visible - near infrared region, a knowledge of degradation products of heated primary olivine and pyroxene assemblages in CO_2-dominated and O_2-bearing atmospheres is essential for interpreting spectral features in the 0.4-2.5 μm wavelength region.

(b) Progress. Mossbauer spectral measurements have demonstrated that Fe^{2+} ions in olivines and different pyroxene-types are vulnerable to aerial oxidation, particularly when the minerals are heated in air and in CO_2-dominated atmospheres. Nanophase hematite obscures the diagnostic Fe^{2+} crystal field spectral features of the ferromagnesian silicate minerals in the "1 micron" region. The ferric iron derived from oxidation of Fe^{2+} ions may remain as structural Fe^{3+} ions in the host olivine or pyroxene crystal structures, or exist as clusters of superparamagnetic nanophase particles of Fe_2O_3 along grain boundaries or on cleavage surfaces. Preliminary measurements of Mg^{2+}-Fe^{2+} disordered orthopyroxenes show intensification of the Fe^{2+}/M1 site band near 1.2 μm, obscuring the identification of olivine and Fe^{2+}-bearing plagioclase feldspar.

(c) Proposed research. A variety of techniques, utilizing visible-near infrared spectra, the Mossbauer effect at ambient temperatures and 4.2 K, and surface-sensitive Auger, ESCA and conversion electron spectroscopic methods, are being used to characterize reaction products of (1) oxidized and thermally-disordered olivines and pyroxenes; (2) ferromagnesian silicates heated in CO_2 atmospheres; and (3) oxysilicates formed from Fe^{2+}-OH^--bearing minerals (amphiboles, micas, clays) after heating in vacuum and CO_2-dominated atmospheres. Characterization of such products are elucidating how surfaces of Venus, Mars and the Archean Earth were modified by chemical reactions with their atmospheres.

(d) Publications. See works by R.G.Burns, D.S.Fisher, S.L.Martinez and/or D.S.Straub in: *Lunar & Planet. Sci.*, XXII, 95-96, 157-158, 389-390, 927-928 and 1349-1350 (1991); *Lunar & Planet. Sci.*, XXI, 145-146, 147-148, 736-737, 1215-1216 and 1217-1218 (1990); *Proc. 21st LPSC*, p.331-340 (1991); *JGR*, 95, 14169-14173 and 14415-14421 (1990); Chs 1 and 13 in *Remote Geochemical Analysis: Elemental and Mineralogical Composition* (in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Donald B. Campbell
528 Space Sciences Building
Cornell University
Ithaca, NY 14853-6801

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: ANALYSIS OF RADAR OBSERVATIONS OF THE MOON AND VENUS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Data sets for Venus and the moon, most of which have been acquired, will be used for: 1) studies of the surface textures and scattering properties of volcanic flows, crater surrounds and areas of high intrinsic reflectivity on Venus utilizing the differing Arecibo and Magellan look geometries and the polarization properties of the reflected signal for the Arecibo observations; 2) continued studies of the scattering mechanisms, and derivable surface properties for lunar impact craters, volcanic domes and mare regions utilizing high resolution (50m or less) radar imagery and studies of the polarization properties of the reflected signal. The possibility of obtaining very precise topography measurements for the moon by means of time delayed interferometry will continue to be investigated.

b) Recent and current work has concentrated on: 1) the analysis of the polarization and relative cross section data for the Sif/Gula Montes area in western Eistla Regio on Venus; 2) the reduction of the northern hemisphere 1988 radar data set for Venus to images in both senses of received circular polarization; 3) the categorization of terrains in the area of the southern hemisphere of Venus covered by the 1988 data including an analysis of the impact crater statistics; 4) the acquisition and reduction of radar data for the moon from which high resolution (50m or less) images will be obtained in both senses of received circular polarization.

c) During the first year the objectives for the Venus work are: 1) complete the processing of the cross-polarized data from the 1988 Arecibo observations, and examine the roughness properties and scattering law for flows in the Sif and Gula Montes area and suggest possible models for their surfaces; 2) use the polarization ratio data for Maxwell Montes in conjunction with the Magellan emissivity and reflectivity data to try to separate the contributions of roughness and reflectivity to the backscatter cross section. For the moon, the objectives for 1992 are: 1) reduce the current Arecibo radar data sets to images in both senses of receive polarization; 2) do initial comparisons with Lunar orbiter, Apollo and Galileo imaging; 3) investigate problems in deriving dielectric constants and porosities over Mare regions and in using time delayed interferometry to obtain high resolution altimetry.

d. Recent Publications: Venus: Crater Distributions at Low Northern Latitudes and in the Southern Hemisphere from New Arecibo Observations, D.B. Campbell, N.J.S. Stacy, and A.A. Hine, *Geophys. Res. Lett.* 17, 1389, 1990. Western Eistla Regio, Venus: Radar Properties of Volcanic Deposits, B.A. Campbell and D.B. Campbell, *Geophys. Res. Lett.*, 17, 1353, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Michael H. Carr

~~U.S. Geological Survey, MS-946~~

~~Menlo Park, CA 94025~~

FTS 459-5174

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Mars Water Cycle

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The overall objective is to better understand the role that water has played in the geologic and climatic history of Mars. Estimates of the amount of water present on the martian surface vary greatly according to the how the estimate is made. Geochemical estimates tend to give relatively small numbers, whereas geologic estimates give relatively large numbers. The amount of water and the nature of the water-worn features have major climatic implications. Some models suggest Mars has had little water outgassed and experienced no major climatic fluctuations. On the other extreme it has bee suggested that oceans periodically formed and dissipated, accompanied by major climate changes. One objective of this proposal is to try and reconcile some of these different concepts as to how Mars has evolved.

(b) In the past year work was completed on deuterium and its implications for past climates. It was concluded that the observed deuterium enrichment indicates very little about the total water inventory at the martian surface. The enrichment probably result because of loss of hydrogen from the top of the atmosphere coupled with extremely slow exchange between the surface and the atmosphere. The D/H ratio was probably frequently reset throughout geologic time as a result of floods, volcanic eruptions, and cometary infall. Work was started on measuring erosion rates of craters, in order to determine how much erosion by the atmosphere has occurred since the Noachian. Work has also started on evaluating why the interior of Mars appears, from SNC meteorites, to be so dry, in contrast to the abundant evidence of water action on the surface.

(c) Future plans. (1) Complete the work already started on erosion rates, and asses their climatic implications. (2) Complete the assessment as to why Mars' interior is dry and compare its water history with Earth and Venus.

(d) Recent publications: Carr, M. H., D/H on Mars: Effects of floods, volcanism, impacts and polar processes. Icarus 87, 210-227 (1990). Carr, M. H. and Wanke, H., Water on Mars: LPSC XXII, 181-182 (1991)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Mary G. Chapman
U.S.G.S., 2255 No. Gemini Dr., Flagstaff, AZ 86001
602-527-7182; FTS 765-7182

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Computer-Generated Maps of Mars: A Supplemental Proposal for Upgrading Computational Capabilities.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives and Justification. The objective of this proposal is to provide computational workstation capabilities to (1) increase efficiency in compilation and publication of the geologic map of MTM 25227 as well as all future geologic maps, (2) allow subsequent updating through review process of the map with minimal effort, (3) permit use of modern database manipulation and analysis techniques on the geologic map and individual Viking images as well as associated geological, photoclinometric, and geomorphic information, and (4) provide a rapid and cost-efficient means of developing visual aids (slides) for data presentation at various meetings.

b. New Proposal.

c. Work Plan for FY 92. Mapping of MTM 25227 on Macintosh IIFx and presentation of results and the compilation technique at annual MGM program meeting and LPSC.

d. Summary Bibliography. Publications pertinent to this project include Acosta, A., and Barrett, J., (in press) U.S. Geol. Survey Bull.; Acosta, A., Barrett, J., and Condit, C.D., 1989, Geol. Soc. Am. Abstr. with Prog., v. 21, p. 108.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip R. Christensen
Department of Geology
Arizona State University
Tempe, Arizona 85287-1404 Ph. (602) 965-7105

CO-INVESTIGATORS: Dr. David Krinsley; Dr. Bruce Jakosky

PROPOSAL TITLE: Thermal-Infrared Laboratory Studies

ABSTRACT:

a) The objective of this work is to determine the thermal infrared properties of planetary materials for comparison with thermal-IR spectral and radiometric planetary observations. This renewal proposal represents the combination of two currently funded proposals to study: 1) the thermal-infrared spectral properties of minerals, rocks, and natural surfaces; and 2) the thermophysical properties of materials under simulated martian conditions. The spectroscopy objectives are to: 1) characterize the thermal-IR spectra of planetary materials in emission; 2) develop quantitative methods for abundance determination from thermal-IR spectra; 3) study the spectral properties of komatiites and basalts; and 4) study the spectral properties of natural surfaces, weathering products, and soils to develop analytical tools to interpret planetary observations. The conductivity objectives are to: 1) determine the dependence of thermal conductivity on the physical properties, including particle size, porosity, packing, and bonding; 2) develop an analytical model of conductivity of particulates; and 3) relate conductivity measurements to remote sensing observations.

b) Renewal proposal. Major accomplishments include: 1) acquisition of mineral and rock samples in emission; 2) detailed studies of spectral properties of ultra-mafic basalts and sediment mixtures; 3) analysis of the effects of composition and vesicularity on volcanic glasses; 4) investigation of Mie and Chandrasekhar (Hapke) theory radiative transfer models; 5) development of the complete laboratory apparatus to perform the necessary conductivity measurements; 6) preparation of samples for conductivity measurements; and 7) acquisition of initial thermal conductivity measurements.

c) Future work will continue laboratory measurements and modeling, including: 1) continued development of a library of thermal-IR spectra of planetary materials in emission over a range of particle size, packing, and surface characteristics; 2) continued development of quantitative, radiative transfer models to model and deconvolve thermal-IR spectra of mixtures; 3) continued investigation of the spectral properties of a wide range of ultra-mafic basalts; 4) field and laboratory investigations of mixtures and coatings of aeolian sands and fan surfaces to develop and test mixing models on real surfaces; 5) collection of the extended matrix of thermal conductivity measurements at Mars pressures ; 6) measurements of mixtures of particle sizes; and 7) determination of the effects of bonding and particle shape on thermal conductivity.

d) Relevant Publications:

Anderson, D.L., J. Carpenter, P.R. Christensen, and P.W. Barbera, Development of a sample chamber for thermal infrared emission spectroscopy,*Lunar Planet Sci. XXI*, *in press.*

Kahle, A., F. D. Palluconi, and P. R. Christensen, , Thermal emission spectroscopy: Application to Earth and Mars, in Remote Geochemical Analysis: Elemental and Mineralogical Composition, C. M. Pieters and P.A.J. Englert eds., submitted.

Christensen, P.R., Multi-spectral thermal infrared observations of Mars: Implications for compositional variations,*Lunar Planet Sci. XXI*, *in press.*

Reyes, D., and P.R. Christensen, Mid-infrared spectra of komatiite vs. basalt, . *Lunar Planet Sci. XX*, 1990.

Presley, M.A. and P.R. Christensen, Laboratory measurement of the dependence of particle size on thermal conductivity under lunar conditions,*Lunar Planet Sci. XXI*, *in press.*

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Names, Address, Telephone Number)
Roger N. Clark
USGS, MS 964, Box 25046 DFC, Denver, CO 80225
(303) 236-1332; -1335; FTS 776-1332; -1335

CO-INVESTIGATORS: (Name Only)
None

TITLE: Quantitative Remote Sensing of Mineral Abundance Using Reflectance Spectroscopy

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of the work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year, as well as how and why; and (d) summary bibliography):

a. We will study the surface composition of planetary surfaces by identifying species present and deriving their abundances. We will refine a non-linear least squares algorithm to solve for mineral abundance from remotely obtained reflectance spectra of planetary surfaces using scattering theories as well as studying the spectral properties of minerals and their mixtures. Such analysis techniques are feasible and very important for geologic remote sensing studies. Furthermore, with the advent of mapping spectrometer instruments, it will be possible to determine and map mineral abundances on a planetary surface. This research is vital to the understanding of data from the Galileo NIMS experiment, Mars Observer TES, Mars 94 VIMS, CRAF VIMS, Cassini VIMS and future missions.

b. During this last year, two papers were published on the discovery and abundance of scapolite on Mars, the ice abundance and non-ice component on Callisto, and mostly completed analysis of new high spectral resolution data on Callisto and Ceres. We have found evidence for ammonium bearing minerals on Ceres and apparently also on Callisto. On Callisto, we have found the presence of a few percent fine grained ice on the leading hemisphere, and can now model the complete spectrum of Callisto better than any previous study, providing the best constraints possible on the surface composition. The USGS digital spectral library and about 63,000 lines of spectral analysis software version 3.0 (beta) has been distributed to the scientific community; full publication should be this summer. We invented a spectacular new spectral feature analysis method that is works better than humans!

c. The surface composition of outer solar system satellites and Mars and asteroids will continue to be analyzed. The new analysis algorithms will be used in the above analyses, and their efficiency and accuracy improved. More optical constants will be derived for geologicly important minerals to be used in the above analyses.

d. Clark, R.N. *et al.*: High Resolution Reflectance Spectra of Mars in the 2.3-μm Region: Evidence for the Mineral Scapolite, *JGR* 95 14463-14480, 1990.

Swayze, G.A. and R.N. Clark: Infrared Spectra and Crystal Chemistry of Scapolites: Implications for Martian Mineralogy, *JGR* 95 14481-14495, 1990.

Calvin, W.M., and Clark, R.N., 1990, Modeling the Reflectance Spectrum of Callisto 0.22 to 4.1 μm, *Icarus* 89, 305-317, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Joy A. Crisp
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

CO-INVESTIGATOR: Stephen M. Baloga

PROPOSAL TITLE: COOLING AND CRYSTALLIZATION OF PLANETARY LAVA FLOWS

A.Objectives: To improve our ability to infer eruption conditions of planetary lava flows, we will study the effects of crystallization and mixing on temperatures during flow emplacement. We will develop improved thermal models, constrain the models with crystallization data, find relationships between flow morphology and model parameters, and apply the models to flows on Mars.

B.Accomplishments: We developed a model to describe the cooling of lava flows and used this model to constrain eruption rates and emplacement durations of flows on Mars. Measurements of crystals in the 1984 Mauna Loa flow were used to estimate crystal nucleation and growth rates. Crystallization during emplacement of this flow could account for an increase of several orders of magnitude in viscosity, suggesting that its flow advance was cooling limited. An analysis of heat budgets of terrestrial lava flows indicated the importance of latent heat and suggests that another process, such as entrainment of crust into core, must be responsible for additional cooling of flow interiors.

C.Proposed Work: Existing theoretical models for the cooling of planetary lava flows will be improved by including the effects of mixing, latent heating, and viscous dissipation. We will study the crystallinity of a variety of terrestrial flows to determine the fraction of crustal material that must be assimilated by the core to offset latent heating. The range of crystallization and cooling rates for flows of different morphologies will be determined, allowing more reasonable extrapolations to flows on other planets. With our improved understanding of the effects of mixing and crystallization, we will estimate eruption rates for martian flows at Alba Patera and Ascraeus Mons and assess the implications for eruption style and volcanic history at these sites.

D. Summary bibliography: J.Crisp and S.Baloga (1991) Thermal processes in lava flows, 22nd LPSC, in press; J.Crisp and S.Baloga (1990) A model for lava flows with two thermal components, JGR, 95:1255-1270; J.Crisp and S.Baloga (1990) A method for estimating eruption rates of planetary lava flows, Icarus, 85:512-515.

Proposal Summary

Principal Investigator: L.S.Crumpler
Box 1846, Brown University,
Providence , RI 02912
401-863-3825, Fax 401-863-3978

Co-investigator: R.A.Craddock

Title: ***Erosional and Depositional History of Central Chryse Planitia***

Abstract:

(a)*Objectives.* The primary objective of this proposal is to support the presentation of results from our analysis of the geologic history of Chryse Planitia. This includes the results for three objectives outlined for this study in the previous funding period: (1) To use high resolution mapping to assess the detailed depositional and erosional history of the central part of the Chryse Planitia basin; (2) To examine the geologic context of the regional plains surface and local surface of the Viking Lander 1 and to determine if the characteristics and history of the local surface are representative of the formation and modification of plains surfaces (a) elsewhere in Chryse Planitia and (b) on Mars in general; (3) To assess the viability of the Viking Lander 1 Chryse Planitia site as a rover/sample return site for future Mars missions.

(b) *Accomplishments.* This is a renewal proposal for completion of work in progress. Significant developments in the past year include progress toward completion of objective 1, initial 1:500 000 scale mapping of terrane and stratigraphic units and tectonic features and determination of the geologic history in Chryse Planitia based on mapping the MTM 20047 and 25047 1:500,000 scale photomosaic sheets. This work implies that Chryse Planitia has demonstrably experience several erosional and depositional events separated by long time intervals that may have affected the site of the Viking Lander 1. Completion of objectives 2 and 3 are to be completed during the remainder of the current funding period.

(c) *Proposed Work.* (1) We will present initial results of the mapping in the MTM 20047 and 25047 1:500,000 scale photomosaic sheets during the 1991 MGM meeting. (2) We will compare the surface seen at the Viking Lander 1 with (a) the surrounding surfaces in Chryse Planitia and (b) observed characteristics of the surface around Viking Lander 1 using regional Viking IRTM data and models of the origin and probable erosional characteristics of plains on Mars. (3) On the basis of (1) and (2), we will (a) assess what Viking Lander 1 determined about the local surface and how it relates to the regional geologic unit on which it rests, and (b) compile a list of questions that the Viking Lander 1 site might reasonably answer both about Mars science and about the current operational unknowns of a lander/rover/sample-return mission.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Jeffrey N. Cuzzi
NASA Ames Research Center, M.S. 245-3
Moffett Field, CA 94035 (415) 604-6343

Co-INVESTIGATORS: (Name Only) Joelle Champney, Anthony Dobrovolskis

PROPOSAL TITLE: Particle-gas Dynamics in the Protoplanetary Nebula

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) This research consists of theoretical modeling of the coupling between the spatial and velocity distributions of both the particle and gas phases of the protoplanetary nebula.

b) In this year, we have improved the physics and numerics of the model in several significant ways. (1) We developed a new formulation for the viscosity of the particle phase, which is required for dense particle layers that may develop in realistic nebula models. In part, the formulation makes use of particle relative velocities derived by V{\ö}lk et al. 1980, but parts of it are quite new. We have implemented the formulation and all particle viscous terms into the code. (2) We performed a complete derivation of the time-averaged fluid and particle equations and modeled all correlation terms so obtained in order to provide a check on our current (mass-averaged) formulation, which we have become suspicious of for the (compressible) particle phase. (3) We made important progress in our turbulence modeling. We have reconciled prior differences between our Prandtl and two-equation models, and find the boundary layer viscosity to be about 25 times larger than we had previously believed which will make all the processes under study more vigorous. We now believe the total uncertainty in our boundary layer turbulent viscosity to be less than a factor of two. (4) We vectorized our code for a factor of eight speedup, coauthored a review chapter for the Arizona volume "Protostars and Planets III", and successfully proposed for 125 Cray hours on the National Aerodynamic Simulator at Ames.

c) In the next year, we plan to: (1) Explore the implications of the new terms obtained by time-averaging the equations instead of mass-averaging. (2) Implement a much improved turbulence model (the so-called "k - equation" model) which accounts in a self-consistent manner for production and transport of turbulence by the mean flow, and dissipation by both molecular viscosity and the particle phase. This treatment will be important not only to our studies of boundary layer turbulence, but to studies by others of thermal convective turbulence which have never before considered dissipation of turbulence by particles. (3) Make a number of nebula model runs at 1 AU, 10AU, and in likely protosatellite nebula environments for a variety of particle sizes and densities. (4) Implement a 2-D version of the code for use at "condensation fronts" in the nebula.

d) S. J. Weidenschilling and J. N. Cuzzi (1991) Formation of planetesimals in the Protosolar Nebula; in "Protoplanetary and Planets III"; University of Arizona Press, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Jeffrey N. Cuzzi
NASA Ames Research Center, M.S. 245-3
Moffett Field, CA 94035 (415) 604-6343

Co-INVESTIGATORS: (Name Only) Richard H. Durisen, Mark R. Showalter, Luke Dones, Linda J. Horn, Anthony R. Dobrovolskis

PROPOSAL TITLE: Planetary Ring Studies

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a) This research consists of integrated theoretical and observational studies of the dynamics, morphology, and particle properties characterizing planetary ring and satellite systems.

b) (1) We have obtained spatial frequency spectra for the entire B ring using both FFT and maximum entropy techniques. Typical structural scales vary with location between 70 and 300 km. (2) We have implemented several physical and numerical improvements to our ballistic transport model. (3) We have found that ballistic transport provides an explanation for the maintenance of the inner edges of the B and A rings, and for some of the associated nearby structure. (4) We have completed a definitive photometric and structural analysis of Saturn's E ring, and made progress in similar studies of Saturn's G and F rings. (5) We directly detected the Encke gap moonlet. (6) We discovered important shortcomings in the "mapping" approach to ringmoon dynamics, and implemented a fast and accurate orbit integration scheme instead. (7) We implemented multiple scattering into our non-classical (arbitrary porosity) ring radiative transfer model. (8) Several papers were published or submitted.

c) (1) We will conclude our B and inner A ring spatial frequency analysis. (2) We will implement a "faster" ballistic transport code with certain approximations to allow longer ring evolutions at higher resolution. (3) We will incorporate extrinsic torques into the model. (4) We will begin study of the properties of disruptive impacts in the rings, and the effects of planet family projectiles as distinct from "Oort cloud" projectiles. (5) We will begin a new study of the transport of non-icy "contaminants" in rings with a subset of our full ballistic transport code. (6) We will pursue our dynamical studies of ringmoon belt interactions using a combination of numerical and analytical techniques. (7) We will initiate a new study of the origin of moonlets near and within planetary Roche zones in the context of disruptive bombardment by large meteoroids. (8) We will implement particle size distributions into our nonclassical radiative transfer model and perform initial modeling of certain specific regions in the rings of Uranus and Saturn. (9) We will complete our G ring analysis and initiate a thorough study of Saturn's Encke gap ringlets and F ring. (10) We plan to submit several papers.

d) Cuzzi, J.N., and Durisen, R.H. (1990), Icarus, 84, 467-501; Durisen, R.H., Bode, P.W., Cederbloom, S.E., Murphy, B.W., and Cuzzi, J.N. (1990), Bull. Am. Astron. Soc., 22, 1045; Horn, L.J., and Cuzzi, J.N. (1990), Bull. Am. Astron.Soc., 22, 1041; Kolvoord, R. A., J. A. Burns, and M. R. Showalter (1990) Nature 345, 695--697; Showalter, M. R. (1990) Bull. Amer. Astron. Soc. 22,1040--1041; Showalter, M. R., and P. D. Nicholson 1990. Icarus 87, 285--306.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip A. Davis
(Name, Address, Telephone Number) U.S.G.S., 2255 N.Gemini Dr.,Flagstaff, AZ
FTS 765-7201 (602) 527-7201
CO-INVESTIGATORS: (Name Only) Kenneth L. Tanaka

PROPOSAL TITLE: Mars Geology and Morphology

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: The objectives of this three-year proposal are to obtain and use photoclinometric data for selected erosional and collapse scarps, grabens, fresh craters, and small volcanoes on Mars to determine (1) from scarp and graben data, subsurface structure and geologic processes that operated within Tempe Terra; (2) from the volcano data, the nature and origin of small volcanoes (basal diameter less than 150km); and (3) from crater data, relations between local and regional geology and crater and ejecta morphometry and volumes.

(b) New Proposal: Although new, this proposal is an extension of an ongoing project to obtain and analyze detailed topographic data of Martian landforms to better understand geologic processes that have operated on Mars. Thus far we have examined the tectonic history of Syria Planum and north Tharsis region, the existence of crustal discontinuities between Syria Planum and the north Tharsis region, the nature of Martian glaciers, the origin of wrinkle ridges, the origin of wall valleys, the rheology of lava flows at Alba Patera, and the composition of wall material in Noctis Labyrinthus.

(c) Work Plan (FY89): Three tasks are identified. The first task is to determine the detailed geology, the nature and depths of mechanical discontinuities, and possible relations between discontinuities and surface features within Tempe Terra. The second task is to collect detailed quantitative topographic data for small Martian volcanoes and to compare these data with similar terrestrial data to infer their origin and nature. The third task is to collect detailed topographic data for fresh craters and to refine our rim-height/diameter relation and to determine its associated error and relations between crater and ejecta morphometry and local and regional geology.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Stanley F. Dermott
(Name, Address, Telephone Number) 224 SSRB, Dept. of Astronomy, U Florida
Gainesville, FL 32611, (904) 392-3748

Co-INVESTIGATORS: (Name Only) Dr. Carl D. Murray
Dr. Peter C. Thomas

PROPOSAL TITLE: Dynamics of Satellites and Dust

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives. (1) To investigate the orbital evolution of dust particles in the solar system. (2) To measure the shapes of satellites. (3) To investigate the dynamics of resonance in the satellite systems of Saturn and Uranus.

(b) Progress. (1) A new secular perturbation theory that incorporates the effects of PR light drag has been developed and proved to be correct through numerical integrations. Analysis of the IRAS data using this theory has revealed not only that the solar system dustbands are related to the Hirayama asteroid families but also that there is observational evidence in the IRAS data for the transport of asteroidal particles to the Earth. (2) The shape of Tethys has been measured: the observed tidal bulge is much smaller than that expected for a homogeneous satellite.

(c) Work Statement. Six papers on dust studies were read at the last DPS meeting. Two other papers on the shapes of satellites are in preparation. The year will be largely devoted to the publication of these results. Work will commence on the origin and evolution of the background zodiacal cloud.

(d) Recent Publications.

1. The Role of Secondary Resonances in the Orbital History of Miranda. Renu Malhotra and Stanley F. Dermott. Icarus 85, 444–480, (1990).
2. IRAS Observations of the "Near-Ecliptic" Solar System Dustbands. S. F. Dermott et al., B.A.A., 22, 1124, (1990).
3. Forced Orbital Elements of Zodiacal Cloud Particles. R. S. Gomes and S. F. Dermott. B.A.A. 22, 1123, (1990).
4. Four other papers were read at the Charlottesville 1990 DPS meeting.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
William B. Durham
University of California, Lawrence Livermore National Laboratory, Livermore, CA 94550
(415) 422-7046

Co-INVESTIGATORS: (Name Only)
Stephen H. Kirby

PROPOSAL TITLE: Rheologies of planetary ices

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) There is clear evidence for tectonic activity on all but the tiniest of the icy moons of the solar system's four giant, low-density planets. The largest satellites whose surfaces are visible, Ganymede, Callisto, and Triton, probably have histories dominated by the activity of water and water ice in several of its polymorphs. Activity on the smaller moons of Saturn and Uranus suggests important amounts of ices and liquids in the NH_3–H_2O system. Methane clathrate is expected to be present on some of the colder moons on the basis of cosmochemical arguments, and solid methane and perhaps nitrogen may be present on the surface of Triton. To aid in the interpretation of geologic features on the surfaces of the icy moons and to help understand the evolution of their interiors, we propose to continue our laboratory measurements of important planetary ices under conditions of pressure and temperature that exist on and within the icy satellites.

(b) A recent hardware improvement allows us to experiment at a 10 times lower strain rate than before, so we have begun measuring the comparative strengths of water ice and solids in the NH_3–H_2O system at temperatures down to 130 K, relevant to near surface conditions of icy moons. To our surprise, we found that at these extremes ammonia dihydrate as well as mixtures of ammonia dihydrate and water are about as strong or even stronger than pure ice, even though at temperatures 10 or 20 K warmer ice is much stronger. We have completed a systematic study of the water ice I→II phase transformation and inferred from the results the mechanism for deep terrestrial earthquakes [*Kirby et al.* 1991]. We have produced, in the manner of our H_2O ice samples, polycrystalline samples of deuterium oxide D_2O ice, soon to be deformed and transformed in our apparatus for eventual textural analysis by neutron diffraction. We have begun the design of a newly funded upgrade: a 1-GPa pressure vessel that will allow us to create and deform the ice VI polymorph.

(c) In the coming year we will (1) publish the results of three years of experimentation in the NH_3–H_2O system; (2) complete research and publish a paper refining the fracture and flow of ice I, emphasizing low-temperature (190 - 130 K) behavior; (3) finish construction and testing of the 1-GPa apparatus; and (4) obtain preliminary results on the rheology of ice VI.

(d) Kirby, S. H., W. B. Durham, and L. A. Stern, Mantle phase transformations and faulting in subduction zones: A unified hypothesis of deep earthquakes, *Science*, in press, 1991. Durham, W. B. and S. H. Kirby, Planetary ices: A comparison of rheologies at $T < 200$ K, *Lunar Planet. Sci.*, *XXI*, 305-306, 1990.

PROPOSAL SUMMARY

A.W. England, Principal Investigator
F.T. Ulaby, Co-investigator
Radiation Laboratory
Department of Electrical Engineering
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The University of Michigan
Ann Arbor, MI 48109-2122
Ph: (313) 764-0500

Title: **THEORETICAL AND EXPERIMENTAL MODELS OF THE DIFFUSE RADAR BACKSCATTER FROM MARS**

ABSTRACT

a) Our objective is to develop a theoretically and experimentally consistent explanation for the diffuse component of radar backscatter from Mars. The strength, variability, and wavelength independence of Mars' diffuse backscatter are unique among our Moon and the terrestrial planets. This diffuse backscatter is generally attributed to wavelength-scale surface roughness and rock clasts within the Martian regolith. Through the combination of theory and experiment, we would bound the range of surface characteristics that could produce the observed diffuse backscatter, and, by geologic inference based upon Viking and other analyses, develop regional scattering models for Mars.

b) This is a new proposal.

c) During the first year, we would gather the existing radar backscatter data, develop computational models for backscatter and emission from random, scaling surfaces, and develop scaled analogs of Mars random surfaces. Both fine-scale roughness and rock clasts contribute to the diffuse backscatter. Our initial focus is upon the contribution of the fine-scale roughness because it constitutes a background for the overall, diffuse backscatter. The combination of theoretical and experimental modeling serves to reduce the uncertainty that is inherent with any modeling approximation.

d) Relevant publications:

England, A.W., "Characterization of Rough Surfaces," Proc. of Workshop on Ground Probing Radar, May 24-26, 1988, Ottawa, Canada, in press.

England, A.W. and G.R. Johnson, "Spectral Gradient of Lunar Radiobrightness--Heat Flow or Volume Scattering?" J. Res. U.S.G.S., Vol. 6, pp. 505-509.

Ulaby, F.T., R.K. Moore and A.K. Fung, "An Introduction to Random Surface Scattering and emission," Microwave Remote Sensing--Active and Passive, Vol. II, Addison-Wesley, pp. 922-1033.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Larry W. Esposito
(Name, Address, LASP/Campus Box 392
Telephone Number) 303-492-7325

Co-INVESTIGATORS: Glen R. Stewart
(Name Only)

PROPOSAL TITLE: Dynamics of Outer Planet Rings

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a. The Voyager occultations provide several uniform and high quality data sets for the rings of Saturn, Uranus, and Neptune. We inter-compare these data and develop theoretical models for particle size and particle transport. A special emphasis is on wave phenomena as probes of ring properties and as tests of ring dynamics models.

b. Particle sizes in Saturn's rings. We have completed development of automated methods to intercompare Voyager Saturn radio, UVS and PPS ring occultations. We have fitted two models to these data: a power law size distribution extending from micron to meter-size particles; and a power law for particles larger than several microns combined with a gamma distribution of submicron particles. These results imply variations among the rings in dust content and the creation of small particles at density wave locations. One paper submitted to Icarus.

Numerical simulation of multiple particle size narrow rings. We have extended our Markov formulation to systems composed of two particle sizes. The larger particles are 8 times more massive than the small particles. These simulations show the development of sharper edges than for rings composed of particles of a single size. Furthermore, the tendency for equipartition results in a slower overall spreading rate for a narrow ring. Two papers published in Icarus.

Analysis of Prometheus and Pandora density waves. The wave amplitudes and wavelengths have been measured for 27 Prometheus and 12 Pandora density waves have been measured. These show intriguing behavior with distance from Saturn and provide a test of models of spiral density wave propagation. One paper in preparation.

c. We will use the Voyager occultation data to derive consistent models of the size distribution and its variation in Saturn's rings, with special attention to density wave locations. We will model the behavior of Prometheus and Pandora density waves and extend, as necessary, the theory of spiral density wave propagation.

These results have implications for the structure and longterm evolution of planetary rings.

d. Summary bibliography (CY90): 4 papers published; 4 abstracts.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Fraser P. Fanale
Planetary Geosciences Div., Dept. of G&G/SOEST
Univ. of Hawaii, 2525 Correa Rd., Hon., HI 96822
(808) 956-3149

Co-INVESTIGATORS: (Name Only)

Susan Postawko
James Salvail

PROPOSAL TITLE: Volatile Evolution

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Our objective is to investigate volatiles in the interiors, surfaces and atmospheres of planetery bodies.

(b) In 1990 we published several papers: 1.) A theoretical study of the effect of volume phase changes and densification on mitigation of the 'icy greenhouse effect' was published in Icarus (1). 2.) A paper on retention of buried water ice which took into account the obliquity and orbit of Phobos was also published in Icarus (2). 3.) A paper on the influence of CO ice on the activity and near surface differentiation of cometary nuclei was published in Icarus (3) and 4.) A paper on possible Mars' brines and their relationship to radar data was published in J.G.R. (4) and 5.) A paper on new models for the origin of the Valles Marineris closed depressions was published in J.G.R. (5). We also have two papers in press and two in review: 1.) a synthesis paper on Mars' volatile inventory, its evolution and its effect on climate change was accepted for publication in the Mars book (6). 2.) A paper on compositional heterogeneity is in press in J.G.R. (7). A laboratory study of the effects of comminution and vitrification on meteorite and asteroid spectra was submitted to Icarus (8), and a paper on the cometary activity of Chiron was submitted to Icarus (9).

(c) 1.) We will apply our recently published improved model of the icy greenhouse to Enceladus in order to estimate the effect on the internal thermal regime. The model is improved in that it incorporates the mitigating effects of mass transport, phase changes and densification on the basic 'icy greenhouse'. 2.) We will study the effects of vitrification and temperature on the spectra of carbonaceous chondritic material, b.) measure the spectrum of adsorbed CO_2 and c.) measure the latitudinal variation in the depth of the water adsorption feature in the spectrum of Ceres. 3.) We will complete the development of a generalized computer model begun last year to investigate the volatile system and climate of Triton. We will use this model to obtain results for an improved seasonal model. We will obtain results for a model that will attempt to simulate the evolution of Triton's atmosphere and the chemical differentiation of its near surface crust. 4.) We will estimate the ice depth and H_2O flux from hypothesized H_2O containing asteroids and 'extinct' comets in Apollo orbits as functions of time, latitude, orbital parameters, obliquity and soil properties. 5.) We will estimate the intensity of putative electromagnetic heating of the asteroids as a combined function of semimajor axis and size to see if the correlation with O-H band depth is improved over that with each variable taken separately. We will then consider any residual effects which may result from conductivity variations and scrambling

(d) Fanale et al. (1990); Fanale and Salvail (1990).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Dr. Jonathan Fink
Department of Geology
Arizona State University
Tempe, Arizona 85287-1404
(602) 965-3195

PROPOSAL TITLE: Determining the Composition of Martian and Venusian Lava Flows

ABSTRACT:

a. Objective: To develop and evaluate morphologic and structural criteria for the remote determination of lava flow rheology and composition.

b. Progress: (1) Conducted two series of laboratory experiments at Australian National University modeling the role of crust growth on the dynamics and morphology of lava flows. The first series (12 runs) quantitatively evaluated the role of basal roughness, which was found to impede spreading and cause transitions between flow types to occur at lower spreading rates. The second series (28 runs) used a tank with a linear (as opposed to point source) vent to eliminate variations in strain rate associated with a radial geometry. A new spreading law was established for this configuration and morphologic transitions were found to occur at the same conditions as for radial flows. These new experiments greatly expanded the applicability of our previous flow simulations. (2) Completed fabrication of a lava flow simulation laboratory at Arizona State University. (3) Ran a series of 12 experiments at ASU to determine how the episodicity of eruption of lava domes controls their aspect ratio, and found that turning an extrusion on and off can result in domes that are twice as high as those formed by continuous eruption. (4) Completed theoretical analyses of lava cooling under different planetary conditions. (5) Tested theoretical and lab results through application to submarine volcanism where ambient temperature, cooling mechansims, and lava compositions are better known than for extra-terrestrial cases. (6) Used the distribution and shapes of venusian lava flows revealed on Magellan images of the Alpha Regio region as an illustration of how domes can serve as constraints on tectono-magmatic history. (7) Analyzed the relative importance of gravity, cooling, and emplacement history on the aspect ratios of domes on various planetary surfaces. (8) Continued isotopic studies of the ways that volatiles influence the surface texture of silicic lava flows, focussing on Mount St. Helens and active domes in Guatemala and Alaska. (9) Continued laboratory and TIMS-based field studies of silicic flows, in order to perfect techniques for remotely mapping lava composition from spectroscopic data.

c. Proposed Work: (1) Continue laboratory simulations of lava flows, focussing on those features that can (or will be able to) be seen on Magellan and Mars Observer images. (2) Correlate eruptive conditions that form surface structures with those that form large constructs visible on planetary images. (3) Use experimental data to define "effective" rheologic parameters for lavas with solidifying crusts. (4) Map the distribution of surface structures on terrestrial, martian, and venusian lava flows. (5) Calculate which surface textures are likely to form on martian and venusian lava flows. (6) Expand TIMS results to additional lava domes of mixed compositions in the Inyo-Mono chain.

d. Publication Summary: 3 papers published, 3 in press, 1 in review; 8 abstracts.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Richard G. French
Department of Astronomy
Whitin Observatory
Wellesley College
Wellesley, MA 02181
(617) 235-0320 (x3747)

PROPOSAL TITLE: Dynamics and Structure of Planetary Rings

ABSTRACT:

(a) Objectives: To investigate the dynamics and structure of the rings and atmosphere of Saturn from multiple observations of the 28 Sgr occultation combined with Voyager results, to observe stellar occultations of the Uranian rings and Neptune's ring-arc system, and to detect weak dynamical effects in the Uranus ring system.

(b) Accomplishments: 1) Comparative structure and kinematics of the Uranian rings; 2) Comprehensive search for excited normal modes in the eccentric Uranian rings; 3) Search for faint rings and ring arcs in the Uranus system in Voyager images; 4) Comparison of upper stratospheric temperatures of Uranus inferred from Voyager with groundbased occultation measurements; and 5) Observation and preliminary analysis of IR imaging and multi-wavelength visual photometric observations of the 3 July 1989 28 Sgr occultation by the Saturn system, from McDonald Observatory.

(c) Proposed Work: 1) Comparative studies of Saturn's rings, including kinematics and geometry, ring particle properties, and the morphology and opacity of the B ring, from observations of the 28 Sgr occultation obtained at McDonald and Palomar Observatories and the IRTF (at 2.1, 3.1, and 3.9 μm, respectively), and Voyager UV, visible, and radio observations 2) Detailed modelling and analysis of multiple ground-based IR imaging observations of Saturn's central flash; 3) Comparison of upper stratospheric temperatures of Saturn inferred from Voyager with groundbased occultation measurements; 4) Analysis of two upcoming June, 1991 stellar occultations by the Uranian rings, and the 18 August 1991 occultation by Neptune's ring arc, to be observed from the IRTF; and 5) Detection and modelling of weak dynamical effects in the Uranus ring system

(d) Summary Bibliography: Baron, French, and Elliot "The Oblateness of Uranus at the 1-μbar level." (1989) *Icarus* 78, 119-130; French, Nicholson, Porco, and Marouf "Dynamics and Structure of the Uranian Rings" (1990), a chapter in *Uranus*, U. of Arizona Press, Bergstrahl and Miner, Eds.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Herbert Frey
Code 921, Goddard Space Flight Center
Greenbelt, MD 20771 301-286-5450

Co-INVESTIGATORS: (Name Only)

Richard A. Schultz

PROPOSAL TITLE: Early Mars: Impact Basins, Crustal Dichotomy and Volcanic Resurfacing

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: Determine the nature of the crustal dichotomy on Mars, the role played by major impacts in the evolution of this dichotomy, and the relationship of impacts and the crustal dichotomy to major volcanic resurfacing early in martian history. These remain among the fundamental unanswered questions in martian geological evolution, and are relevant to comparative planetary understanding of planetary lithospheric evolution. (b) Accomplishments: Searched for large impact basins in the southern hemisphere, finding one excellent candidate located about 3800 km SW of Hellas, with at least 4 rings having diameters 535, 1050, 1610, 2280 km. The overlap of this basin with Hellas may explain the location of ridged plains in Malea Planum. Also identified three other potential candidates in Sirenum and Aonia Terrae. Detailed the relation between topography and physiography along the crustal dichotomy boundary, and showed that the physiographic dichotomy actually lies within a broader lowland in which at least 2-3 km of elevation are lost northwards within the cratered terrain before the dichotomy boundary is reached. (c) Proposed Work: Continue search for impact basins on Mars in the south polar region. Complete mapping of both newly found Malea Basin, other candidates found in the south polar region, and possible outer rings of South Polar Basin. Begin detailed study of dichotomy boundary in Acidalia and adjacent cratered terrain to the south where the boundary departs from the outer Utopia impact basin ring and the relatively simple relation between topography and structure breaks down. Examine possible role of endogenic processes in modifying the original dichotomy. Determine resurfacing history of Malea Planum to assess whether units mapped as *Nplr* on the western side are truly of Noachian age or simply thin Hesperian age flows through which Noachian basement is showing. (d) Publications: Schultz, R. A. and Frey, H. V., A New Survey of Multi-Ring Basins on Mars, *J. Geophys. Res.*, *95*, 14,175-14,189, 1990. Frey, H. and Schultz, R. A., Speculations on the Origin and Evolution of the Utopia-Elysium Lowlands of Mars, *J. Geophys. Res.*, *95*, 14,203-14, 213, 1990. Frey, H. and Grant, T. D., Resurfacing History of Tempe Terra and Surroundings, *J. Geophys. Res.*, *95*, 14,249-14,263, 1990. Frey, H., Doudnikoff, C. E. and Mongeon, A. M., Are Noachian-Age Ridged Plains (Nplr) Actually early Hesperian in Age? *Proceed. Lunar Planet. Sci. 21*, 635-644, 1991. Also, 4 LPSC XXII abstracts, 1 Fall AGU abstract, 3 oral and 1 poster presentation.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael J. Gaffey
(Name, Address, Geology Dept., R.P.I., Troy, NY 12180-3590
Telephone Number) 518-276-6300

Co-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Meteorite Spectroscopy and Characterization of Asteroid Surface Materials

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives and Justification: The goal of this work is to improve our understanding of the nature and evolution of the early inner solar system. Asteroids are surviving in situ fragments from the accretionary and early post-accretionary period. Their compositions constrain early conditions and processes at particular heliocentric distances, and provide a spatial context for data and models derived from meteorite studies. Our work involves mineralogic characterizations of asteroids from reflectance spectra, and laboratory spectral studies of meteorites to develop interpretive calibrations and methodologies.

b. Accomplishments of past year: 1) Completed the initial analysis of the S-type asteroids from the 52-color survey data and showed that a wide range of silicate assemblages ranging from pure olivines (dunites) to basalts are present on S-asteroids; 2) Discussed the consequences of the observed asteroid compositional patterns for early igneous processes in planetesimals; 3) Identified that spinel similar to that in C3V chondrites on two S-asteroids and showed that they may be part of a family; 4) Developed calibrations to detect or place upper limits of asteroidal porphyrin abundances.

c. Proposed Work: Efforts will focus in three general areas. The first will involve an investigation of igneous processes in the asteroid parent bodies by analysis of the rotational spectral variations of asteroids 3 Juno, 6 Hebe, 20 Massalia, 40 Harmonia, 349 Dembowska and 532 Herculina. The second will investigate the compositional gradients of the primordial nebular materials still preserved in the unheated asteroids by analysis of existing CCD spectra of dark asteroids and of spinel bearing CV-like asteroids. The third will involve continued laboratory studies of the spectral effects of metamorphism and aqueous alteration on carbonaceous chondrites; and the spectral calibration of porphyrins and other organics in meteoritic assemblages.

d. Recent Publications: Gaffey, M.J. (1990) Thermal history of the asteroid belt: Implications for accretion of the terrestrial planets. in Origin of the Earth (J. Jones and H. Newsom, eds.), LPI, Houston, Texas, pp. 17-28; Gaffey, M.J. (1991) Styles of asteroidal igneous processes: Observational constraints from rotational spectral investigations. Lunar Planet Sci. XXII, 423-424.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Robert W. Gaskell (tel. (818) 354-2116)
Jet Propulsion Laboratory, MS 301/125L
4800 Oak Grove Drive, Pasadena, CA 91109

CO-INVESTIGATORS: (Name Only) S.P. Synnott

PROPOSAL TITLE: Satellite Shape and Topography

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Determine shape and topography of satellites using Voyager images. Investigate whether a tidally stressed satellite is in hydrostatic equilibrium and, if so, determine whether interior is differentiated. Topographic results may provide insights into crustal geology and tidal dissipation mechanisms. Our techniques (Gaskell, 1988) have already yielded useful scientific results (Gaskell, et al, 1988), suggesting that Io is in hydrostatic equilibrium and that it is differentiated, possibly having an iron core about 800 km in radius. A fourfold rotational symmetry observed in the large-scale topography suggests that the heating of Io occurs primarily by tidal dissipation in a partially molten aesthenosphere. There is some evidence, which is still being examined, that Io may have a differentiated crust, with large areas of low-density, isostatically compensated crustal material accounting for broad topographic highs.

(b) Completion of physical model and computer simulation of Voyager camera distortions and photometric corrections (Gaskell, 1990 and 1991 (in preparation)).

(c) This investigation relies on the precise digital determination of control point locations in image space and the use of stereographic techniques to locate these points in the body fixed reference frame. We shall include digitally identified limb points in the study, providing both increased coverage and a check of our landmark techniques. Initial targets will be Io, Europa, Mimas, Enceladus, Miranda and Ariel. The Io study will continue with the addition of more control points and limb data. Ultimately, we will find shapes and for all satellites having sufficient stereographic coverage.

(d) Summary bibliography

Gaskell, R.W.: Digital identification of cartographic control points. *Photogrammetric Engineering and Remote Sensing 54*, 723-727, 1988.

Gaskell, R.W.; Synnott, S.P.; McEwen, A.S.; and Schaber, G.G.: Large-Scale Topography of Io: Implications for Internal Structure and Heat Transfer. *Geophys. Res. Lett. 15*, 581-584, 1988.

Gaskell, R.W., Distortions and photometric errors in the Voyager imaging subsystem, *1989 Planetary Geology and Geophysics Program Reports*, 1990.

Ross, M.N., G. Schubert, R. W. Gaskell, and T. Spohn, The internal structure of Io as inferred from the observed long wavelength topography, *BAAS* **20**, 817, 1988.

Ross, M.N., G. Schubert, T. Spohn, and R. W. Gaskell, "Internal Structure of Io and the Global Distribution of its Topography", *Icarus* **85**, 309-325, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Jay D. Goguen
4800 Oak Grove Drive, MS 183-501
Pasadena, California 91109
(818) 354-8748, (FTS) 792-8748

CO-INVESTIGATORS: None.

TITLE: Applications of a 'Dense Atmosphere' Model to Scattering from Planetary Regoliths

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of the work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year as well as how and why; and (d) summary bibliography):

A. OBJECTIVES: To develop improved models for the quantitative interpretation of spectrophotometry, bi-directional reflectance, and polarimetry of planetary regoliths in terms of the composition and size distribution of the regolith particles. Applications of this model improve our detailed understanding of regoliths and the physical processes responsible for their evolution.

B. PROGRESS: Adaptation of lunar regolith particle size studies to light scattering calculations. Recognition that sorting is a far more important factor than mean grain size in lunar regolith scattering. Completed particle phase function and polarization survey calculations over the visible and near-IR spectrum for most relevant compositions. Acquired laboratory measurements of known samples and successfully tested dense atmosphere model against them.

C. PROPOSED WORK: 1) Apply and refine dense atmosphere model to acheive quantitative agreement with lunar regolith scattering. 2) Determine the origin of the opposition surge and negative polarization for the moon and other regoliths. 3) Investigate differences between the particle size distributions of icy and rocky regoliths and their implications for regolith evolution. 4) Study the origin of Enceladus unusual photometric properties to test whether it's regolith evolution is dominated by impacts. 5) Use the dense atmosphere model to predict measurements that can be made by the Galileo orbiter that will be most diagnostic of the satellite regolith properties.

D. SUMMARY BIBLIOGRAPHY: Goguen, J. D. et al. (1989), V-filter Photometry of Titania, Oberon, and Triton Icarus 77, 239-247.; Goguen, J. D., and W. M. Sinton (1985), Characterization of Io's Volcanic Activity by Infrared Polarimetry, Science 230. 65-69: Goguen, J. D. et al (1988), Io Hot Spots: IR Photometry of Satellite Occultations, Icarus 76. 465-484; Hillier, J. P., et al. (1990), Voyager Disk-Integrated Photmetry of Triton, Science 250, 419-421; Spencer, J. R., et al. (1990), Discovery of Hot Spots on Io using Disk-resolved Infrared Imaging, Nature 348, 618-621; Brown, R. H., et al. (1991), Triton's Global Heat Budget, Science (in press).

PROPOSAL SUMMARY

Principal Investigator: Matthew P. Golombek
Jet Propulsion Laboratory
Mail Stop 183-501
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-3883 (FTS) 792-3883

Title: TECTONICS OF PLANETARY STRUCTURES

a. Objectives: Develop models for the geometry, kinematics, and dynamics of planetary structural features. Estimate the lithospheric deformation and regional or planetary tectonic strain (expansion or contraction) from kinematic models. Use the characteristics and geometry of structural features as a clue to: 1) the mechanical behavior of shallow planetary crusts, 2) the lithospheric strength and failure characteristics at the time of their formation, and 3) early thermal profiles.

b. Progress: 1) Paper published on mechanical discontinuities in the shallow crust of Mars. 2) Paper published on folding and faulting in the formation of planetary wrinkle ridges. 3) Chapter in press for University of Arizona book on Mars, *Stress and Tectonics on Mars*. 4) Review article in press on tectonic processes on the terrestrial planets. 5) Paper completed that attempts to reconcile stress and structural histories for the formation of the Tharsis region on Mars.

c. Proposed Work: 1) Compare detailed structural mapping results with revised lithospheric deformation models for Tharsis, reevaluate the geometry of the causative stress field around Tharsis, evaluate the subsurface structure of grabens and pits around Alba Patera, based on their width, depth, size, spacing, and likely mechanical models, and constrain martian seismicity from slip estimates on surface structures. 2) Compare the extension and shortening implied by grabens and wrinkle ridges around mascon basins on the Moon with kinematic and dynamic basin subsidence model results. 3) Measure the brittle lithosphere thickness from simple grabens on Io to estimate heat flow in non hot spot country rock. 4) Map the sequence of groove formation around undeformed blocks of cratered terrain on Ganymede to assess any strike-slip displacements.

d. Summary Bibliography: Davis, P. A., and Golombek, M. P., 1990, Discontinuities in the shallow Martian crust at Lunae, Syria, and Sinai Plana: Journal of Geophysical Research, v. 95, p. 14,231-14,248. Golombek, M. P., Plescia, J. B., and Franklin, B. J., 1991, Faulting and folding in the formation of planetary wrinkle ridges: Proceedings of the 21st Lunar and Planetary Science Conference, p. 679-693. Banerdt, W. B., Golombek, M. P., and Tanaka, K. L., in press, *Stress and Tectonics on Mars*, Chapter for inclusion in MARS, Book to be published by University of Arizona Press. Golombek, M. P., in press, Planetary tectonic processes, terrestrial planets: Review article in The Reference Encyclopedia of Astronomy and Astrophysics, January 1991. Tanaka, K. L., Golombek, M. P., and Banerdt, W. B., 1991, Reconciling stress and structural histories of the Tharsis region of Mars: Journal of Geophysical Research, in revision March 1991. Golombek, M, Tanaka, K., Banerdt, W., and Tralli, D., 1991 Mars seismicity through time from surface faulting (expanded abstract): Lunar and Planetary Science XXII, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donn S. Gorsline
(Name, Address, Telephone Number) University of Southern California
(213) 740-5125

Co-INVESTIGATORS: (Name Only) Timothy J. Parker

PROPOSAL TITLE: Geologic Mapping of Argyre Planitia

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives: Investigate the morphology and distribution of the layered plains material and sinuous ridges in central and southern Argyre. Emphasis is placed on a careful analysis of their distributions relative to regional topography and features such as large channel systems radial to the basin. Further emphasis is placed on characterizing the process or processes likely to have been responsible for their formation and what they might suggest about the martian paleoclimate.

b) Progress: Updated Proposal to compile 1:500,000 scale geologic maps. 4 photomosaic base maps of central and southern Argyre Planitia are scheduled to be completed by the USGS by this Fall, in response to the original version of this proposal (FY-1988, with Tim Parker as P.I.).

c) Proposed Work: During fiscal year 1992 and 1993, we will begin mapping, starting with the quadrangles that have the greatest percentage of high resolution and stereo coverage. Much of the preliminary map work on the best imaged areas has already been conducted on overlays of the individual stereo pairs. The MTM numbers for the base maps (in the order they are to be mapped) are: MTM-55036, MTM-55044, MTM-50036, and MTM-50044. Review and any necessary revision of maps and text for map production to USGS standards will be conducted during fiscal year 1994.

d) Summary Bibliography:

Parker, T. J., 1985, Geomorphology and Geology of the southwestern Margaritifer Sinus - Northern Argyre Region of Mars: Master's Thesis presented to the Department of Geology, Cal. State Univ., Los Angeles, 165p.

Parker, T. J., and Pieri, D. C., 1985, Geomorphology and geology of the southwestern Margaritifer Sinus and Argyre regions of Mars - III: Valley types and distribution: Reports of the Planetary Geology Program - 1984, NASA TM 87563, p. 367-368.

Parker, T. J., Pieri, D. C., and Saunders, R. S., 1986, Morphology and distribution of sinuous ridges in central and southern Argyre: Reports of the Planetary Geology Program - 1985, NASA TM 88383, p. 468-470.

Parker, T. J., 1989, Channels and Valley Networks Associated with Argyre Planitia, Mars: Lunar and Planet. Sci. - XX, p. 826-827.

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

Ronald Greeley
Department of Geology
Arizona State University
Tempe, Arizona 85287-1404
(602) 965-7045

PROPOSAL TITLE: *Geologic Mapping of Hadriaca and Tyrrhena Paterae*

ABSTRACT

OBJECTIVE:

The goal of this study is to gain insight into the geological relationships of highland paterae, the Hellas basin, and subsequent modification of the surface by exogenic processes. Highland paterae represent the earliest stage of central vent volcanism on Mars and are important in the geological evolution of several areas of the cratered uplands. 1:500,000 geological maps of the Hadriaca and Tyrrhena Paterae regions are being made as a component of volcanological studies of this type of martian volcano.

PROGRESS:

Regional geologic maps have been produced for Tyrrhena Patera and Hadriaca Patera in which the main geologic units have been identified, stratigraphic relationships determined, and structural features assessed. The general geomorphology of the area has been studied, and geological histories have been drived. Two 1:500,000-scale geologic maps (-30267, -30262) have been produced for the summit region of Hadriaca Patera and submitted to the USGS. They have been reviewed by the project scientist, Dr. David Scott, are currently being revised for the next stage of the review.

PROPOSED WORK:

Geologic mapping of a 1:500,000 sheet will be undertaken for the Tyrrhena Patera summit region.

REFERENCES:

Crown, D.A., K.H. Price, and R. Greeley, 1990, Evolution of the east rim of the Hellas basin, Mars, *Lunar Planet. Sci., XXI*, 252-253.

Crown, D.A., and Greeley, R., 1990, Geologic Map of MTM Quadrangles -30262 and -30267, Hadriaca Patera Region of Mars, U.S. Geological Survey, in review.

Crown, D.A., and Greeley, R., 1990, Hadriaca Patera: Evidence for pyroclastic volcanism in the Hellas region of Mars, *LPI Technical Report 90-04*, 25-26.

Crown, D.A., and Greeley, R., 1990, Styles of volcanism, tectonic associations, and evidence for magma-water interactions in eastern Hellas, Mars, *Lunar Planet. Sci. Conf., XXI*, 250-251.

Greeley, R., and Crown, D.A., 1990, Volcanic geology of Tyrrhena Patera, Mars, *J. Geophys. Res., 95*, 7133-7149.

Porter, T., Crown, D.A., and Greeley, R., 1991, Timing and formation of wrinkle ridges in the Tyrrhena Patera region of Mars, *Lunar Planet. Sci. Conf., XXII*, in press.

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

Ronald Greeley
Department of Geology
Arizona State University
Tempe, Arizona 85287-1404
(602) 965-7045

PROPOSAL TITLE: *Geological Studies in Planetology*

ABSTRACT

OBJECTIVE: The goals of this investigation are: 1) to study aspects of remote sensing that are important for Planetary Geology, including determination of the use of visible and near-infrared imaging data to assess the sources, transportation paths, and deposition sites of surficial materials (principally windblown sand) on planetary surfaces; in addition, to assess the advantages and limitations of using radar images to produce planetary geological maps in which radar constitutes the sole source of data. Both of these aspects of remote sensing are critical for the use and interpretation of existing and future data to be obtained for Mars and Venus; 2) study volcanic geomorphology with the focus on the surface appearance of ash deposits and the morphology and morphometry of very fluid lava flows; the approach is to study terrestrial analogs, extrapolate the results to the martian environment, and analyze specific volcanic features on Mars including highland paterae.

PROGRESS: a) TM data for the Kelso dunes have been analyzed as part of the Geology Remote Sensing Field Experiment (GRSFE), and field work has been completed; a paper on the results has been submitted (Paisley et al., 1991), b) radar geologic mapping has been completed for a GRSFE test site, applying planetary geologic mapping principles, c) a reconnaissance field trip to Ontario, Canada was completed in the summer, 1990 to assess komatiite lava flows, d) a study of a volcanic area on Venus was published (Gaddis and Greeley, 1990), and e) a study of Tyrrhena Patera on Mars has been published (Greeley and Crown, 1990) and a study of Hadriaca Patera has been completed and is in preparation for publication.

PROPOSED WORK: a) continue application of mixing model to the study of the Kelso dune field; extend work using AVIRIS data, b) complete radar geologic mapping of GRSFE site, c) complete studies of ignimbrite deposits in Bolivia, d) complete the manuscript for study of Hadriaca Patera on Mars, e) continue studies of komatiite flows on Earth, f) continue research on image processing, and g) coordinate Planetary Geology Speakers Bureau.

REFERENCES:

Blount, G., Smith, M.D., Adams, J.B., Greeley, R. and Christensen, P.R., 1990, Regional aeolian dynamics and sand mixing in the Gran Desierto: Evidence from Landsat Thematic mapper images, *J. Geophys. Res.*, *95*, 15463-15482.

Crown, D.A. and Greeley, R., 1990, Styles of volcanism, tectonic associations, and evidence for magma-water interactions in eastern Hellas, Mars, *Lunar Planet. Sci.*, *XXI*, 250-251.

Crown, D.A., Price, K.H., and Greeley, R., 1990, Evolution of the east rim of the Hellas basin, Mars, *Lunar Planet. Sci.*, *XXI*, 252-253.

Gaddis, L. and Greeley, R., 1990, Volcanism in northwest Ishtar Terra, Venus, *Icarus*, *87*, 327-338.

Greeley, R. and Crown, D.A., 1990, Volcanic geology of Tyrrhena Patera, Mars, *J. Geophys. Res.*, *95*, 7133-7149.

Paisley, E.C.I., Lancaster, N., Gaddis, L. and Greeley, R., 1991, Discrimination of active and inactive sand from remote sensing: Kelso Dunes, Mojave Desert, California (submitted, *Remote Sensing Environment*).

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

Ronald Greeley
Department of Geology
Arizona State University
Tempe, Arizona 85287-1404
(602) 965-7045

PROPOSAL TITLE: *Martian Aeolian Geology*

ABSTRACT

OBJECTIVE:

The goal of this investigation is to elucidate aspects of aeolian features and processes on Mars and their roles in the evolution of the surface. The proposed research has two tasks. The objective of the first task is to determine the relationships among observed aeolian surface features (wind streaks, dunes, yardangs), rock distributions inferred from the Viking IRTM measurements, and wind shear directions and magnitudes predicted by a general circulation model for present and past conditions on Mars. The second task is to study the physical properties, entrainment mechanisms, and morphology of "parna" deposits on Earth as an analog to martian sand and dust, and apply the results to the interpretation of mantles of windblown material on Mars.

PROGRESS:

Results from the general circulation model have been adapted to determine the maximum shear stresses generated during six seasons on Mars. Comparisons with previous work involving only average shear stresses show marked differences for some areas and a better correlation with local features. These results are also being used to develop "sand roses" to assess sediment transport potential. In the second task, Australian "parna" has been run in the Mars Surface Wind Tunnel to determine threshold conditions for comparison with holocrystalline materials. In addition, experiments with artificially-generated aggregates have been completed to determine both their threshold and their erosive characteristics. Finally, a workshop was organized and conducted on Sand and Dust on Mars, partly sponsored by the Mars Science Working Group.

PROPOSED WORK:

a) Continue to employ the general circulation model (GCM) for Mars to predict surface wind direction and magnitude and compare the results with the distribution and orientation of aeolian surface features using values for maximum winds and consideration of threshold winds for different sizes of particles; extend the study to the polar regions, consider past climates on Mars, and apply the drift potential expression to assess the potential flux of windblown sand on Mars, b) continue the analysis of terrestrial parna as potential analogs to Mars; initiate field studies.

REFERENCES:

Greeley, R., N. Lancaster, S. Lee, and P. Thomas, 1990, Martian aeolian processes, sediments, and features, *in Mars*, Kieffer, H.H., B.M. Jakosky, C.W. Snyder, and M.S. Matthews, eds., Univ. Arizona Press, Tucson (in press).

Greeley, R., A. Skypeck, and J.B. Pollack, 1991, Martian aeolian features and deposits: Comparisons with general circulation model results (in revision).

Greeley, R. (editor) 1991, Workshop on Sand and Dust on Mars, *NASA TM* (in press), 61 p.

Lancaster, N. and R. Greeley, 1990, Sediment volume in the north polar sand sea of Mars, *J. Geophys. Res.*, *95*, 10921-10927.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Richard Greenberg
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721
(602) 621-6940

CO-INVESTIGATOR: None

TITLE: Planet Formation and Evolution: Collisional and Dynamical Processes

ABSTRACT:

(a) Objectives: The purpose of this research program is to understand how interrelated collisional and dynamical processes affected formation of the planets and their subsequent evolution. We are investigating the dominant processes of planetary accretion, including radial transport and low-velocity interactions, how they produced the observed planetary and satellite systems, including the cometary cloud and the Moon, and how these processes govern the evolution of planetary rings, the asteroid belt, and excavation and delivery of meteorites. Studies of the coupled dynamical and geophysical evolution of outer-planet satellites are also included.

(b) Progress in Past Year: Analytic formulae have been developed for impact rates of planetesimals into growing planets. A new numerical procedure is being used to explore the statistical mechanics of close approaches of orbiting bodies. Momentum and mass transport in a particle swarm has been studied with a new approach that allows for realistic collisional processes and non-uniformity of the disk. The role of bodies' rotation, finite size, and collision scattering law in transport processes has been explored further. The dynamics of comets are being studied to model the processes that deliver comets back into the planetary region and to constrain the distribution of the cometary cloud. Delivery of meteorites to Earth has been modeled to show the extent of stochastic variability in the population arriving at Earth. We have also studied the geophysical and dynamical evolution of Europa and Miranda.

(c) Proposed Research: In the coming year we will parameterize the outcomes of low-velocity encounters among orbiting bodies and begin to examine the effects on rotation of growing planets. We will compare the relative roles of physical processes as planetary embryos reach the stage of incipient runaway, growth and begin to evaluate the rates of such growth. Research on meteorite origins and delivery processes will include collisional injection into resonance, and numerical determination of heliocentric orbits of measured fireballs.

(d) Summary Bibliography: 7 papers and 6 abstracts of presentations.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bradford H. Hager
(Names, Address, Department of Earth,Atmospheric and Planetary Sciences
Massachusetts Institute of Technology, 54-622,
Cambridge,MA 02139

Telephone Number) 617-253-0126

CO-INVESTIGATORS:

TITLE: Convection in Venus: Observations,Models and Comparison with Earth

ABSTRACT: Include: a. the overall objectives and justification of the work; b. the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Mantle convection controls the heat transport and tectonics of Venus and Earth. Our main objective is to compare observations and predictions of topography, geoid anomalies, crustal thickness, and state of stress for models of convection in these sister planets, in order to better understand their dynamics. The study is motivated by the strong correlation between geoid and topography on Venus, which suggests that both are primarily the result of mantle convection, by our success with dynamic models of Earth's geoid, by our interest in coupling between mantle convection and crustal deformation, and by the data constraining Venus's tectonics from Magellan.

(b) Walter Kiefer completed his Ph. D. Mark Simons and I developed a marker-chain version on Conman that allows highly accurate tracking of the crust-mantle boundary, as well as compositional and temperature-dependent rheology and used it to investigate the coupling of mantle convection and crustal deformation in Lavinia Planetia.

(c) Our main goal for this year is to apply the numerical codes that we have developed to addressing the interaction of mantle convection with crustal deformation and crustal recycling. These models allow us to extend our simple analytic model for dynamic support of Ishtar, removing restrictive assumptions used for analytic tractability. We will also use these models investigate how Venus can apparently have a relatively thin crust and to test our hypothesis that the cylindrical geometry of plumes is important in explaining how cold downwellings are apparently more strongly coupled to crustal deformation than are hot upwellings. The following year we plan to extend our modeling of the geoid signature of mantle plumes to include the effects of spherical axisymmetric geometry and realistic rheologies. This will allow us to investigate why both hot upwellings and cold downwellings have geoid highs associated with them.

(d) King, S.D., A. Raefsky, and B. H. Hager, ConMan: Vectorizing a finite element code for incompressible two-dimensional convection in Earth's mantle, *Phys. Earth Planet. Int.*, *59*, 195-207, 1990.

Simons, M., S. C. Solomon, and B. H. Hager, Dynamic models for ridge belt formation on Venus, *Lunar Planet. Sci.*, *21*, 1263-1264, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
Vicki L. Hansen
Southern Methodist University
Department of Geological Sciences
Dallas, TX 75275
214/692–4179

CO-INVESTIGATORS: None

PROPOSAL TITLE: Structural, Kinematic, and Strain History Analysis of Ishtar Deformed Belts, Venus: Tectonic Constraints for Geodynamic Modeling

ABSTRACT:

The assumptions made in some of the earlier mapping of Venusian deformation belts require coaxial strain paths that result in unnecessarily complex geologic deformation histories. As a result, it cannot easily be determined whether mechanical differences are present and play an active role in Venusian crustal deformation, or whether horizontal displacement of crustal domains is common. High resolution Magellan Synthetic-Aperture Radar (SAR) imagery, coupled with Magellan altimetry, should provide us with the data necessary to begin to characterize the nature of structures which comprise the deformed belts of Ishtar Terra, and to interpret the geometric, kinematic, and temporal relations between crustal domains. We propose to construct structure and bulk strain maps of the deformed belts which surround Lakshmi Planum using Magellan imagery and altimetry, and principles of modern structural and kinematic analysis, in order to document the overall strain patterns and strain histories of these belts. These data will allow us to evaluate aspects of the deformational histories of these regions within a 3D framework through time (hence 4D). We will consider the possibility that noncoaxial strain paths may have played a pivotal role in the formation of Venusian deformation belts, and that more than one trend of structures can form at the same time. Determination of regional bulk strain regimes, and deformation histories of the deformed belts of Ishtar Terra will enable us to understand the nature and timing of deformed belt evolution, which will provide important geological constraints for geodynamic models of Venus.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bruce Hapke
Dept. of Geology & Planetary Science
University of Pittsburgh
Pittsburgh, PA 15260
(412) 624-8876

SCIENTIFIC COLLABORATORS: R. Nelson and, W. Smythe, JPL

PROPOSAL TITLE: Photometric Analyses of Spacecraft Planetary Images

ABSTRACT:

(a) *Objectives of Proposed Work:* Continue to investigate the nature and composition of planetary surfaces and atmospheres by quantitative analyse of images taken by spacecraft and of ground-based observations, with supporting observational, experimental and theoretical research.

(b) *Accomplishments of Prior Year*: (1) Completed photometric analysis of Voyager and ground- based observations of Europa. (2) Continued experimental and theoretical study of light scattering by large, irregular particles. (3) Continued theoretical study of emittance spectroscopy and of effects of thermal emission on reflectance spectra. (4) Developed major mew model which explains large reflectances and unusual polarizations in radar returns from icy satellites as a result of coherent backscatter.

(c) *Research Proposed for Coming Year*: (1) Continue development of theory to incorporate results from experimental study of light scattering by large, irregular particles, and to further understand effects of thermal emission and polarization. (2) complete experimental study of light scattering by large, irregular particles. (3) Continue experimental investigation of coherent backscatter. (4) Continue to apply the theory of reflectance and emittance developed previously under this grant to solar system bodies.

(d) *Recent Publications*: B. Hapke (1990) "Coherent Backscatter and the Radar Characteristics of Outer Planet Satellites", *Icarus* 88: 407-417. B. Hapke (1991) "Regoliths of Icy Satellites: The Coherent Backscatter Model", *Nature* (submitted). D. Domingue, B. Hapke, G. Lockwood and D. Thompson (1991) "Europa's Phase Curve: Implications for Surface Structures", *Icarus*, in press. B. Hapke (1991) "Combined Theory of Reflectance and Emittance Spectroscopy", in *Remote Geochemical Analyses*, ed. by C. Pieters and P. Englert, Cambridge University Press, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Alan W. Harris
MS 183-501, Jet Propulsion Laboratory
4800 Oak Grove Dr. Pasadena, CA 91109
(818) 354-6741 (FTS) 792-6741

CO-INVESTIGATORS: None

PROPOSAL TITLE: Asteroid and Satellite Studies

ABSTRACT:

a. Objective: Theoretical and observational studies of asteroids and planetary satellites are proposed with the general objective of understanding the origin and evolution of the planetary system.

b. Progress: During the last year, a major publication of lightcurve results has been completed, and is currently in press. As a result of major observing campaigns, we have obtained a set of very precise phase curves of three asteroids which clearly demonstrate that the "H-G" magnitude model is inadequate to represent all phase curves to full accuracy - a third parameter is necessary. Considerable effort has been expended organizing a major conference, "Asteroids, Comets, Meteors 1991", to be held in Flagstaff.

c. Proposed work: 1) Continue reductions of asteroid lightcurve data, concentrating on shape and pole studies, photometric functions (primarily high or low albedo asteroids at very low phase angles), collaborative observations with radar, IR, and occultation techniques, and earth-approaching asteroids; 2) Complete a paper reporting the phase curve observations mentioned above, and begin work on a revised magnitude system with the aim of better representing magnitude data, and extracting physical information from those curves. 3) Edit the proceedings of the "ACM 91" meeting mentioned above. 4) During the next funding period, I will be President of IAU Commission 15, and Chairman of the Division on Dynamical Astronomy of the AAS. These activities will consume a significant fraction of my time, and involve some obligatory travel.

d. Summary bibliography: 1) Harris, A.W., et al. Asteroid Lightcurve observations from 1981. Icarus, in press. 2) Harris, A.W. Rotational properties of the planets. In Encyclopedia of Astronomy and Astrophysics, New York: Van Nostrand Reinhold, in press. 3) Harris, A.W., et al. (1990) Recent results from asteroid photometry. Bul. Amer. Astron. Soc. 22, 1112-1113.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) — William K. Hartmann, Planetary Science Institute, 2421 E. 6th Street, Tucson AZ 85719

CO-INVESTIGATORS: (Name Only) — None

SCIENTIFIC COLLABORATORS: — David Grinspoon, University of Colorado at Boulder; Kevin Zahnle, NASA Ames Research Center

PROPOSAL TITLE: "Early Intense Planetary Cratering and its Effects"

ABSTRACT: (Type single-spaced below line. Letter paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a) I propose start-up of a three-year program to extend my current studies of planetary cratering and its effects on the early evolution of planets. The program would capitalize on our new numerical model of early cratering rates as a function of time and my preliminary evidence of an error in Voyager team interpretation of outer satellite cratering populations due to use of an erroneous calibration to lunar upland cratering. The work will clarify Galileo lunar farside spectral mapping. In addition, I would complete write-up of an experimental result dealing with the geology of the eruptive process on cometary surfaces.

b) The first year's funding has been $20K, allowing limited annual progress. However, the first year has been productive, including progress on a collaborative study and paper with Dr. David Grinspoon (NASA Ames) on early cratering of Earth. This was presented at the 1990 Meteoritical Society Meeting and Workshop on the Earth's Early History. I also completed preliminary studies of crater counts on the Moon's far side and Mare Australe region, casting doubt on the Voyager team interpretation of their lunar calibration curves; this was published in LPSC 1991 abstracts; a full paper is in progress.

c) Proposed tasks are: (1) Completion of a paper on the new crater counts, investigating correlation between various curvatures in the size distribution of craters (claimed by Voyager team as evidence of different impactor populations), and relative area of intercrater plains. (2) Tests of the same correlation on outer planet satellites. (3) Further work in collaboration with Grinspoon and Zahnle on implications of early intense cratering for initial terrestrial and planetary geological and climatic evolution. (4) Completion of paper (in progress) on geologic processes of eruption on the surfaces of cometary bodies.

d) Hartmann, W.K. (1991) Possible Misinterpretation of Lunar Cratering Record in Voyager Team Analysis of Outer Planet Satellites, LPSC XXI Abstracts. Hartmann, W. K. (1990) The Nature and Consequences of Earth's Early Intense Bombardment, Abstracts of Workshop on Early Cratering of Earth, Perth, Australia. Grinspoon, D. H. and W. K. Hartmann (1990) Quantitative Modeling of the Early Intense Bombardment, Abstracts of Workshop on Early Cratering of Earth, Perth, Australia.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) B. Ray Hawke
Planetary Geosciences, Dept. Geology & Geophysics
2525 Correa Rd. Honolulu, HI 96822 (808)956-3133

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Remote Sensing and Geologic Studies of Planetary Crusts

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives: The primary goals of this research are to provide a better understanding of planetary impact and volcanic processes as well as the composition and evolutionary history of a variety of solar system objects including the Moon, Mars, Mercury, and the asteriods, through analysis and interpretation of spacecraft and earth-based imagery and remote sensing data.

b) Progress: The highlights are: 1) we determined that the Aristarchus impact exposed highlands debris with a variety of unusual compositions; 2) we demonstrated that mafic geochemical anomalies on the east limb and farside of the Moon are found in regions which exhibit a high density of dark-haloed impact craters; 3) it was determined that turbulent flow and thermal erosion were largely responsible for the formation of Rima Mozart; 4) a remote sensing study of the Orientale region was conducted in support of the Galileo encounter; 5) a remote sensing study of Alphonsus was published; 6) new pyroclastic deposits on the western limb were identified and investigated; 7) spectral data for lunar impact basins were acquired and analyzed. Pure anorthosite deposits were identified on Orientale, Humorum, Grimaldi, and Nectaris basin rings; 8) definite or probable rotational spectral variations have been found associated with l6 asteroids; 9) Tycho crater excavated highlands material dominated by Ca-rich clinopyroxene; the Tycho dark-halo contains abundant impact glass; 10) impact melt deposits were identified and mapped in and around mercurian craters; volumes were determined and compared with theoretical estimates and volumes associated with lunar and terrestrial craters, and; 11) compositions and eruption mechanisms were determined for several lunar pyroclastic deposits.

c) Work Statement: 1) continue to use near IR spectra and orbital geochemistry data of lunar basin ejecta deposits to study the composition and stratigraphy of the highlands crust and basin-forming processes; 2) spectral studies of fresh impact craters will be conducted to investigate crustal composition and impact process such as ray formation, ejecta emplacement, and impact melt formation; 3) continue to utilize remote sensing data to investigate and characterize highland volcanic deposits and early (>3.9 AE) mare basalts; continue studies of lunar resources and outpost sites; 5) conduct a spectral study of Mercury; 6) continue investigations of impact melt deposits associated with craters on the Moon, Mercury, and Earth; 7) conduct geologic and remote sensing studies of the lunar rilles to better understand the processes responsible for their formation; 8) continue our efforts to understand the composition and mode of emplacement of lunar pyroclastic deposits; and 9) support the Galileo lunar encounter.

d) Summary Bibliography: See Progress Report

Geologic Processes on Evolved Icy Satellites

Principal Investigator: James W. Head, III

Scientific collaborators and their institutional affiliations:

Co-Investigator:
Scott Murchie, Research Associate, Brown University

Scientific Collaborators:
E. Marc Parmentier, Associate Professor, Brown University
Christophe Sotin, Assistant Professor, University of Paris, Orsay, France
Lionel Wilson, Professor, University of Lancaster, Lancaster, U.K.
Jeffrey Plescia, Jet Propulsion Laboratory, Pasadena, CA
Paul Helfenstein, Research Associate, Cornell University, Ithaca, N.Y.

Abstract:

a) Objectives: Comparative planetological studies of icy satellites: 1) To document the geology, distribution, and interrelationships of grooved-terrain volcanic and tectonic features on Ganymede; to develop an understanding of these features' genetic mechanisms; and to identify possible implications for the satellite's internal dynamics and thermal evolution. This study will be used as a basis for similar work on the evolved surfaces of Enceladus, Ariel, and Triton, to address the questions of what internal thermal and dynamical processes were responsible for formation of grooved terrain, and of why such terrain is not observed on Callisto. 2) To undertake a theoretical study of the melting, ascent, and eruption of NH_3-H_2O magma on Ganymede and Callisto; to predict volcanic landforms and deposits, and their scales, topography, and photometric properties; and to test these predictions using the observed photogeologic properties, photometric properties, and crater-ages of volcanic deposits on Ganymede.

b) Progress: Publication of an investigation of Ganymede dark terrain volcanism and tectonism and the relationship to bright terrain; publication of an overview synthesis of the geologic history of Ganymede; publication of a synthesis of volcanism and tectonism on the icy satellites of Jupiter, Saturn, and Uranus. Progress on the classification and compilation of features in the grooved terrain assemblage. Documentation of new central vent structures and small domes of volcanic origin.

c) Proposed Work: (a) We will continue the detailed investigation of the tectonic evolution of grooved terrain on Ganymede, digitizing, plotting and analyzing the data, and will undertake similar investigations of analogous terrains on other evolved icy satellites, with the goal of a comparative planetologic assessment of possible internal driving forces in the evolution of these bodies. (b) We will continue the investigation of theoretical aspects of ammonia-water volcanism on large icy satellites, complete photoclinometric assessments of topography, complete compilation and analysis of crater density data, and will assess geologic evidence for the involvement of ammonia in icy-satellite volcanism.

d) Summary bibliography: (1) Murchie, S., J. Head, and J. Plescia, Tectonic and volcanic evolution of dark terrain and its implications for the internal structure and evolution of Ganymede, *J. Geophys. Res.*, 95, 10743-10768, 1990; (2) Murchie, S., The volcanic and tectonic history of Ganymede, *Lunar Planet. Sci. XX*, 742-743, 1989; (3) Murchie, S., The tectonics of icy satellites, *Advances in Space Research, 10*, 173-182, 1990; (4) Sotin, C., and S. Murchie, Internal dynamics of a differentiated Ganymede: Constraints from experimental data, *Lunar Planet. Sci. XIX*, 1107-1108, 1988; (5) Murchie, S., and J. Head, The evolution of volcanism on Ganymede: Possible importance of a low melting-point volatile, *Lunar Planet. Sci. XIX*, 819-820, 1988; (6) Murchie, S., The geologic evolution of Ganymede and its implications for the origin of the Ganymede-Callisto "dichotomy," *Advances in Space Research, 10*, 183-186, 1990.

PROGRESS REPORT - PLANETARY DATA ANALYSIS AND PROCESSES OF CRUSTAL FORMATION AND EVOLUTION

PRINCIPAL INVESTIGATOR: James W. Head, III

SCIENTIFIC COLLABORATORS: D. B. Campbell, P. Hess, L. Wilson, A. Basilevsky, J-P. Bibring, S. Murchie, L. Crumpler, D. Senske, K. Roberts, S. Keddie, B. Pavri.

a) Objectives: 1) To analyze a range of planetary data from Earth-based observations, USSR spacecraft missions, and other sources in order to accomplish the following objectives: a) familiarization and preliminary analysis, b) correlation with other data sets, c) enhance availablity to the community, and d) application to a range of scientific problems. 2) To assess modes of formation and evolution of planetary crusts to work toward an understanding of their development.

b) Progress: 1) Planetary Data Analysis: a) completion of detailed data reduction and analysis from the Arecibo Venus 1988 opportunity and distribution to the scientific community; b) completion of analysis of assemblages of Venera geologic units; c) completion of analysis of Pioneer-Venus equatorial radar images; d) completion of preliminary analysis of Phobos ISM data for Mars. 2) Processes of Crustal Formation and Evolution: a) completion of initial assessment of major processes of crustal formation and evolution on Venus; b) continued study of the formation of plume plateaus; c) progress on the analysis of underthrusting and melting relationships at compressional deformation zones; d) analysis of possible accretion of plume plateaus and protocontinental formation on Venus and Earth; e) documentation of petrological evolution of the crust of Venus in different tectonic environments; g) analysis of formation and evolution of primary and secondary crusts on one-plate planets with emphasis on the secondary crust of the Moon.

c) Proposed work: 1) Planetary Data Analysis: a) Continuation of analysis of Phobos ISM data for Mars with emphasis of the Valles Marineris region. 2) Processes of Crustal Formation and Evolution: a) continuation of assessment of major processes of crustal formation and evolution on Venus; b) continued study of the formation of plume plateaus; c) continued documentation of petrogenesis of the crust of Venus in different tectonic environments; d) continued analysis of formation and evolution of primary and secondary crusts on one-plate planets with emphasis on the secondary crust of the Moon.

d) Summary bibliography: (1) Campbell, D.B. *et al.*(1991) Venus southern hemisphere: Geologic character and age of terrains in the Themis-Alpha Regio-Lada Terra region, *Science* **251**, 180-183. (2) Head, J.W. (1990) Assemblages of geologic/morphologic units in the northen hemisphere of Venus, *Earth, Moon and Planets* **50/51**, 391-408. (3) Head, J.W. (1990) Processes of crustal formation and evolution on Venus: An analysis of topography, hypsometry, and crustal thickness variations, *Earth, Moon and Planets* **50/51**, 25-55. (4) Senske, D. (1990) Geology of the Venus equatorial region from Pioneer-Venus radar imaging, *Earth, Moon and Planets* **50/51**, 305-327. (5) Head, J. W. and Crumpler L. S. (1990) Venus geology and tectonics: Hotspot and crustal spreading models and questions for the Magellan mission, *Nature* **346**, 525-533. (6) Vorder Bruegge, R.W. and Head, J.W. (1990) Tectonic evolution of Eastern Ishtar Terra, Venus, *Earth, Moon and Planets* **50/51**, 251-304. (7) Hess, P.C. and Head, J.W. (1990) Derivation of primary magmas and melting of crustal materials on Venus: Some preliminary petrogenetic considerations, *Earth, Moon and Planets* **50/51**, 57-80. (8) Ford, P. and Senske, D. (1990) The radar scattering characteristics of Venus landforms, *Geophys. Res. Lett.* **17**, 1361-1364. (9) Senske, D. *et al.* (1991) Geology and tectonics of Beta Regio, Guinevere Planitia, and Western Eistla Regio, Venus: Results from Arecibo image data, submitted to *Earth, Moon and Planets*. (10) Senske, D. *et al.* (1991) Geology and tectonics of the Themis Regio-Lavinia Planitia-Alpha Regio-Lada Terra area, Venus: Results from Arecibo image data, submitted to *Earth, Moon and Planets*. (11) Head, J. and Wilson, L. (1991) Lunar mare volcanism: Stratigraphy, eruption conditions, and the evolution of secondary crusts, submitted to *Geochim. Cosmochim. Acta.* (12) Crumpler, L. and Head, J. (1990) Formation and evolution of plume plateaus on Venus, LPSC XXI, 254-255. (13) Erard, S. *et al.* (1991) Spatial variations in composition of the Valles Marineris and Isidis Planitia regions of Mars derived from ISM data, *Proc. Lunar and Plan. Sci.* **21**, 437-455

ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head, III

SCIENTIFIC COLLABORATORS:

L. Crumpler, E. Parmentier, L. Wilson, D. Campbell, D. Senske, S. Keddie, J. Burt, J. Aubele, A. deCharon.

PROPOSAL TITLE: Geological Processes on Planets and Satellites: Tectonism

ABSTRACT:

a) Objectives: To understand processes of tectonic evolution and mechanisms of heat transfer on planets and satellites.
b) New proposal.
c) Proposed Work: We outline a series of studies dealing with tectonic deformation in extensional, compressional, and complex tectonic environments. 1) Extensional environments: We propose to study selected features that appear to be forming in relatively shallow parts of the crust and lithosphere (fractures, normal faults, and simple graben) and to examine their links to sources of regional tectonic stress (e.g., impact basins, rift zones) and stresses associated with magma emplacement and migration (e.g., magmatic fracturing, magma withdrawal). A second part of this study deals with extensional environments in which the features influence relatively deeper parts of the crust and lithosphere (rift zones). Here, specific analyses are proposed to document the nature of rift zone structures and patterns (kinematics) in order to prepare for later studies of the dynamics of rift formation and to assess the relation between lithospheric stretching and rift formation, and pressure-release melting and volcanism. 2) Compressional environments: We propose to continue the examination of orogenic belts on Venus, assessing architectural elements, and relations to structures representing more limited shortening (ridge belts), and examining evidence for their evolution and mechanisms of crustal loss. 3) Complex environments: We propose to continue our assessments of the tessera terrains on Venus and analogs on Mars and the Earth, with emphasis on mapping and classifying different tessera types and identifying the nature and sense of deformation of the tectonic elements that make up the tesserae. In later years, we plan to build on these basic descriptive studies to unravel the sequence and style of deformation in several regions of tessera in order to assess models for tessera origin.

d) Summary Bibliography: (1) Crumpler, L.S., Aubele, J.C., and Head, J.W. (1991) Calderas on Mars: Models of formation for the Arsia-type: *Lunar & Planet. Sci. Conf. XXII,* 269-270. (2) Senske, D.A., Head, J.W., Stofan, E.R., and Campbell, D.B.(1991) Geology and Structure of Beta Regio, Venus: Results from Arecibo radar imaging: Submitted to *Geophys. Res. Letters.* (3) Pronin, A.A. and Stofan, E.R. (1990) Coronae on Venus: Morphology, classification, and distribution: *Icarus, 87,* 452-474. (4) Frank, S.L. and Head, J.W. (1990) Ridge Belts on Venus: Morphology and origin: *Earth, Moon, and Planets, 50/51,* 421-470. (5) Head, J.W., Vorder Bruegge, R.W., and Crumpler, L.S.(1990) Venus orogenic belt environments: Architecture and origin: *Geophys. Res. Letters, 17,* 1337-1340. (6) Vorder Bruegge, R.W., Head, J.W., and Campbell, D.B. (1990) Orogeny and large-scale strike-slip faulting on Venus: Tectonic evolution of Maxwell Montes: *J. of Geophys. Res., 95,* B6, 8357-8381. (7) Solomon, S.C. and Head, J.W. (1990) Lithospheric flexure beneath the Freyja Montes foredeep, Venus: Constraints on lithospheric thermal gradient and heat flow: *Geophys. Res. Letters, 17,* 1393-1396. (8) Vorder Bruegge, R.W. and Head, J.W. (1990) Processes of formation and evolution of mountain belts on Venus: submitted to *Geology.* (9) Bindschadler, D.L. and Head, J.W. (1991) Tessera terrain, Venus: Characterization and models for origin and evolution: in press *J. Geophys. Res.*

ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head, III

COLLABORATORS: L. Wilson, E. Parfitt, L. Crumpler, K. Roberts, S. Keddie, and J. Aubele

PROPOSAL TITLE: Geological Studies of Planets and Satellites: Planetary Volcanism

ABSTRACT:
a) Objectives: To study the process of planetary volcanism from theoretical, observational, systems, and comparative planetological points of view.

b) New Proposal:

c) Proposed work: 1) Examination of aspects of volcanic activity in terrestrial basaltic environments and assessment of implications for interpretation of planetary processes and deposits, including (a) studies of magma chambers and reservoirs (magma chamber wall stress model, comparison of model to magmatic history of Kilauea); (b) studies of rift zones, dike emplacement, and flank eruptions (relation between parameters characterizing cyclic rift zone eruptions; study of the transition from short-lived to long-lived eruptions; the size and geometry of dike segments; the specific conditions under which rift zone *eruptions* occur; the nature of eruptive products and the styles of flank eruptions; the geometry of dike systems and predictions of associated features; and aspects of caldera formation processes); (c) assessment of the nature of pyroclastic activity and how it is related to mass flux and gas content. 2) Observations on the terrestrial planets and application of basic principles to planetary problems, including (a) study of the influence of gravity and other factors on the sizes of volcanic plumbing systems and implications for eruption rates; (b) assessment of volcanic centers and eruption styles in a high temperature/pressure surface environment; (c) observational and theoretical analysis of lunar sinuous rilles and thermal erosion; (d) critical analysis of the assumptions in the relation between volcano height and depth to the magma source zone; (e) assessment of the reasons why there are apparently no large shield volcanoes and calderas on the Moon; (f) analysis of the characteristics and distribution of clusters of small volcanic edifices on the Earth, Moon, and Venus.

d) Supplementary bibliography:
(1) J. Head and L. Wilson (1989) Basaltic pyroclastic eruptions: Influence of gas release patterns and volume fluxes on fountain structure, and the formation of cinder cones, spatter cones, rootless flows, lava ponds, and lava flows: *Jour. Vol. Geotherm. Res., 37,* 261-271.
(2) K. Roberts and J. Head (1990) Lakshmi Planum, Venus: characteristics and models of origin, *Earth, Moon and Planets, 50/51,* 193-250.
(3) L. Wilson and J. Head (1990) Factors controlling the structures of magma chambers in basaltic volcanoes. *LPSC XXI*, 1343-1344.
(4) J. Aubele and E. Slyuta (1990) Small domes on Venus: characteristics and origin, *Earth, Moon and Planets, 50/51,* 493-532.
(5) L. Wilson, E.A. Parfitt and J.W.Head (1991) The relationship between the height of a volcano and the depth to its magma source zone: some popular misconceptions. *LPSC XXII*, 1517-1518.
(6) E.A. Parfitt (1991) The shape of dikes emplaced laterally within volcanic edifices. *LPSC XXII*, 1027-1028.
(7) L. Wilson and J.W. Head (1991a) Neutral buoyancy zones in the Venus lithosphere: influence on volcanic landforms and the presence or absence of magma chambers. *LPSC XXII*, 1513-1514.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ken Herkenhoff
(Name, Address, Telephone Number) JPL 1830-501, 4800 Oak Grove Drive
Pasadena, CA 91109 (818) 354-3539

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Geology of the South Polar Layered Deposits on Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The polar regions of Mars contain the best record of Martian climate changes over the last 100 million years. In order to infer the geologic history of the layered deposits, the processes that formed and modified them must first be understood. The extensive exposures of south polar layered deposits are especially suited to studies of weathering and erosion. The dark, saltating material found in both polar regions probably plays an important role in the erosional evolution of the layered deposits. Therefore, determination of its source and current extent is crucial to the interpretation of polar geology. I intend to evaluate new hypotheses for layered deposit formation and evolution by examining geologic evidence in an area that has not previously been studied in detail. Comparison of the inferred geologic history of the south polar layered deposits with previous results concerning the north polar region will constrain possible mechanisms by which Martian climate variations are recorded.

b. New proposal.

c. A new Viking Orbiter digital color mosaic will be constructed, revealing color/albedo units within the layered deposits between 80°S and 87°S latitude and between 240°W and the prime meridian. Recently calibrated Mariner 9 images (the highest-resolution data available) will be used to study the geology of the layered deposits in this area, where significant amounts of dark material appears to exist. The areal distribution of mantling dust and dark, saltating material will test the validity of current interpretations and should indicate the source of the dark material. Study of the association of saltating material with possible source regions of exposed layered deposits, perhaps at scarps where erosion is expected to be more rapid, is an important aspect of the proposed work. Orientations of eolian features such as yardangs and dunes will determine the main direction of polar winds, and therefore the paths of windblown materials. The thickness of a recent deposit will be determined by measuring the sizes of partially buried craters, resulting in an estimate of the current deposition rate.

d. Herkenhoff and Murray (1990a), *J. Geophys. Res.* **95**, 1343-1358; Herkenhoff and Murray (1990b), *J. Geophys. Res.* **95**, 14,511-14,529.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ken Herkenhoff
(Name, Address, Telephone Number) JPL 183-501, Pasadena, CA. 91109
(818)354-3539

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Mars Geologic Mapping in the South Polar Region

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The polar regions of Mars contain the best record of Martian climate changes over the last 100 million years. In order to infer the geologic history of the layered deposits, the processes that formed and modified them must first be understood. The extensive exposures of south polar layered deposits are especially suited to studies of weathering and erosion. The dark, saltating material found in both polar regions probably plays an important role in the erosional evolution of the layered deposits. I intend to evaluate new hypotheses for layered deposit formation and evolution by examining geologic evidence in an area that has not previously been studied in detail. Comparison of the inferred geologic history of the south polar layered deposits with previous results concerning the north polar region will constrain possible mechanisms by which Martian climate variations are recorded.

b. New proposal.

c. Viking Orbiter digital color mosaics will be used to map color/albedo units within the 1:500,000-scale quadrangle MTM -85280. Recently calibrated Mariner 9 images (the highest-resolution data available) will be used to study the geology of the layered deposits in this area, where significant amounts of dark material appears to exist. A digital mosaic of the best Mariner 9 images of this area will be prepared and used to complete the photogeologic mapping of the quadrangle. The areal distribution of mantling dust and dark, saltating material will test the validity of current interpretations and should indicate the source of the dark material. Orientations of eolian features such as yardangs and dunes will determine the main direction of polar winds, and therefore the paths of windblown materials. Analysis of these observations will allow the recent geologic history of the south polar layered deposits to be inferred in the proposed quadrangle.

d. Herkenhoff and Murray (1990a), *J. Geophys. Res.* **95**, 1343-1358; Herkenhoff and Murray (1991), Geologic Map of the South Polar Quadrangle, Mars (USGS, in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Lon L. Hood
(Name, Address, Telephone Number) Lunar & Planetary Lab./Univ. of Arizona
Tucson, AZ 85721 (602) 621-6936

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Lunar Paleomagnetism & Magnetic Effects of Impact Processes.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The investigation is designed to increase our understanding of the origin of lunar paleomagnetism and the general nature of plasma, magnetic field, and remanent magnetization effects of large-scale impacts on planetary surfaces. The work will further constrain the origin of the Reiner Gamma swirls which have been suggested to be the product of either (i) relatively recent cometary impacts on the Moon; or (ii) deflection of the solar wind ion bombardment by locally strong crustal magnetic fields.

b) During the past year, we have reported a detailed theoretical study of the the expansion of the partially ionized vapor cloud produced in lunar basin-forming events and its interaction with a simulated solar wind plasma and magnetic field. Results for impact velocities of 15 to 20 km/sec showed that a magnetic field and plasma compression event occurs in the zone antipodal to the impact point in a time of 400-500 seconds. This time interval is comparable to that required for compressional seismic waves to converge in the same zone.

c) During the coming year, we plan to extend our calculations of the magnetic field effects of large-scale planetary impacts by considering more general plasma and field environments including those appropriate for Mercury, outer planet satellites, and a Moon with a former intrinsic magnetic field. In addition, we will explore several methods for improving our models of the interaction of solar wind ions with local crustal magnetic fields. The latter calculations are relevant to the surface distribution of solar wind implanted hydrogen and helium-3 as well as to the possible origin of the lunar swirls.

d) Hood, L. and C. Williams, The lunar swirls: Distribution and possible origins, *Proc. Lunar Planet. Sci. Conf. 19th*, pp. 99-113, 1989.

Lin, R.P., K.A. Anderson, and L. Hood, Lunar surface magnetic field concentrations antipodal to young large impact basins, *Icarus, 74*, 529-541, 1988.

Hood, L. L. and Z. Huang, Formation of magnetic anomalies antipodal to lunar impact basins: Two-dimensional model calculations, *J. Geophys. Res.*, in press, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Keith A. Holsapple
(Name, Address, University of Washington FS-10
Telephone Number) Seattle, WA 98195

CO-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Fundamental Studies of Impact Mechanics VI

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work

a. Objectives: The research performs theoretical and numerical studies focused on a variety of impact-related phenomena of planetary sciences, including cratering, mass expulsion, and catastrophic disruptions. The unifying themes of the research are 1). to theoretically derive and test scaling laws to apply to experimental results, 2). to perform fundamental studies using code calculations starting from first principles to test those scaling laws and to determine results for important cases of interest, and 3). to develop better numerical tools for this class of problems.

b. Progress: During the last year, progress has been made in three areas, First, studies were made of the applicability of previous scaling laws to impacts into finite-sized spherical bodies and at relative low velocities. Secondly, the scaling laws were applied to experimental results of the Boeing group for the catastrophic disruption of small bodies where gravitational stresses were simulated using external pressure. Finally, a good beginning was made on an entirely new, finite-element based numerical method that shows great promise for calculations where shock waves exist.

c. Proposed Work: Complete the code calculations of impacts into smaller bodies, with special emphasis of the low velocities commonly used for experiments. Do code calculations of the explosive-based experiments of the Boeing group of catastrophic disruptions, in order to determine a basis for the bridge to impact-generated disruptions. Continue work on incorporating better fracture models based on modern fracture theories into the existing finite-difference codes. Develop the discontinuous finite element based code method to apply to the case of general non-linear compressible materials.

d. Relevant Publications:

Housen, K.R., R.M. Schmidt and K.A. Holsapple, "Laboratory Simulations of Large Scale Fragmentation Events", Accepted for Publication in *Icarus*, (1991).

Holsapple, K.A. and K.Y. Choe, "Energy Coupling in Catastrophic Collisions", *Lunar and Planetary Science XXII*, (1991) .

Schmidt, R.M., K.R. Housen, K.A. Holsapple and D.R. Davis,, "Scaling of Fragmentation Events Conducted at Elevated Pressure" *Lunar and Planetary Science XXII*, (1991)

Choe, K.Y. and K.A. Holsapple, "The Discontinuous Finite-Element Method with the Taylor-Galerkin Approach for Nonlinear Hyperbolic Conservation Laws" Accepted for publication in *Computer Methods in Applied Mechanics and Engineering*, (1991)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Alan D. Howard
Department of Environmental Sciences
University of Virginia
Charlottesville, VA 22903 (804) 924-0563

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: GROUNDWATER AND PERMAFROST PROCESSES ON MARS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) *Objectives:* Task I of the proposed research will develop quantitative models of groundwater flow on Mars and the interaction of that flow with surface processes, ground ice, and the regolith. Such flow-related processes have been important in redistributing water on Mars and have significantly affected surface landforms and the regolith. The flow models utilize a combination of regional and cross-sectional simulations and will be coupled with models of surface processes. Effects that will be considered include recharge, confinement of flow beneath permafrost, geothermal processes, ice-injection features, tectonic effects, loading and unloading effects, and water-rock chemical interactions. Surface landforms influenced by surface and groundwater flow processes include scarps, fluvial channels, chaotic and fretted terrain, putative glaciers, and possible pseudo-volcanic landforms. Task II involves development of a general model for valley and slope erosion of cratered surfaces by surficial and groundwater processes in order to understand the extent of erosional modification of old cratered terrain on Mars and the prevailing climatic conditions.

(b) *Research Progress:* Experiments and theoretical models have been developed of the evolution of scarps and valleys by the processes of groundwater sapping, scarp backwasting, and fluvial downcutting. Morphometric techniques have been developed to objectively characterize and compare scarp and valley landforms on Earth and Mars. A Global groundwater flow model has been developed and tested, and is now being extended in the range of conditions to which it applies. Initial stages of development of the cratered terrain erosional model has begun.

(c) *Proposed Research:* Various parameter values and boundary condition scenarios will be examined using the global groundwater flow model. The cratered terrain simulation model will be refined. Specific simulation studies will be initiated of landforms that may have resulted from interactions of artesian groundwater with ground ice, such as chaotic and fretted terrain and pseudo-volcanic landforms.

(d) *Summary Bibliography:*

Baker, V. R., R. C. Kochel, Laity, J.E., and Howard, A.D. and C.F. McLane, 1990, Spring sapping and valley network development. Geol. Soc. Amer. Spec. Paper 252, p. 235-266.

Howard, A.D., 1990, Theoretical model of optimal drainage networks. Water Resources Res., 26, 2107-2117.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

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Boulder, CO 80309-0392 (303) 492-8004

Co-INVESTIGATORS: (Name Only)

none

PROPOSAL TITLE: Remote Sensing of Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Our objective is to understand the local and global nature of the martian surface by using available in-situ and remote-sensing observations. By bringing a physical understanding of the constraints brought by each type of observation, we can synthesize seemingly disparate observations and analyses and derive a more-appropriate and self-consistent view of the nature of the martian surface. The derived surface properties and their spatial variations serve as boundary conditions on ongoing physical and chemical processes which act in the near-surface region.

(b) Last year, we completed our analysis of the effects of atmospheric radiation on the interpretation of thermal inertia on Mars, made significant progress in understanding and modelling thermal emissivity of planetary materials, and made progress on modelling the role of surface particle size in the visible and near-infrared reflectance spectrum of the martian surface.

(c) During the coming year, we will do additional modelling of the effects of the atmosphere on the surface temperatures, incorporating significant upgrades to the numerical model and applying the results to different problems; complete our modelling of the infrared emission from particulate surfaces and apply the results to various terrestrial and planetary problems; and begin construction of our model of the near-surface temperature gradients in planetary surfaces and their roles on the infrared emission spectrum.

(d) Jakosky et al., Directional variations in thermal emission from geologic surfaces, GRL, 17, 985-989, 1990.

Haberle and Jakosky, Atmospheric effects on the remote determination of thermal on Mars, Icarus, in press, 1991.

Jakosky, The Fourth International Conference on Mars, JGR, 95, 14089, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
RAYMOND JEANLOZ
DEPARTMENT OF GEOLOGY/GEOPHYSICS
UNIVERSITY OF CALIFORNIA, BERKELEY
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CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: EXPERIMENTAL STUDIES OF CORE/MANTLE--VOLATILE EQUILIBRIA AND GLOBAL DIFFERENTIATION

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The proposed work involves application of the laser-heated diamond cell to carry out experiments pertaining to core formation, outgassing and thermal histories of terrestrial planets. Phase equilibria, synthesis of new phases and study of kinetic properties are conducted under calibrated P and T in the range 10 to 150 GPa and 1500 to 7000 K. Equilibria among core-forming metal (iron alloy), mantle minerals (silicates, oxides) and volatile constituents under conditions of planetary interiors receive particular emphasis.

b. Results are described in publications listed in the Appendix, and mainly include:
1) Hydrous silicates have been experimentally shown to be stable to ultrahigh pressures for the first time. 2) Experiments demonstrate that deep-focus seismicity observed in the Earth's mantle can be attributed to the presence of hydrous phases being subducted. In combination with (1), the experiments document the deep mantles of Earth and Venus as potentially being *the* major reservoirs of water for these planets. 3) Chemical reactions that occur between liquid Fe (and alloys) and crystalline silicates at ultrahigh pressures have been characterized through chemical microanalysis. Such reactions are thought to be significant for the evolution of the mantle–core systems of large terrestrial planets.

c. 1. Characterize the changes in metal–silicate differentiation mechanisms induced by pressure deep inside terrestrial planets *via* electron microscopic studies of grain-boundary wetting of crystalline silicates by Fe and Fe alloy melts. 2. Study volatile- (Ar-, Xe-, and C/CO_2-) reactions with iron alloys and silicates under high P and T to establish planetary atmosphere and core formation processes. 3. Carry out x-ray diffraction on glasses formed from silicate melts quenched in pressure but not in temperature in order to document structural changes which are thought to significantly affect differentiation of the bulk of the large terrestrial planets.

d. See Appendix.

Knittle, E., and Jeanloz, R., 1991, Earth's core–mantle boundary: Results of experiments at high pressures and temperatures, *Science*, 251, 1438-1443.
Li, X., and Jeanloz, R., 1991, Phases and electrical conductivity of a hydrous silicate assemblage at lower-mantle conditions, *Nature*, 350, 332-334.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: R. E. Johnson
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PROPOSAL TITLE: Charged Particle Induced Alterations of Surfaces in the Outer Solar System

ABSTRACT:

a) Calculations are made on the effect of bombardment of surfaces in the outer solar system by charged particles and micrometeorites in order to calculate resurfacing rates for outer planet satellites and Pluto, and to calculate the state of surfaces of ring particles, comets, and cometary debris. This is done to interpret remote sensing and spacecraft data and to prepare for expected missions.

b) The irradiation processes occurring on the surface of Pluto were evaluated and shown to be small in one orbit,but affect resurfacing rates over many orbits. The radiation-produced primordial comet mantle was shown to be able to survive the thermal shock on entrance to the inner solar system. Plasma bombardment profiles of the surface of Europa were correlated with the extracted UV/OR absorption coefficients showing a clear correlation in longitude. The plasma in the inner magnetosphere of Saturn, to be measured by CASSINI, was shown to be uniquely useful for determining trace elements on satellite surfaces.

c) Because of the proposed outer solar system mission, calculations on the effect of radiation and micrometeorite bombardment on the surfaces of Charon, Neriad, and Triton will be made and those on Pluto extended. Calculations of weathering processes on Oort-cloud comet surfaces will be integrated. Recent laboratory data on bombardment of H_2O/CO will be used to understand the Voyager observations of the Uranian satellites. The deposition of sulfur species on Amalthea will be calculated to interpret its reflectance, and the radiation production of trace species on the surface of Europa will be further evaluated.

d) Magnetospheric Ion Bombardment Profiles:Europa and Dione(Icarus 78,11,1989). Effects of Irradiation on the Surface of Pluto(GRL 16,1233,1989). The Primordial Comet Mantle(Icarus in press,1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Torrence V. Johnson
(Name, Address, Jet Propulsion Laboratory, 183-501
Telephone Number) 4800 Oak Grove Drive, Pasadena, CA 91109
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Co-INVESTIGATORS: Dennis L. Matson, Robert H. Brown,
(Name Only) Jay Goguen

PROPOSAL TITLE: Analysis of Planetary Satellite Data

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. OBJECTIVES: This proposal supports our on-going research on planetary satellites (previously titled Multispectral Analysis). Its objectives are to study the chemical and mineralogical composition of satellite surfaces, to understand the behavior of volatile ices on these bodies and the interactions of the surface with the atmosphere, space environment and internal volcanic and geophysical processes. The studies included under this proposal use both telescopic and spacecraft data and involve the analysis of spectral, photometric, radiometric, and multispectral imaging data sets. Recent work has focused on studies of Io using Voyager and ground based infrared data, and analysis of Voyager data from the Saturn, Uranus and Neptune satellite systems.

B. PROGRESS: Research highlights since the last full proposal include: (1) completion of analysis Io occultation observations and planning for the 1991 events, (2) participation in analysis of new IR camera results for Io hot spots and surface volatile distribution, (3) completion of review chapter on Uranus satellites for Uranus book, (4) support of Voyager Neptune planning and data analysis in the areas of camera calibration, Triton size and albedo, Triton photometric function, and interior structure, (5) continued studies of solid state greenhousing, including applications to the driving mechanisms for Triton's active plumes, (6) analysis of Uranus satellite densities and interior models, (7) imaging analysis of 1985 U1, (8) disk integrated photometry of the five large Uranus satellites, (9) mapping of the distribution of SO2 on Io, (10) review of the characteristics of Io's tenuous atmosphere in "Origin and Evolution of Planetary and Satellite Atmospheres, (11) study of the color distribution on Saturn satellites, (12) studies of Triton's geysers, characteristics and energy sources, (13) photometric studies of Triton's albedo and photometric function.

C. PROPOSED WORK: During the upcoming proposal period, we expect to continue analysis of Io mutual event data in conjunction with multi-bandpass disk integrated radiometry, extend our work on Voyager photometry of Triton and the energy sources required to drive its geyser activity, and collaborate with Galileo imaging and NIMS investigators to study lunar multispectral data for the lunar far side.

D. SUMMARY BIBLIOGRAPHY: See attached bibliography for work supported by this proposal over the last proposal cycle.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William M. Kaula
(Name, Address, Telephone Number)
University of California, Los Angeles
Department of Earth & Space Sciences
405 Hilgard Avenue
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213-825-4363

PROPOSAL TITLE: Origin Dynamics and Venus Tectonics

ABSTRACT:

a. Objectives: (1) to determine the nature of heterogeneities occurring in the collapse of the protosolar cloud; (2) to study the evolution of small body orbits in the solar system, with a view to estimating the roles of resonances and chaos in the formation of planets from planetesimals; (3) to compute finite element models of mantle convection and its interaction with a crust, to help understand tectonic features on Venus.

b. Accomplishments of the prior year: These three tasks all entail modelling on the SDSC Cray Y-MP. (1) The rectilinear hydrodynamic code for stellar collapse was completed, and several production runs were made. The most marked new result is that differential rotation in the protostellar cloud strongly favors fragmentation. (2) An N-body code has been running smoothly for several months, applied to searches for stability in the asteroid belt and Jupiter-Saturn zone. The main recent effort has been in experiment design and output representation. (3) The CONMAN finite element code has been adapted to multi-component flows, with differences in temperature dependent viscosity as well as density. About six cases in 700-km square boxes have been run, with interesting implications as to the evolution of convergent zones over times up to 400 million years.

c. Plans for the coming year: (1) Write-up the stellar collapse models for publication in the Astrophysical Journal. (2) Apply the N-body code to problems on which significant results should be achievable on runs of less than 100 million years: i.e., from the asteroid belt to the vicinities of Saturn's Lagrangian Points. (3) Apply the finite element code to idealized problems related to the mechanisms of formation of Beta Regio and Ishtar Terra.

d. Recent relevant publications: Kaula, W.M. 1990 Mantle convection and crustal evolution on Venus, GRL **17** 1401-1403; Bindschadler, D.L. et al 1990 Mantle flow tectonics and the origin of Ishtar Terra, Venus, GRL **17** 1345-1348; Kaula, W.M. 1990 Differences between the Earth and Venus arising from origin by large planetesimal infall, The Origin of the Earth, Newsome & Jones, eds., LPI, Houston, 45-57; Kaula, W.M. & Newman, W.I. 1991 The origin of Neptune Adv. Space Res. **10**, accepted; Lenardic, A. et al 1991 A finite element model of crustal deformation on Venus, Lunar & Planetary Science **22**, submitted.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Susan Werner Kieffer
Department of Geology, Arizona State University, Tempe, AZ 85287
(602) 965-7877

PROPOSAL TITLE: Fluid Dynamics of Multiphase Flow in Volcanic Environments on the Earth, Io, and Other Planets

ABSTRACT:

A. Objective and justification: The objective of the proposed work is to formulate numerical models for the flow of multiphase fluids through volcanic systems under planetary conditions where phase changes within the conduit and/or surface plumes and flows are important, and where transitions may occur from incompressible, subsonic to compressible, supersonic flow. Numerical one-dimensional models are to be implemented within the grant period, and the possibility of use of Cray supercomputing models in the future is to be investigated. The work will extend volcanic eruption models to pressures, temperatures, and chemistries not yet quantitatively examined; it can provide a conceptual framework for interpretations of planetary images; and it may provide suggestions for specific observations that can be made by future spacecraft missions and by ground-based observatories.

B. Progress: We have: (1) collected and begun analysis of thermodynamic data for water, carbon dioxide, sulfur, and sulfur dioxide; (2) implemented a pipe-flow model for boiling fluids; (3) explored the application of Cray supercomputing models for analysis of planetary volcanism studies; (4) developed, at ASU, computer animation graphics for the flow model (and colleagues at Los Alamos National Laboratory have perfected video display techniques for displaying flow dynamics); and (5) completed 1.5 drafts of a new book "Volcanism: A Planetary Perspective" that will be the major written report on this work.

C. Work Plan: (1) I plan to finish the equation-of-state work compilation, evaluation, and numerical analysis this year. This work will be distributable on disks in a form easily used by personal computers. (2) I have been delayed in implementing the set-up of my computer laboratory at ASU because my future laboratory space is that currently occupied by Mike Malin, whose departure from ASU was delayed by 6 months. We have been improvising by using Fortran on Macintoshes. (3) We will develop the pipe flow model currently being evolved to consider not only the phase changes, but simple models for rheology as the fluid evolves from liquid to froth to vapor laden with particulate material. (4) I have "leap-frogged" ahead in the time-table of proposed work, and begun a successful collaboration on Cray volcanic modelling with collaborators (Ken Wohletz and Greg Valentine) at Los Alamos National Laboratory. We are evolving their current models for terrestrial volcanism with the perspective of being able to do planetary models as the next step in this research. Their main model (DASH) has been imported to the ASU Cray and has been run successfully. Visualization techniques are being developed and this proposal includes a supplemental request for computational upgrading capabilities to allow development of these techniques for planetary volcanism problems.

D. Publications: (1) Valentine, G., Wohletz, K., and Kieffer, S., Effects of topography on facies and compositional zonation in caldera-related ignimbrites, submitted to Bull. of the GSA, Sept. 1990, approx. 50 pages of manuscript; (2) Valentine, G., Wohletz, K., and Kieffer, S., Video of Cray simulations of central-vent caldera eruptions, distributed through LANL, 1990; (3) Valentine, G., Wohletz, K., Kieffer, S., and Hodson, S.W., Sources of unsteady column dynamics in pyroclastic flow eruptions, submitted to JGR, March, 1990. (4) Levine, A., and Kieffer, S., Hydraulic analysis of pyroclastic flows, to be submitted to Geology, March, 1990.

PROPOSAL SUMMARY

(Names, Address, Telephone Number)

Trude V.V. King
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(303) 236-1373; FTS 776-1373

CO-INVESTIGATORS: R.N. Clark

TITLE: SPECTROSCOPIC SEARCH FOR MINERALS ON MARS, CERES, AND OTHER BODIES

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered a. through d. should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.):

a. The proposed work will integrate the spectra (0.2-200μm) of standard laboratory mineral and rock samples in conjunction with theoretical mineral mixing models to more accurately determine the composition of the surfaces of Mars, Ceres, Pallas, and Iapetus as determined by telescopic and spacecraft data. The observational data and Mariner 7 (3.9-14.4 μm) and Mariner 9 (~6.0-50 μm) data will be compared and contrasted to the laboratory mixtures and theoretical calculations. The results of this investigation will further constrain models of primary and secondary processes in the solar system. The results of this work will be valuable for the Mars Observer Mission.

b. New proposal

c. Continue interpretation of exisiting observational data of Ceres. Propose for additional observation time (separate proposal) to acquire high-resolution data for Pallas and Iapetus. Reduce and interpret new telescopic observations. Begin to reduce, calibrate, and interpret Mariner 7 data for the wavelength region from 3.9-14.4 μm Produce labortory mixtures and theoretical calculations to substantiate the remotely sensed data.

d. Calvin, W.M., and T.V.V. King, 1991, Spectral evidence for carbonates on Mars: Hydrous carbonates. Abstract, *Lunar Planet. Sci. Conf.*, XXII, pp. 169-171.

Calvin, W.M., R.N. Clark, and T.V.V. King, 1991, New spectral observations of Callisto and leading/trailing hemisphere distinctions. Abstract, *Lunar Planet. Sci. Conf.* XXII, pp. 171-172.

King, T.V.V., R.N. Clark, W.M. Calvin, D.M. Sherman, G.A. Swayze, and R.H. Brown, 1991, Evidence for ammoniun-bearing minerals on Ceres. Abstract, Lunar and Planet. Sci., XXII, pp. 717-718.

King, T.V.V., R.N. Clark, W.M.Calvin, G.A. Swayze, and R.H. Brown, Ammonium-bearing mineral species on Ceres. abstr., *Bull. Am. Astrn. Soc.*, 22, p 1123.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Randolph L. Kirk
USGS, 2255 N.Gemini Dr., Flagstaff, AZ 86001
602-527-7020; FTS 765-7020

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Digital Modeling of Planetary Surface Environments.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: To develop and demonstrate a set of computationally intensive techniques for the investigation of planetary and satellite surface processes and material properties. These techniques will allow one to deconvolve hyperspectral image data to derive information about the spectral reflectance, albedo, spatial distribution of surface materials, and topographic relief at high resolution, while accounting fully for the effects of atmospheric radiative transfer. Integration of these techniques will not only increase the amount of scientific information extractable from a given dataset, but it will also open the door to analyses of datasets too complex to be studied by each of the individual methods below, which when used standing alone usually require restrictive assumptions about the nature of the planetary surface and atmospheric environment.

The ingredients needed in an integrated approach to planetary surface modeling are now largely available. They include 1) an efficient method of full two-dimensional photoclinometry (modeling of the brightness information in an image to solve for a complete topographic map of the imaged region); 2) multispectral linear-inverse mapping (mapping the proportions of a set of end-member spectral units at every point in a multispectral image while accounting for the effects of topography on the image brightness); 3) estimation of the spectral end members from the data with no a *priori* information; and 4) a comprehensive treatment of the radiative transver between surface and atmosphere (a generalized order-of-scattering approach will be used to model the irradiance field that interacts with the surface). A significant amount of experience and success of the proposer with the analytic methods to be used—in particular, with photoclinometry—is an additional, important resource that will be drawn upon in the proposed work.

Three specific scientific problems will be studied: 1) analysis of a pair of multispectral image sets of the south polar region of Mars with greatly differing illumination conditions, both as a robust test of the integrated modeling approach and in order to determine the mesoscale topography and spectral reflectance of the sand sheets, bedrock debris, dust, and ice units; 2) quantitative analysis of the amount of "terrain softening" on Mars as functions of geologic setting, age, latitude, and horizontal scale, resulting in specific estimates of the thickness of a putative subsurface ice layer (Squyres and Carr 1986); and 3) integrated compositional unit mapping and topographic modeling of Io's surface (Use of color to separate intrinsic and slope-related brightness variations, in combination with photoclinometry to estimate of material strength, effusion volumes, and rates.).

b. Progress: New Proposal.

c. Work Plan FY92: Apply the order-of-scattering model to correct images for atmospheric scattering effects; also fit photometric functions to very high-resolution images and topographic map of part of the Olympus Mons aureole. Validate integrated modeling approach by applying to multispectral mosaics of the Martian south pole, and publish results.

d. Relevant Bibliography: KIRK, R. L. (1987) *A Fast Finite Element Algorithm for Two-Dimensional Photoclinometry.* Part III, Ph.D. Thesis (unpubl.), Caltech, 165–258. KIRK, R. L., AND MOORE, H. J. (1991) Mars Surface Roughness Statistics: Initial Comparison of Results from Radar and Two-dimensional Photoclinometry (preprint).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David L. Kohlstedt, Professor
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CO-INVESTIGATORS:

TITLE: Physical Properties of Partially Molten Ammonia-Water Ice: Permeability and Rheology

ABSTRACT:
(a) Over the past few years, systematic experimental investigations of the rheology of the various high-pressure phases of H_2O ice have been undertaken to provide physical constraints on models of the tectonic behavior of icy satellites in the outer solar system. Recently, this work has been extended to include flow of NH_3-H_2O ice, primarily below its solidus temperature. Images from the Voyager mission, however, reveal geologic features on the surfaces of icy moons indicative of extensive volcanic and igneous activity. Therefore, to provide the fundamental data base required to analyze the such surface features as well as to understand the evolution of these icy bodies, laboratory measurements of the rheology of partially molten NH_3-H_2O ice and transport of a liquid phase through NH_3-H_2O ice are essential. Consequently, an investigation of the creep behavior and permeability of partially molten NH_3-H_2O ice at temperature and pressures appropriate for these icy moons is proposed. Because both of these properties are critically dependent on the distribution of the distribution melt phase, careful microstructural characterization will form an essential part of this project.

(b) New proposal.

(c) Primary goals for the first year of this new research effort are [i] to determine the grain-scale distribution of the melt phase in subliquidus, H_2O-rich, two-phase samples of NH_3 + H_2O and [ii] to initiate creep experiments both at high pressures and at one-atmosphere total pressure on these partially molten samples. Two compositions in the range $0.01 \le NH_3/(NH_3+H_2O) \le 0.05$ will be examined over the approximate temperature range 180-250 K (giving volume fractions of melt in the range 0.03 to 0.30, depending on temperature). During the academic year, one-atmosphere experiments will be carried out at the University of Minnesota; during the summer, high-pressure experiments (confining pressures ~50 MPa) will be carried out at Lawrence Livermore National Laboratory.

(d) R.F. Cooper and D.L. Kohlstedt, "Rheology and structure of olivine-basalt partial melts", *J. Geophys. Res.* 91, 9315-9323 (1986).

R.F. Cooper, D.L. Kohlstedt, and K. Chyung, "Solution-precipitation enhanced creep in solid-liquid aggregates which display a non-zero wetting angle", *Acta Met.* 37, 1754-1771 (1989).

G.N. Riley, Jr., and D.L. Kohlstedt, "An experimental study of melt migration in an olivine-melt system", in *Magma Transport and Storage*, ed. M.P. Ryan, John Wiley & Sons, 77-86 (1990).

G.N. Riley, Jr., D.L. Kohlstedt, and F.M. Richter, "Melt migration in a silicate liquid-olivine system: an experimental test of compaction theory", *Geophys. Res. Lett.* 17, 2101-2104 (1990).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Larry A. Lebofsky
Senior Research Scientist
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721
602-621-6947

PROPOSAL TITLE: AN INFRARED REFLECTANCE STUDY OF LOW ALBEDO SURFACE CONSTITUENTS

ABSTRACT:

a) We propose to expand upon our previous laboratory IR-reflectance studies of low-albedo materials. Our objective is to analyze our telescopic data obtained under separate funding, obtain spectra of laboratory analogs, and compare these spectra in order to determine the mineralogy of low-albedo asteroids. It has been shown that the asteroids were probably formed fairly close to their present locations and the majority may be relatively unaltered since their formation. Thus, studies of these primitive bodies is important to our understanding of the formation and evolution of the solar system. Our work is also directly applicable to data analysis from spacecraft encounters with asteroids and other small bodies by missions such as Phobos, Galileo, Cassini, CRAF, and other potential missions to comets or asteroids. b) During the past two years, we have obtained visual and infrared spectra of a suite of meteorites and low-albedo materials and have continued our comparisons with telescopic observations. Dan Britt, originally from Brown University is now working with us and so we now have access to meteorite spectra from the large RELAB spectral data set. c) During the next year, we propose to continue our laboratory studies. We are delaying the purchase an environmental chamber for cooling our samples. Though this work is important, we are still trying to establish our own spectroscopy laboratory here and will intall the cooling equipment in that. At the same time, our observational studies of primitive asteroids are also expanding so we will have a much larger data base for analysis and comparison. Our groundbased program is growing with Dan Britt working on the inner belt dark asteroids and graduate studen Ellen Howell working on the relationship between comets and asteroids. Our primary goals are to: 1) analyze near IR (1.0 to 4.0 μm) spectra of asteroids obtained under separate NASA funding 2) compare these to our presently existing laboratory spectra of meteorites, meteorite analogs and other low-albedo materials 3) conduct a literature search, reanalysis of our old data, and new reflectance studies of low-albedo candidate materials for comparison with unidentified spectral features in our existing spectra of outer belt and Trojan asteroids, 4) incorporate the reflectance database on dark meteorites that has been obtained by Dan Britt at Brown, and 5) expand our lab studies to include other low-albedo meteorites that may be important asteroid analogs such as the black chondrites. d) Jones (1988), Lebofsky *et al.* (1990), Jones *et al.* (1990), Gaffey *et al.* (1991), Lebofsky *et al.* (1991).

PROPOSAL SUMMARY – ABSTRACT

PRINCIPAL INVESTIGATOR: Eugene H. Levy, Professor of Planetary Sciences
Lunar and Planetary Laboratory
University of Arizona
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(602) 621-6962

TITLE: Generation and Behavior of Solar System Magnetic Fields

ABSTRACT:

(a) Many solar-system objects possess intrinsic magnetic fields generated by internal dynamos. The fields influence planetary dynamical processes, and provide clues about planetary interiors. Evidence suggests the presence of an intense magnetic field in the early solar-system nebula, which may have had significant effects on the solar system's formation. This research is aimed at elucidating the generation, behavior and influences of such solar-system magnetic fields.

(b) Investigated generation and behavior of dynamo magnetic fields in the protoplanetary nebula and in planets; continued investigation of electrical conductivity of protoplanetary nebula gas, involving careful examination of the interaction of free charge with dust in the relatively dense bath of nebular gas; continued investigation of internal dynamics of planetary of a planetary core as it interacts with a dynamo-generated magnetic field.

(c) We will continue exploration of magnetic field generation, behavior, and effects in the protoplanetary nebula. We will continue studies of nebular disk flares, with emphasis on their possible role in chondrule formation and other transient disequilibrium phenomena that could have produced anomalous chemical states in meteorites. We will continue investigations of meteorite chondrules and the implications for the nature of processes in the protoplanetary nebula. We plan to complete work on the generation of dynamo magnetic fields in the presence of imposed ambient fields, exploring the possibility that polarity asymmetries in Earth's magnetic field were induced in this way, and to develop some possibly new insights into the way in which planetary magnetic fields achieve dynamical equilibrium. We will continue to investigate the electrical conductivity of protoplanetary nebula gas in order to explore basic questions that stand in the way of understanding the magnetic behavior of the nebula. We will carry out studies of the behavior of the terrestrial magnetic field to further understanding of planetary magnetic field generation more generally.

(d) 1989, *Magnetic Reconnection Flares in the Protoplanetary Nebula and the Possible Origin of Meteorite Chondrules* (E.H. Levy and S. Araki) **Icarus, 81**, 74.

1990, *Dynamo magnetic field-induced angular momentum transport in protostellar nebulae: The minimum-mass protosolar nebula* (T.F. Stepinski and E.H. Levy) **Astrophysical Journal, 350**, 819.

1991, *Generation of Dynamo Magnetic Fields in Thin Keplerian Disks*, (T.F. Stepinski and E.H. Levy), submitted for publication.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Jack Lissauer
ESS Dept., SUNY, Stony Brook, N. Y. 11794-2100
(516) 632-8225

Co-INVESTIGATORS: (Name Only) None

PROPOSAL TITLE: DYNAMICAL PROBLEMS IN THE SOLAR SYSTEM

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives: To develop a better understanding of several aspects of the origin and evolution of the solar system. The process of planetary accretion will be investigated in an effort to place constraints on the surface mass density distribution of the protoplanetary disk and the time scales of planetary growth. The ring systems of the giant planets will be studied to improve understanding of physical processes important in the solar nebula and other disk systems. The cratering record on some of the oldest surfaces in the solar system will be analyzed to learn about debris remaining at the end of the accretion epoch.

(b) Progress: 1) Finished analysis of identified spiral waves in Saturn's rings detected in the Voyager radio occultation data. 2) Continued analysis of Voyager PPS uranian ring occultation data. 3) Continued and expanded investigation of three-body planetary accretion rates in planetesimal disks with low random velocities. 4) Wrote review chapter on planetesimal dynamics for *Protostars and Planets III* book. 5) Completed preliminary investigation of heating of chondrule rims upon impact into planetesimal regoliths.

(c) Proposed Work: 1) Study unidentified wave features observed in the Voyager radio occultation of Saturn's rings. 2) Finish deriving best-fit optical depth estimates with error bars for Voyager PPS uranian ring data. Use these results to compute local eccentricity gradients for the ε and δ rings. 3) Develop new model of angular momentum transport between rings and moons which follows eccentricity vectors of ring particles. 4) Compute protoplanet accretion rates in a gas-rich solar nebula. 5) Incorporate three-body accretion rates of solid planetary bodies into a self-consistent model of core and envelope growth of the jovian planets. 6) Apply statistical tests developed in the study of the cratering record on Saturn's moons to other heavily cratered surfaces in the solar system.

(d) Major Recent Publications: 1) Rosen and Lissauer (1988) "The Titan -1:0 Nodal Bending Wave in Saturn's Ring C" *Science,* 241, 690. 2) Greenzweig and Lissauer (1990) "Accretion Cross Sections of Protoplanets" *Icarus,* 87, 40.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Baerbel K. Lucchitta
USGS, 2255 N.Gemini Dr., Flagstaff, AZ 86001
602-527-7176; FTS 765-7176

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Structure of the Valles Marineris

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

Objectives: The objective of the study is to contribute to an understanding of the origin and evolution of the Valles Marineris troughs by conducting a detailed analysis of structures within the troughs and on the nearby plateaus. The study will shed light on such questions as (1) the time of opening of the troughs and the influence of regional stress systems on their formation and evolution; (2) the relative importance of tectonic movement, surficial collapse, and erosional widening; and (3) the relative merits of models of origin involving either withdrawal of material at depth and collapse or plate-tectonic style rifting.

Progress: 1) A morphometric study comparing trough widths and depths showed that pit chains probably formed by surficial collapse and troughs by deeper seated processes perhaps involving the entire lithosphere. 2) A study of age relations suggested that the troughs may be split lengthwise into northern and southern segments that differ in age, rather than being split into eastern and western segments as geophysical models predict. 3) We have begun to map fault traces and fault profiles on stereo-photogrammetric image models to determine fault plane attitudes. 4) We compiled and digitized a new geologic/geomorphic map that corresponds to the digital terrain models, and we calculated volumes of void spaces and deposits. Preliminary results show that the volume of materials eroded from the walls far exceeds the volume of interior deposits.

Anticipated work: Additional fault attitudes will be determined photogrammetrically and strains will be calculated. We will refine the volume calculations, perform calculations for individual troughs, and investigate geologic implications of the numerical results. We will initiate terrestrial analog studies and prepare reports.

Bibliography:

Lucchitta, B.K., 1987, Recent mafic volcanism on Mars: Science, v. 235, p. 565-567.

Lucchitta, B.K., 1987, Valles Marineris, Mars: Wet debris flows and ground ice: Icarus, v. 72, p. 411-429.

Lucchitta, B.K., 1990, Valles Marineris, Mars: Are pit chains formed by erosion and troughs by tectonism? (abs.), in Lunar and Planetary Science 21: The Lunar and Planetary Institute, Houston, Texas, p. 722-723.

Lucchitta, B.K., 1990, Young volcanic deposits in the Valles Marineris, Mars: Icarus, v. 86, p. 476-505.

Lucchitta, B.K., Clow, G.D., Geissler, P.E., McEwen, A.S., Schultz, R.A., and Squyres, S.W., The canyon system on Mars: In "Mars" The University of Arizona Press, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Paul G. Lucey
Planetary Geosciences, Dept. Geology & Geophysics
2525 Correa Rd. Honolulu HI 96822 (808)956-3137

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Mineralogical Mapping of the Moon

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The objective of this work is to determine whether a magma ocean existed on the Moon by measuring the plagioclase abundance of the lunar nearside and by mapping the distribution of anorthosite and anorthosite-related rock types. The measurements will rely upon visible imaging spectroscopy and IR imaging to collect sufficient spectral and spatial data to map the distribution of anorthosite and model the plagioclase content of lunar soils, and upon emission spectroscopy to determine the nature of troctolitic areas on the Moon. The measurement will be used to determine if there is sufficient plagioclase in the lunar crust to require a magma ocean. The presence or absense of a lunar magma ocean has implications not only for the origin and evolution of the Moon, but the initial thermal state of all large objects in the solar system. The fundamental question addressed is: Does accretion occur rapidly enough to produce global or even total melting?; b) new proposal; c) IR data collected under the Planetary Astronomy program will be reduced to reflectance; IR and visible data will be coregistered; maps of anorthosite occurrences will be produced; emission spectra of mixtures of lunar analog material will be obtained to examine the behavior of emission spectral features; emission spectra of lunar soils and agglutinate separates will be obtained to determine the effects of soil maturity. on emission spectra. d) Lucey, P.G., Comparison of thermal emission spectroscopic measurements of the lunar surface: 1968-1990, *Proc. Lunar Planet Sci Conf 21*, pp417-423,1991; Lucey, P.G., B.C. Bruno, and B.R. Hawke, Preliminary results of imaging spectroscopy of the Humorum Basin region of the Moon, *Proc. Lunar Planet Sci Conf 21*, pp391-403,1991; Bruno, B.C., P.G. Lucey, and B.R. Hawke, High resolution UV-visible spectrocopy of lunar red spots, *Proc. Lunar Planet Sci Conf 21*, pp391-403,1991.

Proposal Summary

PRINCIPLE INVESTIGATOR: Jonathan I. Lunine
Lunar and Planetary Laboratory
University of Arizona
Tucson AZ 85721

CO-INVESTIGATOR:

PROPOSAL TITLE: Theoretical studies of volatile processes in the atmospheres and surfaces of outer solar system bodies.

ABSTRACT:

(a) Investigate the role of volatile materials and processes in determining the present-day surfaces, atmospheres and evolution of outer solar system bodies. Infer the composition of volatile molecular species on outer solar system bodies from spacecraft and ground-based data, and use these along with semi-analytic thermodynamic and radiative transfer models to constrain chemical/ physical models of their origin. Data sets utilized inlcude published ground-based studies, and Voyager results.

(b) (1) The dynamics of the Triton atmosphere have been modeled and a mechanism for driving material into the middle atmosphere completed and published; (2) the thermal history of the Titan atmosphere and surface have been modeled using a non-grey radiative-convective atmosphere code and new surface models; (3) preliminary calculations on the effect of carbon dioxide clathrate on the cooling of the Martian surface and atmosphere were undertaken; (4) a study of the rheology of the ammonia-water system was completed and published; (5) the physical and chemical evolution of interstellar grains from molecular clouds to their inorporation in the solar nebula was studied to understand the chemical signatures of outer solar system bodies; (6) review papers on Titan, Triton, satellite origins, interstellar/nebular chemistry were prepared.

(c) (1) Models of Ionian hot spots will be constructed for comparison with anticipated data from ground-based observations; additional models of volatile transport on Io will be considered; (2) models of the earliest evolution of Titan's surface and atmosphere will be undertaken; (3) surface-atmosphere models of Triton and Pluto will continue to be pursued, including implications for origin.

(d)Yelle, R.V., Lunine, J.I. and Hunten, D.M. 1991. Energy balance and plume dynamics in Triton's lower atmosphere, *Icarus 89*, 347-358; Lunine, J.I., Engel, S. and Rizk, B. 1991. Sublimation and reformation of icy grains in the primitive solar nebula, *Icarus*, submitted.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Michael C. Malin
Malin Space Science Systems, Inc.
55 N. St. Hdhn Ave
Pasadena, CA 91103 (818) 796-4266

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Planetary Geomorphology

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a. Objectives: to develop and apply quantitative techniques to the study of planetary geomorphic processes. Specifically, to continue and expand laboratory measurements of the thermophysical properties of silicate and ice/silicate mixtures under simulated martian conditions.

b. Progress: 1) completed Ph.D. dissertation on sublimation experiments of bare and dust-covered ice under simulated martian conditions; 2) student continued stability analyses of steep martian cliff; 3) paper on Venus tectonics complete; 4) paper on eolian processes in Iceland completed; and 5) analysis of martian sedimentary processes using IRTM continued.

c. This Year: 1) initiate study of multi-component, non-volatile mixtures (dust, sand, crust, and rock) under simulated martian conditions and measure thermophysical properties; and 2) complete papers on boulder population evolution and implications for martian surface exploration.

d. Summary Bibliography:

Fink, J. H., Malin, M. C., and Anderson, S. W., 1990, Intrusive and extrusive growth of the Mount St. Helens lava dome, *Nature* 348, 435-437.

Phillips, R. J., Grimm, R. E., and Malin, M. C., 1991, Hot-spot evolution and the global tectonics of Venus, *Science* (in press).

Malin, M. C., Danielson, G. E., Ravine, M. A., and Soulanille, T. A., 1991, Design and Development of the Mars Observer Camera, *Int. J. Imaging Sys. Tech.* (in press).

Malin, M. C., Danielson, G. E., Ingersoll, A. P., Masursky, H., Veverka, J., Ravine, M. A., and Soulanille, T. A., 1991, The Mars Observer Camera, *J. Geophys. Res.* (in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Ho-kwang Mao
Carnegie Institution Washington, Geophysical Lab.
5251 Broad Branch Road, N. W., Wash., D.C. 20015
(202) 686-2410

CO-INVESTIGATORS: (Name Only) Russell J. Hemley

PROPOSAL TITLE: High-Pressure Studies of Planetary Gases and Ices

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objective. We propose to study the high-pressure properties of planetary gases and ices in the system C-H-He-O-N to maximum pressures of 300 GPa (3.0 Mbar) and variable temperatures from 30 to 800 K. Phase transitions (including insulator-metal transitions), crystal structures, equations of state, and optical and dielectric properties of principal phases will be determined as functions of pressure and temperature. The results will be used to constrain models of the outer planets.

b. New Proposal.

c. Proposed Work for this Year. (1) The infrared absorption and reflectivity measurements on hydrogen will be extended to higher pressures (above 200 GPa) to temperatures below 77 K to characterize the properties of the solid in its high-density semiconductor, semimetallic, and metallic states, and the determine the effect of temperature on metallization and associated transitions. (2) Single-crystal x-ray diffraction measurements will be performed on H_2, He, and H_2-He mixtures to the 60 GPa range and at 30-500 K with a liquid helium cryostat and resistive heating. Using this technique in conjunction with optical spectroscopic methods, the P-T-X phase diagram will be determined over this range, and accurate P-V-T equations of state will be obtained for application to Jovian interior conditions.

d. Relevant Publications. (1) H. K. Mao, R. J. Hemley, and M. Hanfland, Infrared reflectance measurements of the insulator-metal transition in solid hydrogen, *Phys. Rev. Lett. 65*, 484-487, 1990; (2) R. J. Hemley, H. K. Mao, L. W. Finger, A. P. Jephcoat, R. M. Hazen, and C. S. Zha, Equation of state of solid hydrogen and deuterium from single-crystal x-ray diffraction to 26.5 GPa, *Phys. Rev. B 42*, 6458-6470, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Terry Z. Martin
Jet Propulsion Laboratory
Pasadena, CA 91109
(818) 354-2178 (FTS) 792-2178

TITLE: MARINER 7 INFRARED SPECTROMETER DATA: TOWARDS A PHYSICAL DATA SET

ABSTRACT:

a. The Mariner 6/7 IRS data set, the only available spacecraft spectral data for Mars between 2 and 5 µm, contains valuable information about the presence and nature of Martian mineral species, the surface hydration state, and the presence of various salts. It has recently been restored by the author into digital form and archived via the Planetary Data System (PDS); that product has since been subjected to analysis by several investigators. Each of them has had to deal with the calibration problem, because no calibration was applied to the archived raw data. In order to expedite further work, it is proposed that a data set be prepared in physical units (radiance and brightness temperature versus wavelength).

b. New task

c. The procedure described in the first reference below will be systematically applied to the 512 spectra, removing the instrumental response by use of inflight space observations, inflight polystyrene wavelength reference spectra, and laboratory observations of blackbodies and, for the short wavelength region (1.9 - 3.0 µm), Nernst glowers. The spectra will be archived as radiance versus wavelength over the entire spectral range, and as brightness temperature versus wavelength beyond about 4 µm. The data set will be archived following PDS standards and submitted to PDS.

d. Mariner 6/7 Infrared Spectrometer: data set restoration. T.Z. Martin, submitted to Icarus, 1991 (attached).

Data set restoration: the Mariner 6/7 Infrared Spectrometer. Bulletin of the AAS vol. 17, 723 (1985).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dennis L. Matson
(Name, Address, Telephone Number) Jet Propulsion Laboratory 183-501
Pasadena, CA 91109 (818) 354-2984 FTS 792-2984

Co-INVESTIGATORS: (Name Only) Torrence V. Johnson, Glenn J. Veeder
Robert H. Brown, Jay Goguen

PROPOSAL TITLE: Surface Chemistry and Geophysics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. OBJECTIVES: To carry out investigations of the physical chemistry, composition, and geophysics of satellites in the solar system. Emphasis is given to work which, in addition to yielding significant scientific results, gives information useful in planning measurements to be made by the Galileo and Cassini missions.

B. PROGRESS: The study of Io's hot spots was furthered by the occurrence and observation of a series of occultations of Io by Europa. We carried out model studies which established the importance of these events and then alerted observers to the significance of these events for Io astronomical and geophysical studies. We supported observers through the generation of predictions and analysis of the circumstances of each event. Many of the occultations were successfully observed. We are now starting to analyze a number of these events in order to obtain locations and temperatures for some of Io's hot spots. Enough observations were made of Loki, the largest hot caldera on Io, that it may be possible to form a tomographic image and a temperature map.

C. PROPOSED WORK: The Io hot spot work will continue with analysis of the 1991 occultation data base. An effort to understand Io's polar units (which may contain H_2S frost) will be resumed.

D. SUMMARY BIBLIOGRAPHY: Two papers published in scientific journals; 3 two page abstracts and 3 short abstracts published.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Dr. Ted A. Maxwell
National Air and Space Museum
Washington, D.C. 20560 (202) 357-1424

Co-INVESTIGATORS: (Name Only) Dr. Thomas R. Watters

PROPOSAL TITLE: Photogeologic Investigations of Planetary Tectonic Features

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal is for renewal of NASA Grant NAGW-129, to support studies of the origin of tectonic landforms on the surfaces of the inner planets. This work entails mapping specific landforms, age-dating exposed surfaces via crater frequency and superposition relations, and developing models for the origin of surface features.

(b) During the past year, work has continued on the dating of ancient highland surfaces in the equatorial region of Mars, with emphasis on the nature and ages of erosional and depositional periods of resurfacing. Two manuscripts are in preparation detailing our results suggesting that erosional resurfacing was much more extensive than previously thought, and that the age of highland surface stability varies with elevation.

(c) For the coming year, we will complete the two papers cited above, and continue modeling the nature of erosion of martian terrain by: 1) Comparing denudation rates for terrestrial and martian climatic zones; 2) Studying in detail the sources and sinks of surface materials in the highlands using detailed topography that is now available; and 3) Using our extensive data base of fresh and eroded craters to determine a new standard crater production curve for Mars.

(d) Craddock, R. A. and Maxwell, T.A., Resurfacing of the martian highlands in the Amenthes and Tyrrhena region. Jour. Geophys. Res., v. 95, p. 14265-14278 (1990). Craddock, R. A. and Maxwell, T.A., Nature of Early Fluvial Processes on Mars (Abstract) <u>in</u> Geol. Soc. America Abstracts with Programs, v. 23, p. A402 (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Thomas B. McCord, University of Hawaii
Planetary Geosciences Division, Dept. G & G
2525 Correa Rd., Honolulu, HI 96822
808 958 6488

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Remote Compositional Analysis of Lunar and Planetary Sucraces

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Continue longterm investigation of the mineralogy of solar system objects to: 1) add knowledge of the planetary system; 2) develop techniques for remote sensing analysis; 3) train scientists. This program also supports existing and planned planetary missions such as Galileo, Mars Observer, CRAF/Cassini, Lunar Observer and asteroid missions.

b. During the past year we have continued to analyzed the telescopic reflectance data we acquired for Mars during the 1988 and 1986 prime oppositions. We also prepared for and carried out measurements of Mars during the 1990 opposition. Recent work further supports the discovery of an absorption band at 4.5 μm and our interpretation of SO4 in the Mars surface. The existence of crystalline iron oxides including at least hematite on Mars was determined. Laboratory study of Mars analog minerals supports small-scale, short heat-pluse events for modifying Mars soil material. Major input has been made to the calibration of the Mars 94 VSK-FREGAT imaging experiment data.

c. The main tasks for the coming year are: 1) interpret the past and the upcoming 1990 Mars opposition telescopic data we have acquired to determine the type of sulfate and iron oxide minerals present; 2) continue laboratory study of iron oxides; 3) analyze ISM Mars data in conjunction with our telescopic and laboratory data; 4) analyze Galileo NIMS and SSI Moon data from the Earth-Moon I encounter in December 1990.

d. Blaney D.B., and T.B. McCord, An observational search for carbonates on Mars, *J. of Geophys. Res*, *94,* 10,159-10,166, 1989. Blaney D.B. and T.B. McCord, Constraints on the climate and weathering histories of Mars from ground based spectroscopy between 3.2 μm and 4.2 μm.*J. Geophys. Res*., revised May, 1990, accepted July, 1990, in press. Blaney, D.B. and T.B. McCord, Spectroscopy of Mars between 4.5 μm and 5.1 μm and indications of sulfate minerals. *J. Geophys. Res*., submitted January 1991. J.F. Bell III, P.G. Lucey, and T.B. McCord, Charge Coupled Device Spectra of Mars: 4000-8040 A Data and Implications for Surface Mineralogy, *Astron. J*., submitted 1991. J.F. Bell III, T.M. McCord, and P.D. Owensby, Observational evidence of crystalline iron oxides on Mars. *J. Geophys. Res*., 95 14447-14461, 1990. J.F. Bell, T.B. McCord, and P.G. Lucey, Imaging spectroscopy of Mars (0.4 - 1.1 μm) during the 1988 opposition, *Proc. 20th Lunar and Plant. Sci. Conf*., p479-486, 1991

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Alfred S. McEwen
USGS, 2255 N. Gemini Dr., Flagstaff, AZ 86001
602-527-7194; FTS 765-7194

Co-INVESTIGATORS: (Name Only) Laurence A. Soderblom

PROPOSAL TITLE: Thermophysics of Io.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: Proposed here are one major and two smaller Io projects. The major project consists of refining analyses of the IRIS data (for hotspot, passive temperature, and compositional models) through improving the pointing solutions for the Voyager 1 scan platform and correlating IRIS data with imaging data. The smaller projects are surface compositional modeling based on comparison of Voyager multispectral mosaics with recently acquired laboratory spectral reflectivities of candidate materials, and geophysical and geological interpretations of new geodetic and topographic models of Io.

b. Progress: (1) A high-resolution (1 km/pixel) controlled digital mosaic of the hemisphere of Io centered on longitude 310° has been completed (McEwen et al., 1991). The improved set of discrete camera angles derived from this effort is being used in conjunction with the space telemetry pointing history file (the IPPS file), corrected on 4- or 12-second intervals, to derive a revised time history for the IRIS pointing. (2) Comparison of Io's large-scale topography (Gaskell et al., 1988) and SO_2 frost distribution (McEwen et al., 1988) shows that SO_2 is concentrated in equatorial topographic basins. This relation may be due to enhanced asthenospheric tidal heating in Io's equatorial region and consequent epeirogenic movements and distributions of heat flow and volcanic activity.

c. Work Plan FY92: (1) Complete new uplift models and write and submit paper "SO_2-Rich Equatorial Basins and Epeirogeny of Io." (2) Correct the IPPS file for IRIS observations acquired between camera shutterings, and use the IRIS observations to construct new background and hotspot thermophysical models. Extract image areas corresponding to the fields-of-view of IRIS spectra from the digital mosaic and use them to constrain background contributions in hotspot models and to place the results in geologic context. Write and submit paper. (3) Merge high-resolution mosaic with low-resolution (~3.4 km/pixel) mosaics in four colors to produce high-resolution color images; compare with the geologic map of this region.

d. Bibliography: (1) McEwen, A., Lunine, J., 1990, Comment on "The surface of Io: A new model" by Bruce Hapke, **Icarus 84**, 268-274. (2) McEwen, A., 1991, Io: Volcanism and geophysics, in **Reference Encyclopedia of Astronomy and Astrophysics**, in press. (3) McEwen, A., 1991, SO_2-rich equatorial basins and epeirogeny of Io, abstract for Reports of the Planetary Geology and Geophysics Program - 1990. (4) McEwen, A., Duck, B., Edwards, K., 1991, Digital cartography of Io, LPSC XXII, 873.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Lucy-Ann McFadden
(Name, Address, Cal Space 0216, UCSD, La Jolla, CA 92093-0216
Telephone Number) 619-534-3915

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Asteroid Surface Processes: Experimental Studies of the Solar on Reflectance and Optical Properties of Asteroids.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a)This is a three part proposal. In Part I, we will model the effects of sputtering of solar wind ions on asteroids. In part II, we examine the effect of the solar wind on the optical properties of meteorites to determine whether the solar wind can alter the properties of ordinary chondrite parent bodies resulting in the spectral properties of S-type asteroids. In part III, we will analyze the existing database of optical properties of asteroids to determine the effect of solar wind in altering asteroid surface properties. Justifications include: Previous models of the effects of solar wind on asteroids have not included sputtering. Previous studies of solar wind bombardment on lunar materials can be built upon and expanded. Problems of laboratory simulation of the solar wind are currently better known than in the past and can be overcome. New analytical techniques are available to determine the physical and chemical changes due to solar wind, increasing the potential to understand the processes producing observed optical properties. The structure of the solar wind in the asteroid belt is different than that used in simulations at the Moon. The asteroid database has not been systematically examined since the 1970's.

b) Literature search was carried out on previous experiments of solar wind bombardment on the Moon and models of asteroid surface alteration. Experiments were planned. First chemical analyses on samples were begun.

c)Apply sputtering model to asteroids. Measure the optical properties of forsterite olivine and three ordinary chondrite meteorites (an H, L, LL), bombard them with 1-3 KeV protons simulating the solar wind at doses simulating both ambient solar wind over time, and high velocity, high density streams. Measure the neutral and ion mass spectrum above the sample, use a Scanning Electron Microprobe at the surface of the sample before and after bombardment to document the physical-chemical changes independently of the optical properties. Measure the optical properties of the bombarded samples. Compare the results with existing asteroid optical properties to evaluate the validity of the current working assumption used to interpret optical properties of asteroids: that asteroids are represented by unaltered, powdered meteoritic material.

d.) Gaffey,S. McFadden,L. and Nash,D. 1991, Ultraviolet, Visible and Near-Infrared Reflectance Spectroscopy: Laboratory Spectra of Geologic Materials. in *Remote Geochemical Analysis: Elemental and Mineralogical Composition*, Pieters and Englert, eds. Lunar and Planetary Institute, Houston. Vilas,F. and McFadden,L. 1990, CCD Reflectance Spectra of Selected Asteroids. LPSC XXI, 1272-1273.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
George E. McGill
Department of Geology and Geography
University of Massachusetts
Amherst, MA 01003 Tel. (413) 545-0140

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Planetary tectonics, areal geology, and geological histor

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. Objectives: To understand the tectonic behavior and evolution of planetary crusts. Geological mapping and topical studies of stratigraphy and geomorphology are combined with kinematic analyses of structures to infer crustal history. When possible, results are compared with the predictions of published geophysical models.

B. Accomplishments: Completed analysis of Mars dichotomy boundary in MC-5SE; constrained volume of northern plains sediments derivable from fretted terrain; completed review of hypotheses for crustal dichotomy; published detailed description of data supporting an endogenic origin for the crustal dichotomy; submitted Ganymede JG-2 and JG-5.

C. Anticipated effort: Continue studies of northern lowlands and dichotomy boundary; improve image-processing capability; continue studies of Venus structural geology and crustal evolution (begun as Magellan Guest Investigator); revise Ganymede JG-2 and JG-5, as necessary.

D. Summary bibliography (1 Feb'90 - 31 Jan'91): 2 papers, 7 abstracts, 6 presentations

Dimitriou, A.M., An estimate of the amount of material removed from the martian fretted terrain, Geophys. Res. Letts., 17, 2461-2464, 1990.

McGill, G.E., and A.M. Dimitriou, Origin of the martian global dichotomy by crustal thinning in the late Noachian or early Hesperian, J. Geophy. Res., 95, 12,595 -12,605, 1990.

Proposal Summary

Principal Investigator: Christopher P. McKay
Space Science Division
NASA Ames Research Center
Moffett Field, CA 94035
(415) 604-6864

Co-Investigators: Jeffrey Cuzzi, NASA Ames; Dina Prialnik, Tel Aviv University; Yuri Mekler, Tel Aviv University; Morris Podolak, Tel Aviv University

Abstract: a. Objectives: The objectives of this proposal are to continue the joint NASA Ames/Tel Aviv University study on the thermal processes within comets. This joint activity began last year on a tentative basis and is progressing well. As we continue this initial investigation we will continue to focus on the application of numerical models to the diffusion of volatiles within the nucleus in response to thermal gradients and the resulting loss of these volatiles from jets at the comet's surface. b. Accomplishments: We received approval for beginning this work six months ago and have established formal ties between the Tel Aviv group and NASA Ames to support graduate student studies at Tel Aviv. We have modified the model so as to include mixtures of ice, dust and free gases. The new model has been tested for different initial compositions, and optimal parameters for the numerical calculations have been found. It is already obvious from these preliminary studies that the presence of gas and vapor in the interior of a comet affects its thermal structure and evolution. Some of these calculations, involving the release of volatiles trapped in the ice matrix, have been published (Prialnik and Bar-Nun, 1990). The work described in Mekler *et al.*, (1990) has been extended to allow for the presence of dust in the cometary mantle (Prialnik and Mekler, 1991). This work included the effect of the dust mantle on the gas flow. Assuming that the thickness of the dust mantle is fixed, and that it has a constant porosity, it was shown that the dust inhibits the escape of the gas and forces more of it into the deeper layers of the nucleus.
c. First-Year Plans: The numerical model that serves as basis for our work is that of Prialnik and Bar-Nun (1987). The vapor transport equations are coupled to the temperature equation, allowing for realistic transport of volatiles in response to thermal gradients, and allowing for transport of latent heat resulting from volatile diffusion. We will extend this model to include the presence of other frozen gases, such as CO and CO_2 in addition to water ice, gases trapped in the ice and water vapor itself. We will run this extended model for different orbital parameters to determine how the volatiles may be distributed within the nucleus for different types of comets. Short period comets are particularly interesting in this regard, since for small perihelion distances heat conduction by gas transport should be important, and the porosity of the cometary nucleus should play an important role. We will also couple the comet nucleus model with a surface thermal model under development at Ames. With this coupled model we plan to investigate volatile loss from surface jets.

d. Relevant Publications of PI and Co-Is:

McKay, C.P., S.W. Squyres, and R.T. Reynolds, (1986) Methods for computing comet core temperatures. *Icarus* **66**, 625–629.

Mekler, Y., D. Prialnik, and M. Podolak (1990). Evaporation from a porous cometary nucleus. *Astrophys. J.* **356**, 682–686.

Prialnik, D. and A. Bar-Nun (1987). On the evolution and activity of comet nuclei. *Astrophys. J.* **313**, 893–905.

Prialnik, D. and A. Bar-Nun (1988). The formation of a permanent dust mantle and its effect on cometary activity. *Icarus* **74**, 272–283.

Prialnik, D., A. Bar-Nun, and M. Podolak (1987). Radiogenic heating of comets ^{26}Al and implications for their time of formation. *Astrophys. J.* **319**, 993–1002.

Prialnik, D., and Y. Mekler (1991). The formation of an ice crust below the dust mantle of a cometary nucleus Astrophys. J. **366**, 318–323.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William B. McKinnon
Dept. Earth and Planetary Sci.
Washington University
Saint Louis, MO 63130
314-889-5604

CO-INVESTIGATORS: None

TITLE: **Structure and Evolution of Outer Planet Satellites, NAGW-432**

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a) Objectives and Justification: the purpose of this work is to explore the origin, structure, evolution, and bombardment of outer planet satellites (and Pluto). This includes understanding the relative importance of large impacts, orbital dynamics, and internal processes for tectonics and other surface modifications (with implications for interior properties), the origin and evolution of impactor populations (relevant to accretion time scales and the interplanetary correlation of geologic time), and cratering mechanics in icy and other targets (morphology, phase changes, jetting, effects of atmospheres, etc.).

b) Accomplishments: evaluated the relative probabilities of gas drag, collisional, and tidal capture for Triton; evaluated the relative roles of asynchronous rotation and polar wander in producing Europa's tectonics, finding that asynchronous rotation remains the best explanation and that polar wander is not, in general, indicated; calculated the chemical consequences for Triton of hydrothermally processing its carbon- and nitrogen-bearing organics during the phase of extreme tidal heating, finding that any initial CO is efficiently converted to CO_2 or organic species; analyzed peak and multiringed basins on Venus from Arecibo and Venera images, and modeled their formation with finite element simulations; completed study of mercurian crater terrace widths, with implications for crater collapse models.

c) To be done this year: further explore consequences of capture and alternative origins for Triton; estimate the amount of ice jetted from Pluto during a Charon-forming collision; analyze peak and multiringed basins on Venus using Magellan data; analytically model some aspects of the effects of Venus' dense atmosphere on crater formation; further constrain relationships between impactor populations in solar system using spatial statistics of Callistoan craters; complete analysis of lineament patterns on Saturnian and Uranian satellites, and viscous relaxation on Ariel; analytically model aspects of formation of the Galileo-Marius Regio furrow system and Ithaca Chasma; complete revision of Ganymede map.

d) Publications: Schenk, P.M., and W.B. McKinnon, 1991. Dark-ray and dark-floor craters on Ganymede, and the provenance of large impactors in the Jovian system. *Icarus* 89, 318–346; McKinnon, W.B, C.R. Chapman, and K.R. Housen, 1991. Cratering of the Uranian satellites. In *Uranus*, J. Bergstralh, E.T. Miner, and M.S. Matthews, eds. (Tucson, Univ. of Arizona Press), in press; De Hon, R.A., A.C. Leith, and W.B. McKinnon, 1991. Geologic map of the Hathor Quadrangle of Ganymede. USGS Misc. Inv. Map., in revision; McKinnon, W.B., and A.C. Leith, 1991. Gas drag and the evolution of a captured Triton. *Icarus*, in revision; Leith, A.C., and W.B. McKinnon, 1991. Terrace width variations in complex mercurian craters, and the transient strength of cratered mercurian crust. *J. Geophys. Res.*, submitted; Leith, A.C., and W.B. McKinnon, 1991. Is there evidence for polar wander on Europa? *Icarus*, submitted.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
H. J. Melosh
Lunar and Planetary Laboratory
University of Arizona, Tucson, AZ 85721
(602) 621-2806

Co-INVESTIGATORS: (Name Only)
Ann M. Vickery

PROPOSAL TITLE: Impact Mechanics and the Evolution of the Terrestrial Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal consists of a number of related tasks that have in common the theoretical study of planetary evolution and surface processes. Using continuum mechanical models we can study the origin of the moon, impact evolution of atmospheres, fragmentation of objects in the asteroid belt, and various tectonic processes. Most of this work is heavily computer based and uses a number of hydrocodes, fragmentation algorithms, and a finite element code.

(b) In the past year we completed detailed studies of the production and expansion of melt and vapor in impact events, devised a theory of melt droplet formation in impacts and successfully compared the predictions of the theory to melt droplets found at the K/T boundary, microtektites, and the ejecta of the Acraman crater. An analytic model of jetting from impacts on planar targets was constructed and tested by comparison with data from Gault, and computations were made of the amount and distribution of melt expected in impact craters on Venus, Earth, and the moon. The implications for giant impacts for core formation on growing planets was examined, new studies of crater relaxation on Venus were performed, and a statistical orbital mechanical code to follow the evolution of ejecta from the planets was devised. A major success was achieved in modeling fragmentation of solid bodies by impacts. Our new fragmentation code agrees well with laboratory data, and was extended to compute the fragmentation of asteroid-size bodies in which gravity plays a major role. The fragmentation code was also applied to study of the effect of the Stickney impact on Phobos, where it was found that the ejection velocities are not sufficient to eject the regolith.

(c) Next year's work will be principally concerned with impact-atmosphere interactions on Venus and the Earth using the computer code CSQ. The fragmentation work will be used to model the breakup of a projectile entering the Venusian atmosphere, modeling Schmidt's pressure-vessel fragmentation experiments, and studying the relative fragmentation of rocky vs. iron meteorites in space. We will add porosity to our equations of state and study its effects for asteroid melting and the compaction of planetesimals in the early solar system. The implications of giant impacts for planetary evolution will be studied further. Finally, a program of study of relaxation of very large craters on Earth (Sudbury, Vredefort) will be undertaken using our finite element code.

(d) H. J. Melosh and B. Tonks and H. J. Melosh, both in Origin of the Earth, Oxford (1990); H. J. Melosh, N. M. Schneider, K. J. Zahnle, and D. Latham, Nature 343 251-254 (1990); D. M. Janes and H. J. Melosh, JGR 95, 21, 345-21,356 (1990), A. M. Vickery and H. J. Melosh, Proc. Conf. on Global Catastrophes (1990); H. J. Melosh, COSPAR (1990); H. J. Melosh and A. M. Vickery, Nature, in press (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Albert E. Metzger
(Name, Address, Telephone Number) Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena, CA 91109

CO-INVESTIGATORS: (Name Only) Eldon L. Haines

PROPOSAL TITLE: Planetary Gamma-ray Spectroscopy

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. Gamma-ray spectroscopy is capable of measuring the surface composition of planets, asteroids, quiet comets, and satellites, yielding results relevant to the origin, history and present state of the body. Gamma-ray spectrometer (GRS) experiments are currently under development for Mars Observer and under consideration for Lunar Observer and other missions. Science studies are required to optimize instrument design, extend experiment capability, and fully interpret flight data.

B. Efforts to date have consisted of 1) developing the techniques with which a GRS can monitor atmospheric thickness and surface pressure at Mars by three different methods, 2) addressing issues of carbon in the regolith, of stratigraphy, and of atmospheric fractionation via the GRS at Mars, 3) analyzing the quantitative capability of combined neutron mode and gamma-ray mode measurements, including the ability to detect the possible presence of frozen H_20 at the lunar poles and to uniquely identify lunar rock types, and 4) an analysis of laboratory data on the response of passive and active neutron modes.

C. In the coming year we plan to 1) continue modeling the GRS Mars polar cap composition and seasonal cycle capability, 2) model the sensitivity of measuring the dust-to-ice ratio in polar regions, 3) analyze the ability of the GRS to derive stratigraphic information, and 4) document the analysis of thick target data.

D. Recent publications: 1) Metzger and Drake, "Identification of Lunar Rock Types and Search for Polar Ice by Gamma Ray Spectroscopy," *JGR* 95, 449-460 (1990); 2) Metzger and Haines, "Atmospheric Measurements at Mars via Gamma-ray Spectroscopy," *JGR* 95, 14695-14715 (1990); 3) Metzger, "Composition of the Moon as Determined from Orbit by Gamma-ray Spectroscopy" prepared for Remote Geochemical Analysis, to be published by Cambridge University Press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Henry J. Moore MS-946, U.S. Geological Survey
345 Middlefield Road, Menlo Park, CA 94025

(415) 329-5175 FTS 459-5175

CO-INVESTIGATORS: (Name Only)

None

PROPOSAL TITLE: GOLDSTONE 1990-91 RADAR OF MARS

ABSTRACT: Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification for the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. OBJECTIVES AND JUSTIFICATION. This is a proposal to examine the 1990-91 Goldstone continuous-wave (CW) dual-polarization radar observations of Mars at 3.5-cm wavelength. There are six objectives: (1) to compare polarized and depolarized echoes at two wavelengths (3.5 cm and 12.6 cm), (2) to interpret the echoes in terms of geologic conditions, (3) to provide information on potential future landing sites, (4) to obtain probability density distributions of quasi-specular and diffuse echo reflectivities and to make quasi-specular echo surface roughness estimates, (5) to model the 1990-91 polarized and depolarized echoes, and (6) to confirm results from previous radar experiments. The results will be published on a timely basis.

This study should be undertaken because the CW dual-polarization observations will provide data on echoes at a shorter wavelength (3.5 cm) that can be compared with previous data at a longer wavelength (12.6 cm) in the same regions. This comparison will add a new dimension to Mars radar studies because radar echoes are wavelength dependent and CW observations of diffuse echoes at 3.5 cm are rare. An understanding of these echoes is important to the interpretation of geologic processes and future Mars surface missions, because they provide information of surface roughness at a scale larger than the wavelength, quasi-specular reflectivity of the uppermost surface (related to bulk density), and information on wavelength-size diffuse scatterers.

B. PROGRESS. New proposal. Similar objectives for 12.6-cm wavelength CW dual-polarization observations have been successfully met and completed.

C. WORK PLAN. We plan to accomplish objectives 1 through 4 and commence objective 5 in FY 92.

D. PUBLICATIONS.

Thompson, T. W. and Moore, H. J.: (a) 1990, LPSC XXI, p.1252-1253; (b) 1990, Repts. PGGP, NASA TM 4210, p. 300-302; (c) 1990, EOS, v. p.713-714. (d) Moore, et al., 1991, LPSC XXII, in press.

Moore and Thompson, 1991, Lunar Planet. Sci. Conf. 21st, p. 457-472.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Henry J. Moore MS-946, U.S. Geological Survey
345 Middlefield Road, Menlo Park, CA 94025

(415) 329-5175 FTS 459-5175

CO-INVESTIGATORS: (Name Only)

None

PROPOSAL TITLE: TEMPE-MAREOTIS VOLCANICS

ABSTRACT: Type single-spaced below line. Lettered paragraphs (a) through (d) should included: a. brief statement of the overall objectives and justification for the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. OBJECTIVES AND JUSTIFICATION.

(1) Place the Tempe-Mareotis volcanics within the context of volcanism of the Tharsis region and elsewhere on Mars.
(2) Determine the structural environment of the Tempe-Mareotis volcanics.
(3) Compare the volcanic landforms with similar landforms of Earth.
(4) Determine a local stratigraphic sequence for the geologic units.
(5) Estimate absolute ages of the stratigraphic units.
(6) Estimate the compositions of the volcanic materials

B. ACCOMPLISHMENTS. New proposal.
A proposal was submitted year before last requesting that six-controlled photomosaics be prepared at 1:500,000-scale.

C. WORK PLAN.
Prepare a geologic map of two MTM quadrangles (beginning with 35087 and 35092 or 40087 and 40092 - whichever pair is available first).

D. PUBLICATIONS.

Moore, H. J. and Thompson, T. W., 1991, A radar-echo model for Mars: Lunar and Planet. Sci. Conf., 21st, p. 457-472.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Peter J. Mouginis-Mark
Planetary Geosciences Division
University of Hawaii
Honolulu, Hawaii 96822
(808) 956-6488 (voice)
(808) 956-6322 (FAX)

Co-INVESTIGATORS: Dr. Bruce Campbell, University of Hawaii

PROPOSAL TITLE: QUANTITATIVE ANALYSIS OF SMALL VOLCANOES ON MARS AND VENUS

ABSTRACT:

A) Objectives: 1) We propose to make quantitative measurements of the volumes and slopes of small (<200 km basal dia.) Martian volcanoes. Via detailed geologic mapping, we hope to place constraints on the style eruptions and geologic history of such volcanoes as Hecates, Tharsis and Ceraunius Tholi. Where suitable data are available, these topographic studies will be augmented by Earth-based radar measurements and by color analyses of calibrated Viking Orbiter data in order to more fully investigate the diversity of surface materials on each volcano.
2) Small volcanic domes and lava flows in Eistla Regio, Venus, will be investigated using Magellan SAR and altimetric data. We hope to better understand eruptive processes on Venus by analysis of the public-release Magellan data and use of multi-incidence angle, multi-polarization radar data that we collected in 1990 over Kilauea and Mauna Loa volcanoes in Hawaii.
B) Work Plan: Task #1: We will construct topographic profiles for ~10 small Martian volcanoes using the PICS image processing software. Geologic maps will be produced to aid the interpretation of the structural history and the eruption characteristics of each volcano. The Goldstone Earth-based radar data collected in 1980 and 1988 will be used to inter-compare PICS profiles with an independent data set to test for consistency. Calibrated Viking Orbiter color data will be used to search for lithologic and photometric variations on these volcanoes.
Task #2: We will focus our Venus research on the Eistla Regio region, particularly the spatial variability and dimensions of flows and domes surrounding the volcanoes Sif and Gula Montes. These volcanoes show a broad range of lithologies and spatial variability in flow structure. Multi-incidence angle, multi-polarization aircraft radar data for Hawaii will be used to study of the Mauna Iki and Mauna Ulu lava shields, as well as numerous historic lava flows.
C) Progress: This is a new proposal.
D) References: 1) Mouginis-Mark, P. (1981). Late-stage summit activity on Martian shield volcanoes. Proc. Lunar Planet. Sci. Conf. 12B, 1431 - 1447. 2) Mouginis-Mark, P. , L. Wilson, & J. Zimbelman (1988). Polygenic eruptions on Alba Patera, Mars. Bull. Volcanol., 50, 361 - 379. 3) Mouginis-Mark, P., L. Wilson, & M. T. Zuber (1991). The Physical Volcanology of Mars. In: MARS, Univ. Arizona Press, Tucson, in press. 4) Campbell, B. & D. Campbell (1990). Western Eisila Regio, Venus: Radar properties of volcanic deposits, Geophys. Res. Lett. 17, 1353 - 1356. 5) Campbell, B., S. Zisk & P. Mouginis-Mark (1990). A quad-pol radar scattering model for use in remote sensing of lava flow morphology. Rem. Sen. Environ., 30, 227 - 237. 6) Robinson, M., M. Smith & J. Adams (1991). Time variable spectral feature at Apollinaris Patera, Mars. Lunar Planet. Sci., XXII, 1127 - 1128.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Duane O. Muhleman
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, California 91125
818/356-6186

Co-INVESTIGATORS:

PROPOSAL TITLE: Analysis of Synthetic Aperture Radar Images of Mars, Venus and Mercury

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Massive data sets exist for high spatial resolution maps of Mars and Venus made with the VLA/JPL-Goldstone radar system. Full disk maps of Mars with spatial resolution better than 100 km at the subearth point were made at 12 minute intervals in both right and left circular polarization after illumination by right circulation polarization (2 × 38 maps). Since the rotation of Venus is very slow, depolarized maps for 2 full days are available for interpretation. Such maps of Mercury will be made in August, 1991 of the side of the planet not mapped by Mariner 10. Only the highlights of the existing data sets have been interpreted as yet. The Mars maps must be "de-rotated" and combined into images of distinct features at multiple look angles and, above al, be interpreted in the geophysical sense. The features include Stealth, the south polar ice cap, and strangely distinct points on the volcanoes: Olympus Mons, Arsia Mons, Pavonis Mons, and Ascraeus Mons. We have found a few Stealth-like regions other than the massive one which will help us understand the geophysical significance of these structures. The Venus work involves the correlation of our depolarized images with the conventional ones from Magellan. In particular, we are addressing the altitude-depolarization correlation that we have discovered.

(b) New proposal.

(c) The new work is outlined in paragraph (a). It is driven by the need to develop better images from the multiple look angle data and to interpret them in a geological and geophysical context. A new data set for Mercury will become available which will reveal the hemisphere of the planet never before seen with any resolution!

(d) Muhleman, D.O., Butler, B., Grossman, A., and Slade, M. (1991). Radar images of Mars. Submitted to *Science*, April, 1991.

Muhleman, D.O., Grossman, A., Butler, B., and Slade, M. (1990). Radar reflectivity of Titan. *Science* **248**, 975.

ABSTRACT

PRINCIPAL INVESTIGATOR: Douglas B. Nash
San Juan Capistrano Research Institute
31872 Camino Capistrano
San Juan Capistrano, California 92675
(714) 240-2010

CO-INVESTIGATORS: None

PROPOSAL TITLE: SURFACE PROPERTIES OF PLANETARY BODIES

OBJECTIVES: Study spectral reflectance, surface composition, charged-particle and UV effects on surface properties of planetary satellites, especially Io and the Moon. Conduct key experiments and use lab data to interpret spacecraft and groundbased observations, and derive improved composition and surface process models for satellites and other planetary bodies.

PROGRESS: Completed study of solid-state phase transformations and reflectance spectra of sulfur allotropes; showed that metastable phases and temporal variations in color may be common in sulfur deposits on Io's surface; paper published. Continued work on calorimetric properties of vacuum-weathered sulfur; paper drafted. Continued developing theoretical model on vacuum weathering of condensed multi-component (alloy) volatile materials; paper drafted. Revised theoretical paper on S-O-Na chemistry and recycling of Io's surface. Completed mid-IR (4-15 μm) study of plagioclase feldspars, showing vitrification does not destroy Christiansen-frequency information; paper submitted. Began mid-IR study of silicate minerals typical of lunar surface, and similar study of lunar rock and soil samples; abstract published. Completed paper evaluating thermal emission spectroscopy for compositional mapping from lunar orbit.

PROPOSED WORK: Coordinated tasks as follows: (1) Lab study of vacuum weathering effects with applications to Io surface. (2) Lab study of UV-IR spectral properties of condensed SO_2, H_2S, CO_2, and related compounds. (3) Measure mid-IR spectra of H_2S + SO_2 frost mixtures and relate to Io surface models. (4) Measure spectra of heavy isotope SO_2 and H_2S to investigate extent of chemical fractionation of Io crustal material. (5) Examine effects of solar UV on Io surface. (6) Measure sputtering yields of polymeric sulfur under low-energy proton irradiation. (7) Continue general spectroscopy measurements of candidate materials for planet, satellite, comet, and asteroid surfaces. (8) Detailed mid-IR spectral study of silicate mineral mixtures and glasses with applications to terrestrial planetary remote sensing.

BIBLIOGRAPHY: Moses, J., and D. Nash (1991); phase transformations and spectral reflectance of solid sulfur: can metastable allotropes exist on Io?; Icarus 89, 277-304. Nash, D. and J. Salisbury (1991); IR reflectance (2.2-15 μm) of plagioclase; Geophys. Res. Ltrs. (submitted). Nash, D. (1991); IR reflectance spectra of lunar samples; LPSC XXII, 957-958.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) W. J. Nellis, L-299
Lawrence Livermore National Laboratory
P.O. Box 808, L-299, Livermore, CA 94550
(415) 422-7200

Co-INVESTIGATORS: (Name Only) N. C. Holmes, A. C. Mitchell, M. Ross
D. A. Young

PROPOSAL TITLE: Properties of Planetary Fluids at High Pressure and Temperatures

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: The goals are measurements of equation-of-state (EOS), electrical-conductivity and shock-temperature data of fluids thought to exist in the interiors of the giant planets. Conductivity data is needed for dynamic or kinematic calculations of the magnetic fields of Uranus, Neptune, Jupiter, and Saturn. Shock-wave EOS and shock-temperature data are needed to validate theoretical EOS and for analyzing electrical conductivity data. Fluids of particular interest are H_2 and "synthetic Uranus."

(b) Progress: New Proposal. In FY91 three electrical conductivities of shock-compressed liquid hydrogen were measured. The data yielded a value for the electronic energy bandgap of hydrogen near 8 cm^3/mol. This is the first direct measurement of the bandgap of hydrogen at high pressures. The result is in agreement with a recent theoretical prediction. These data will yield a scaling relation for the electrical conductivity at conditions in the envelopes of the giant planets. A double-shock temperature was measured for "synthetic Uranus," near 1 Mbar at conditions similar to the interiors of Uranus and Neptune.

(c) Work Statement: We will measure temperatures of shock-compressed liquid hydrogen and measure the electrical conductivity of liquid hydrogen compressed quasi-isentropically up to 1 Mbar.

(d) Publications: 1) W. J. Nellis et al, "Properties of Planetary Fluids at High Shock Pressures and Temperatures," to be published in the proceedings of the Fourth U. S.-Japan Seminar on High Pressure Research in Mineral Physics: Applications to Earth and Planetary Sciences, January, 1991; 2) H. B. Radousky et al, "Shock Temperature Measurements of Planetary Ices: NH_3, CH_4, and "Synthetic Uranus"," J. Chem. Phys. 93, 8235 (1990); 3) W. J. Nellis et al, "Equation-of-State, Shock-Temperature, and Electrical-Conductivity Data of Dense Fluid Nitrogen in the Region of the Dissociative Phase Transition," J. Chem. Phys. 94, 2244 (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Robert M. Nelson
183-501 Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, (818) 354-1797

Co-INVESTIGATORS: (Name Only) William D. Smythe

PROPOSAL TITLE: THE OPPOSITION EFFECT AND COHERENT CONSTRUCTIVE INTERFERENCE

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A) Overall Objectives. The objective of this investigation is to test the hypothesis that the pronounced surge in brightness in the electromagnetic radiation reflected from atmosphereless solar system bodies when observed at small phase angles, the opposition effect, is due to a combination of mutual shadowing between the regolith grains and coherent constructive interference between light rays passing through the medium along the same path but in opposite directions. We propose an investigation into the intensity and polarization change in the reflected electromagnetic radiation from simulated and candidate planetary regolith materials in order to test the predictions of the coherent backscattering hypothesis. This hypothesis, if confirmed by the experiments proposed in this investigation, would:

1) Permit inferences to be made regarding the microstructure of the surface of a solar system body from observations undertaken at a spatial resolution many orders of magnitude larger than the size of the inferred texture.

2) Suggest new ground-based photometric and polarimetric visual observations and radar observations of icy satellites to refine interpretations based on the hypothesized coherent backscatter phenomenon.

3) Explain the unusual radar reflectivities of Europa, Ganymede and Callisto which find that much of the observed polarization is in the opposite sense of what would be predicted from single specular reflection.

4) Explain the well known, but poorly understood, phenomenon of the change in polarization with phase angle observed in particulate media; particularly the negative branch of the polarization curve which is observed in many materials between 0 and 25 degrees phase angle.

B) New Work

C) What will be done this year. We will study the reflectance as a function of phase angle of ensembles of polystyrene spheres held in suspension in liquids with differing indices of refraction. This will be done as a function of wavelength of the incident radiation. We will vary the size of the spheres. We will begin modifications to our goniometer to accommodate the polarizers and analyzers required for the second year's research.

D) Relevant Bibliography

Nelson, R. M. *et al.*, Voyager 2 Photopolarimeter Observations of the Uranian satellites. J. Geophys. Res., **92,** 14905-14911.

Hapke, B. W. Coherent backscatter and the radar characteristics of outer planet satellites. Icarus, **88,** 407-417, 1990.

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Philip D. Nicholson
418 Space Sci. Bldg., Cornell University
Ithaca, NY 14853 (607)255-8543

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Dynamical Studies of Planetary Rings

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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1. Overall goals: To characterize the dynamical state and particle size distribution of planetary ring systems, and to investigate satellite-ring interactions.

2. Progress: (a) Completed first-cut reduction of Palomar 28 Sgr occultation data for Saturn's rings, including preliminary optical depth comparisons and astrometric solutions. (b) Published results of absolute radius scale/pole investigation for Saturn's rings. (c) Published synthesis of ground-based occultation data for Neptune's rings. (d) Successfully imaged Saturnian co-orbital satellites in the IR, and determined their mean densities.

3. Proposed work: (a) Continue analysis for 28 sgr data, to establish accurate optical depths and map the decimeter to meter-size particle distribution. (b) Obtain and analyze near-IR photometry and spectrophotometry of Mimas, Enceladus, Miranda and Triton, and Saturn's major ring regions.

4. Bibliography: 3 papers published; 1 review article co-authored; 2 abstracts published; 3 oral presentations.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James Orenberg
(Name, Address, San Francisco State Univ., Dept. of Chemistry
Telephone Number) 1600 Holloway Ave., San Francisco, CA 94132
(415)338-1292

Co-INVESTIGATORS: Ted Roush
(Name Only)

PROPOSAL TITLE: Determination of the Optical Constants of Hydrates Carbonates, Sulfates, & Nitrates for the Interpretation of Thermal IR Spectra of Martian Surface & Atmospheric Materials

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The objective of this research is to derive mid-infrared (MIR, 5-25μm) optical constants of volatile-bearing compounds (*e.g.* carbonates, sulfates, hydrates, and nitrates) which are believed to have played key rolls in the evolution history of Mars' atmosphere and surface. Quantitative modelling of thermal infrared data currently rely upon such optical constants. The pertinant materials included here are: 1)hydrated and/or hydroxylated silicates; 2)hydrous and anhydrous carbonates; 3)hydrous and anhydrous sulfates; and 4)hydrous and anhydrous nitrates.

b. During the past year we have derived the MIR optical constants for a number of hydrated and/or hydroxylated silicates. Optical constants in the region of the 6μm H-O-H bending region were derived for the hydrated smectites montmorillonite and saponite, as well as, a palagonite sample.

c. During the next year we will focus on derivation of optical constants for carbonates, sulfates, and nitrates.

d. Roush, T.L., J.B. Pollack, and J.B. Orenberg (1990) Derivation of Mid-infrared (5-25μm Optical Constants of Some Silicates and Palagonite, LPSC XXI, 1043-1044.
Roush, T., J. Pollack, and J. Orenberg (1991) Derivation of Mid-infrared (5-25μm Optical Constants of Some Silicates and Palagonite, ***submitted to Icarus,*** Janurary 1991. Roush, T., J. Pollack, and J. Orenberg (1991) Derivation of Mid-infrared (5-25μm Optical Constants of Some Silicates and Palagonite, *Workshop on Mars Sand and Dust,* Tempe, Arizona, February 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Steven J. Ostro
300-233
Jet Propulsion Laboratory
Pasadena, CA 91109
(818) 354-3173

TITLE: **ASTEROID LIGHTCURVE INVERSION**

ABSTRACT

A. Objective: Theoretical development, calibration, and application of techniques that optimize extraction of information from optical/IR/radar observations of solid-surfaced planetary bodies. Each technique uses some *measurement* available as a function of an object's rotation phase, and inverts the data to obtain some *constraint* that characterizes the object's shape and/or albedo distribution. *In each case, the constraint's dimension exceeds the measurement's intrinsic dimension by one.*

B. Progress: (1) Development and publication of a "doppler imaging" technique for using echo spectra as a function of rotational phase to construct a spherical body's albedo distribution. The technique is being applied now to Ganymede, Callisto, and Mars, and eventually will be useful for imaging Ceres, Pallas, Vesta, and Titan. Preliminary images of Callisto indicate that the Valhalla and Asgard regions are anomalously bright at radar wavelengths. (2) Convex-profile inversion of lightcurves obtained by W. Wisniewski for near-Earth asteroid 1917 Cuyo yield estimates of that object's mean cross section with a very modest elongation, ~1.15, consistent with the asteroid's almost constant radar echo bandwidth. (3) Slow progress in development of an inversion technique to reconstruct the 3-D shapes of small asteroids from delay-doppler images.

C. Proposed Work: (1) Continue development of procedures for inverting delay-doppler radar images of small bodies to estimate their three-dimensional shapes, including the requisite error analyses; then apply the procedures to images available for the contact-binary object 1989 PB and possibly to other small, radar-imaged asteroids. (2) Completion and publication of doppler images of Europa, Ganymede, and Callisto that are likely to be the best radar images of those objects available during this decade. (3) Use convex-profile inversion to estimate the mean cross sections of selected mainbelt asteroids.

D. Recent Publications: (1) Ostro, S. J., K. D. Rosema, R. F. Jurgens 1990. The shape of Eros. Icarus 84, 334-351. (2) Hudson, R. S., and S. J. Ostro 1990. Doppler-radar imaging of spherical planetary surfaces. J. Geophys. Res. 95, 10947-10963.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David A. Paige
(Name, Address, Telephone Number)
Department of Earth and Space Sciences, UCLA
Los Angeles, CA 90024 (213)825-4268

CO-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Mars Polar Surface and Subsurface Properties

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Maps of the thermal and reflectance properties of Mars represent one our most important quantitative data sources regarding the physical properties of Martian surface materials and the processes responsible for their distribution. Until recently, only the midlatitude region from -60° to +60° latitude had been mapped. One of the primary goals of this study is to use IRTM observations in conjunction with diurnal and seasonal thermal models to extend these maps to both poles to obtain complete global coverage. Other related activities include investigations of atmospheric effects on remotely-sensed surface thermal inertias and albedos at high latitudes; investigations of the effects of geographic variations in surface soil properties on the distribution of Martian ground ice; and studies of seasonal temperature variations at high latitudes to infer the thermal properties of subsurface materials.

(b) Last year, we completed maps of measured albedo, apparent thermal inertia, and derived surface albedo for both the north and the south polar regions.

(c) This year, we plan to investigate a number of very interesting phenomena that our newly completed maps have revealed. These include investigations of the effects of atmospheric radiative and dynamic processes on our derived surface thermal properties using a one-dimensional radiative convective model, as well as geologic interpretations of our polar inertia maps in conjunction with Viking and Mariner 9 images.

(d) Keegan, K. D., J. E. Bachman and D. A. Paige, Thermal and Albedo Mapping of the North Polar Region of Mars, XXII Lunar and Planetary Science Conference, p. 701, (1991).

Paige, D. A. and K. D. Keegan, Thermal and Albedo Mapping of the South polar Region of Mars, XXII Lunar and Planetary Science Conference, p. 1013, (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) E. M. Parmentier
Department of Geological Sciences
Brown University (401) 863-3338

CO-INVESTIGATORS: (Name Only) NONE

PROPOSAL TITLE: Planetary Geophysics and Tectonics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

Research funded by grant NAGW-1928, completed thus far during the funding period 10/1/90-9/30/91 has focussed in the following areas. (a) We are continuing to study problems related to lithospheric dynamics and to better interpret the origin of tectonic features observed on planetary surfaces. Two studies comprise this part of our work. The first explores the relationship of the width of strike-slip fault zones in a rigid-brittle lithosphere to flow stresses in the underlying ductile (viscous) part of the lithosphere. This makes predictions concerning the dependence of fault zone width on the various parameters including the slip rate on the fault and the thickness of the brittle layer. The width of MidAltlantic Ridge transform faults are shown to demonstrate the predicted dependence on slip rate. With a the brittle layer that is thinner than on the Earth, faults on Venus are expected to be wider (1). The regular spacing of tectonic features, such as the Venusian Ridge Belts, suggest that they have formed at a dominant wavelength of unstable deformation. However, most previous models have treated only the linearized, small amplitude stability problem and have not considered realistic strength stratifications. We are developing finite amplitude buckling models using finite element approximations. This will allow us to interpret the amount of horizontal deformation from the topographic amplitude of tectonic features (2). (b) We are continuing to explore the possible dynamic consequences of a thermally and compositionally stratified planetary interior. From a simple parameterized convection model of a two layer mantle,we show that episodic, large-scale (whole mantle) mantle overturn may occur due radioactive heating in a chemically denser mantle layer (3).

During the next year of funding work will continue in each of these areas. Studies of the width of fault zones will be applied to examples on planetary surfaces. This work will be extended to treat normal and thrust faults as well as strike-slip faults. Studies of finite amplitude unstable deformation will be completed and publcation of this work is anticipated. Two dimensional numerical models will be applied to further explore the dynamics of thermally and compositionally stratified planetary mantles and specifically to investigate further the possibility of the episodic large-scale mantle overturn predicted on the basis of simpler models. Finally we will apply studies of thermal and compositional buoyancy in mantle plumes (4) to planetary examples in collaboration with other innvestigators.

References: (1) Parmentier, Lunar Planet. Sci. 22, 1037-1038, 1991. (2) Zuber and Parmentier, E.O.S. Trans. A.G.U. 71, 1607, 1990. (3) Herrick and Parmentier, Lunar Planet. Sci. 22, 557-558, 1991. (4) Parmentier, E.O.S. Trans. A.G.U. 71, 1582, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: S. J. PEALE
(Name, Address, Telephone Number) DEPARTMENT OF PHYSICS, UNIVERSITY OF CALIFORNIA
SANTA BARBARA, CA Telephone: 805 893 2977

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: SOLAR SYSTEM PHYSICS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Overall objectives are to understand the dynamical evolution of solar system configurations leading to constraints on their histories, infer the origin of various resonant configurations, constrain properties of planetary interiors and develop techniques in dynamics which aid in this understanding. Constraints on nebular models affecting rates of planetary accretion are also sought.

b. Progress: A paper "Accretion rates of protoplanets" has been published in *Icarus*. A second paper "Accretion rates of protoplanets II: Gaussian Distribution of Planetesimal Velocities" is complete and will be submitted to *Icarus*. A review of the rotational properties of planetary satellites will be published this year in *The Reference Encyclopedia of Astronomy and Astrophysics*, Stephen P. Maran, Ed. The possibility that magnetic forces herd charged dust particles along a ring into higher concentrations called ring arcs has been investigated. The perturbation of small charged dust particles relative to the Kepler motion of larger particles is potentially large, but no reason for a preferred longitude has yet been realized. A Hamiltonian based on expansions of the disturbing function to second order in the eccentricities has been shown to be a poor approximation even for following the history of the Titan-Hyperion orbital resonance, although it works quite well for those resonant situations where the eccentricities remain small.

c. Proposed work: A new method of converting a set of differential equations governing orbital motion into a very generally applicable algebraic map is to be used to study the evolution of the Titan-Hyperion resonance. The rapid integration of the motion with the map will allow the motion to be followed at an appripriately slow expansion rate for Titan's orbit. A rotation state coupled perhaps with nuclear thermal properties for Halley's comet will be sought that is consistent with the large asymmetry of activity about perihelion as well as other constraints. The effect of nebular drag on the evolution of the stability of Trojan asteroids will be investigated where various realistic models of the nebular gas distribution may lead in some cases to asymptotic stability in the presence of the dissipation. The algebraic map will be applied to the Unanus satellite system to test whether perturbations from Titania can disrupt a hypothetically long-lived 2/1 orbital resonance between Ariel and Umbriel in which Ariel could have repeated episodes of resurfacing. Other problems include the effect of nebular drag on planetary accretion, the effect of a magnetic field on the dust in Neptune's ring arcs, and the discrepancy between Io's heat flow and orbital constraints on the dissipation rates.

d. Recent Publications: Greenzweig and Lissauer, (1990) Accretion rates of protoplanets *Icarus* 87, 40–68. Pollack, Podalak, Hubickyj Bodenheimer, Lissauer, Greenzweig, (1990) Simulations of the accretion of the giant planets, *BAAS* 22, 1081. Peale and Lissaur, (1989) The rotation of Halley's comet, *Icarus* 82 36–49. Peale (1989) An analysis of arc ring dynamics, *BAAS* 21, 1015. continue

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John C. Pearl
Goddard Space Flight Center, Code 693.2
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(301) 286-8487

CO-INVESTIGATOR: Mario J. Ospina

PROPOSAL TITLE: Compositional and Surface Properties of Io from Analysis of its Thermal Spectrum.

ABSTRACT:

a) Significant quantities of sulfur, oxygen, sodium, and potassium, are released from Io into its torus. Arguments have been made for the presence of SO_2, sulfur, H_2S, H_2O, S_2O, and polysulfur oxides on the surface. Surface irradiation and chemical processing during crustal recycling can produce additional compounds. The thermal infrared spectrum of Io's surface shows moderately strong spectral features, not all of which have been identified. We propose laboratory measurements (2-160 μm) of a number of compounds (as solids or as frozen volatiles) which may be produced in a system containing S, O, Na, K, and H, to discover the materials responsible for the features. We will then examine the overall chemical system required to produce the assemblage so determined. We will also devise a radiative transfer model to quantify the abundances of the components, and to study the implications of subsurface thermal emission for the surface thermal flux and physical properties; optical constants derived from the above measurements will be used for this effort. This work complements ongoing research supported by the Planetary Geology and Geophysics Program to assemble and interpret spatially resolved, visible-to-thermal-infrared spectra based on Voyager 1 imaging and infrared spectrometer data. The laboratory spectral information and optical constants will also be of use for the interpretation of Galileo PPR thermal infrared measurements. (Essentially this same proposal was submitted last year; though it received favorable reviews, it could not be supported due to funding limitations.)

b) New proposal.

c) During the first year, several polythionates will be produced, their mid-infrared transmission spectra measured, and their optical constants derived. A radiative transfer code will be developed for the thermal emission from a semi-transparent medium.

d) "Identification of Gaseous SO_2 and New Upper Limits for Other Gases on Io", Nature, 280, 755 (1979).

"Crystalline Sulfur Dioxide: Crystal Field Splittings, Absolute Band Intensities, and Complex Refractive Indices Derived from Infrared Spectra", Spectrochim. Acta, 44A, 581 (1988).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
Roger J. Phillips
Southern Methodist University
Department of Geological Sciences
Dallas, TX 75275
214/692-3196

CO-INVESTIGATORS: None

PROPOSAL TITLE: Planetary Interior Modeling and Tectonic Implications

ABSTRACT:

a. *Objective:* Gain an improved understanding of the relationship between the thermal evolution and the tectonic evolution of terrestrial planetary bodies. Specific objectives include analysis and interpretation of venusian gravity data and tectonic models for Venus with an emphasis on (i) quantitative models for the formation and evolution of highland regions on Venus, (ii) magma generation on Venus, (iii) lithospheric recycling on Venus, and (iv) comparative models of planetary resurfacing using Venus and Mars. Additionally, we are carrying out a theoretical study of martian seismicity.

b. *Progress:* 1) Completed work on elastic-plastic analysis of proposed underthrusting zone on Venus. 2) Published hot-spot model for Lakshmi Planum, Venus. 3) Published model for transient plume evolution on Venus. 4) Completed work on global separation of dynamic and lithospheric components of long-wavelength topographic support on Venus. 5) Published analysis of resurfacing models for Venus. 6) Completed paper on the global tectonic evolution of Venus. 7) Completed gravity analysis of Eistla Regio, Venus.

c. *Proposed Work:* 1) Continue analysis of models of venusian highland evolution, including testing the hypothesis that compressional tectonics can be associated with hot spots either through lateral heterogeneities in lithospheric strength or collapse of topography as dynamic support abates. This will be done with a finite element convection code (ConMan). 2) Study the effect of residuum on the magmatic evolution of Venus and make comparisons to terrestrial environments (also using ConMan, with a double–diffusive capability). 3) Continue inversion of venusian gravity data for comparison to tectonics. 4) Development of resurfacing models for Mars and Venus. 5) Develop models of martian seismicity that can be used to help define a martian seismicity experiment.

d. *Summary Bibliography:* 8 papers published or in press, 4 papers submitted, 8 papers presented at meetings, e.g.:

Phillips, R.J., N.H. Sleep, and W.B. Banerdt, Permanent uplift in magmatic systems with application to the Tharsis region of Mars, *J. Geophys. Res., 95*, 5089–5100, 1990.

Herrick, R.R., and R.J. Phillips, Blob Tectonics: A prediction for western Aphrodite Terra, Venus, *Geophys. Res. Lett., 17*, 2129–2132, 1990.

Grimm, R.E., and R.J. Phillips, Gravity anomalies, compensation mechanisms, and the geodynamics of western Ishtar Terra, Venus, in press, *J. Geophys. Res., 96*, 1991.

Phillips, R.J., R.E. Grimm, and M.C. Malin, Hot-spot evolution and the global tectonics of Venus, research article in press, *Science*, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Address, Phone)

Dr. Carle M. Pieters
Department of Geological Sciences
Brown University
Providence, RI 02912
(401/863-2417)

TITLE: Remote Sensing Information Applied to Geological Studies of Planets (NAWG-28)

ABSTRACT: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year; c. brief listing of what will be done this year as well as how and why; and d. recent publications relevant to the proposed work.

a) Objectives: The central objectives of the research proposed here are to determine the composition of unexplored surfaces and to use this information to understand the geologic evolution of the planetary body. Diverse geoscience research topics that concern exploration of the Moon, asteroids, and Mars are all included in a single proposal. Our approach relies on integration of observational, laboratory, and theoretical investigations using optical and infrared spectroscopic data.

b) Activities during last year: A major book on *Remote Geochemical Analysis* is near publication (with LPI and Cambridge University Press). A chapter summarizing remote observations for the Moon was prepared and published as part of the *Lunar Sourcebook* (in addition to several subsections on spectroscopy of lunar materials). Two publications have been submitted on the character and frequency of black chondrites (possible products of regolith processes on meteorite parent bodies). Analysis of imaging spectrometer data for Mars (ISM on Phobos) resulted in an initial publication with the French and preliminary analysis of the Syrtis Major volcanic plateau. The foundation of lunar spectroscopy was used to verify calibration of Galileo SSI images of the Moon.

c) Proposed tasks: Laboratory reflectance measurements will be obtained and analyzed using the RELAB bi-directional reflectance spectrometer (0.3 - 3.5μm) and a new Nicolet FTIR instrument (1.0 - 25 μm). Projects include pyroxene and olivine separates and mixtures, a suite of low albedo meteorites, selected lunar meteorites, Mars analogues (Fe-rich clays and basalts with ferric coatings), irradiated samples, and several general materials that will form the core of coordinated spectra from the visible to mid-infrared. Modeling of the natural system will use the MGM model to quantify absorption parameters for principal mafic minerals (olivines and pyroxenes), and the Hapke model to simulate and unmix mineral mixtures. An alternate approach, the "Isograin" model, will be tested for applicability to Mars and mineral mixtures. Irradiated (Mev, Kev protons) samples will be analyzed to study the optical effects of galactic cosmic rays and solar wind on exposed samples. Analysis of metal dispersion in chondritic samples (the apparent cause of shock darkening) will be completed. Several experimental studies will be performed to constrain interpretations of spectroscopic properties of Mars. Analyses include the conditions for and implications of ferric coatings on silicate substrate and the inter-related effects of Fe and H_2O on fundamental and combination bands of clays. Lunar applications focus on crustal diversity: Analysis of multispectral images of Bullialdus should complete the case for excavation of a layered pluton (a 3 component stratigraphy observed). High resolution multispectral images of the surveyor I site suggest a multi-phase late mare fill. The implications of these data for basalt evolution and emplacement will be assessed. A lunar gabbroic meteorite (Asuka-31) has been requested for spectral analysis. Compositional comparison will be made with telescopic spectra for fresh craters on the Moon as well as with the properties of spectra for Apollo basalt samples. We have joined a meteorite sample analysis consortium for the somewhat enigmatic carbonaceous chondrites (Y-86720, Y82162, and B-7904). Samples have been received and are ready for analysis during the year. We will continue working with colleagues in the Soviet Union who perform detailed petrographic analyses of selected C1 and CM meteorites.

d) Bibliography: Direct results from this grant during the last year include 4 manuscripts, a book near completion, 10 diverse LPSC22 abstracts of work in progress, plus a variety of shorter science abstracts and presentations.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jeffrey Plescia
Jet Propulsion Laboratory
California Institute of Technology
MS 183-501
Pasadena, CA 91109
818-354-6936 (FTS 792-6936) (NASAMAIL::JPLESCIA)

CO-INVESTIGATORS:

NONE

PROPOSAL TITLE: *SURFACE GEOLOGIC PROCESSES*

ABSTRACT:

a. Four tasks are identified in this proposal: (I) Mars Tectonics, (II) Martian Volcanism, (III) Ganymede-Callisto Surface Age Relations, and (IV) Terrestrial Impact Craters. *Mars Tectonics*: The focus is an assessment of the net extension and compressional associated with grabens and wrinkle ridges in Tharsis and Elysium and to assess the isotropy of regional strain. *Martian Volcanism*: Task focuses on the most recent volcanism of the large Tharsis and Elysium volcanoes and the volcanic history of the small, "enigmatic" Tharsis volcanoes (e.g., Tharsis Tholus). These two tasks (I and II) provide important information about the tectonic and volcanic history of Mars. *Ganymede-Callisto Surface Age Relations*: Objective is to develop a global stratigraphy for the most widespread geologic terrains on Ganymede. A second aspect of this task is an assessment of the extent of surface age variation and hence an understanding of the extent of geologic evolution of the surface of Callisto. This work will provide an understanding of how these two large icy satellites have evolved over time. *Terrestrial Impact Craters*: Focus is on the modelling of gravity data to determine the crustal structure of three large impact craters on the Australian shield (Connolly Basin, Mt. Toondina, and Kelly West).

b. Progress: Only 0.1 man years of effort have been expended during FY91 to data on this project and progress has been more limited than anticipated. Task I: Analysis of wrinkle ridges in northern Lunae Planum and construction of a profile at 20°N has been completed. Data indicate about 1840 m of shortening across Lunae Planum, corresponding to 0.29 % regional strain. Profile across northern Tharsis at 35°N completed to assess late Amazonian extension due to graben formation. Data indicates that total extension across this region amounts to 6940 m, corresponding to strain of 0.39 %. Preparation of 3 papers and several abstracts. Task II. Beginning of mapping of small volcanic features of Elysium, completion of Icarus paper and presentation of invited paper. Task III. Progress limited to preparation of image base materials and recompilation of data for collaborative efforts with S. Murchie et al. at Brown on geologic problems of Ganymede. Task IV. Data reduction is complete. Isolation of residual anomalies for Mt. Toondina impact structure have been completed and modelling efforts indicate impact structure dominated by a diapir in the central peak of relatively high density material surrounded by a slightly overthickened annulus of relatively low density material. Preparation of an abstract.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Pollack
(Name, Address, Telephone Number) NASA/Ames Research Center, Space Science Div.
MS 245-3, Moffett Field, CA 94035
(415) 604-5530

CO-INVESTIGATORS: Ted Roush
(Name Only)

PROPOSAL TITLE: Studies of Surfaces and Rings

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The purposes of the proposed research are to define the properties of solar system surfaces and rings and the processes that affect them.

b) Recent accomplishments include: 1) Tentatively identifying features in our 1988 KAO thermal emission spectra of Mars as being due to sulfates, carbonates, and hydrates ; and obtaining new thermal emission spectra of Mars from the KAO aircraft and the IRTF. 2) Determining the effects of CO absorption features in the 2.3 micron region on spectra of Mars used to define surface mineralogy. 3) Estimating the mass fractions of water ice, hydrated minerals, and opaques on Callisto's surface. 4) Determining the wind stress pattern across the Martian surface with a general circulation model (GCM). 5) Determining the photometric properties of Saturn's F ring for the full collection of Voyager 1 and 2 images.

c) During the next year, the following research is proposed: 1) Completing the reduction and performing initial simulations of our new thermal emission spectra of Mars to detect and determine the abundances of key mineral phases, especially those produced by weathering processes. 2) Analyzing Voyager images of Callisto to determine the spatial distribution of albedo units for use in modeling near IR spectra. 3) Performing an in-depth comparison of GCM wind stresses with aeolian features, including streaks and dune fields. 4) Analyzing images of the shadow of the F ring on the satellite Epimetheus to bound this ring's inclination and thickness.

d) Pollack, J.B., Roush, T., Witteborn, F., Bregman, J., Wooden, D., Stoker, C., and Toon, O.B. (1990). Thermal emission spectra of Mars (5.4-10.5 μm): Evidence for sulfates, carbonates, and hydrates. *J. Geophys. Res.*, 95, 14, 595 - 628; Roush, T., Pollack, J.B., Witteborn, F.C., Bregman, J.D., and Simpson, J.P. (1990). Ice and minerals on Callisto and Ganymede: A reassessment of the reflectance spectra. *Icarus*, 86, 355 - 382.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Pollack
(Name, Address, NASA/Ames Research Center, MS 245-3
Telephone Number) Moffett Field, CA 94035 (415) 604-5530

CO-INVESTIGATORS: Patrick Cassen, William Cabot, and
(Name Only) Kevin Thompson

PROPOSAL TITLE: Protostellar Disks and the Solar System

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The purposes of the proposed research are to derive improved parameterizations of key physical processes operating in the solar nebula (e.g., turbulence), to model various stages in this accretion disk's development and evolution, and to derive observational constraints on the nature of the early solar system. These efforts are directed at constraining theories of the origin of the planets and satellites. (b) Key recent accomplishments include: 1) conducting numerical simulations of turbulence in the presence of sheared rotation, for conditions relevant to the solar nebula; 2) constructing models of the solar nebula in which the inhibiting effects of low optical depth and the solar luminosity on thermal convection and disk evolution were simulated; 3) demonstrating that torques generated by gravitational instabilities in protostellar disks are ultimately regulated by the rate at which energy can escape. 4) constraining the oxidation state, ice to rock ratio, and the C content of planetesimals in the outer solar nebula. (c) During the forthcoming year, we propose to: 1) continue our numerical simulations of turbulence by examining the effects of compressibility and developing subgrid scale models for use at high Reynolds numbers; 2) study the evolution of the solar nebula when it was tidally truncated by one or several giant planets; 3) continue the simulations of the evolution of gravitationally unstable disks by simulating larger disks and commencing studies of dissipation mechanisms; 4) conduct initial studies of the phase changes and chemical transformations that occurred as the grains and gases of an infalling molecular cloud approached and passed through the shock interface of the solar nebula. (d) Cabot, W., Hubickyj, O., Pollack J.B., Cassen, P., and Canuto, V. (1990). Direct numerical simulations of turbulent convection I. Variable gravity and uniform rotation. *Geophys. and Astrophys. Fluid Dyn.*, 53, 1-42; Simonelli, D., Pollack, J.B., McKay, C.P., Reynolds, R.T., and Summers A.L. (1989). The carbon budget in the outer solar system. *Icarus* 82, 1-35; Tomley, L., Cassen, P., and Steiman-Cameron, T. (1991). On the evolution of gravitationally unstable protostellar disks, submitted to Ap. J.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Katherine H. Price
206 Julian Center, DePauw University
Greencastle, IN 46135
(317) 658-4668

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Mars Geologic Mapping: Dao, Harmakhis, & Reull Valles

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The primary objective of this project is to determine stratigraphic relationships among geologic units on the east rim of Hellas basin by detailed geologic mapping of three MGM 1:500,000 quadrangles (-40272, -40267, -40262). Specifically, the geological questions that will be addressed are: (1) What are the relative ages of and water sources for the valley networks of the channeled plains unit of the Hellas rim?, (2) What are the relative ages and types of mass wasting in the outflow channels and on the upland surfaces of Hellas rim?, (3) What roles do fluvial, eolian, and glacial processes play in the erosional history of this portion of the east Hellas rim?, and (4) What are the ages of the channels relative to the filling of Hellas basin and resurfacing of Hellas rim?

(b) I was notified that I had been funded in December, 1990. My base mapping materials arrived in February, 1991, and mapping is now in the preliminary stages.

(c) During 1991 I will map MGM -40267 following standard planetary geologic mapping principles specified by Wilhelms (1972). I am beginning with the center quadrangle because it exhibits many of the stratigraphic units associated with outflow channels, valley networks, and erosional scarps which must be resolved to address the objectives in (a). Mapping will be done by interpretation of high-resolution Viking Orbiter images and by stereo interpretation where possible. I will consult with Ronald Greeley and David Crown as necessary throughout the project.

(d) Crown, D.A., K.H. Price, R. Greeley, 1990, "Evolution of the East Rim of Hellas Basin, Mars", Lunar & Planetary Science Conference, XXI, p.252-253.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Professor Carl Sagan
Space Sciences Bldg., Cornell University, Ithaca, NY 14853
(607) 255-4971

Co-INVESTIGATORS: (Name Only) B. N. Khare
W. R. Thompson

PROPOSAL TITLE: Interdisciplinary Studies of Comparative Planetology

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Impact delivery and erosion of volatiles and organics by meteoritic and cometary sources on the early terrestrial planets. Triton and Titan surface condensates, spectral classification, and chemistry. Radar properties of Titan condensates. Oxidant diffusion on Mars. Optical constants of ices and minerals. Laboratory simulation of CH_4/H_2O and other ice irradiation chemistry in outer solar system bodies and comets; comparison with spacecraft observations.

b. Analysis of windblown streaks on Triton (Sagan and Chyba 1990). Demonstration of importance of impact delivery of organic carbon to the early Earth inventory (Chyba *et al.* 1990); extension which demonstrates importance of impact shocks to the early Earth organic inventory (Chyba and Sagan 1991). Characterization of radar properties of materials relevant to Cassini radar sounding of Titan and demonstration of wavelength limitations for a sounding mode (Thompson and Squyres 1990). Identification of major color/albedo units on Triton, and chemical constraints on the age of spectral units (Thompson and Sagan 1990). Assessment of the consistency of impact delivery of volatiles to the early Earth with lunar and terrestrial geochemical constraints (Chyba 1991).

c. Completion of studies involving impact delivery and other impact mediated processes as sources and sinks of volatiles and organic compounds on the early terrestrial planets. Refinements of Triton chemistry and relationship to surface spectral properties, including detailed treatment of magnetospheric electron flux and new laboratory models of chemistry in 10^{-5}-CH_4 in N_2 atmospheres. Completion of current optical constants work on simple hydrocarbon ices (CH_4, C_2H_6) with new measurements for C_2H_2. Resumption of color/albedo evolution studies of irradiated ices if major equipment request is granted.

d. Sagan and Chyba (1990), Windblown dust on Triton, *Nature 346*, 546–548; Chyba *et al.* (1990), Cometary delivery of organic molecules to the early Earth, *Science 249*, 366–373; Chyba (1991), Constraints on terrestrial volatile accretion during the heavy bombardment, (submitted to *Icarus*); Khare et al. (1990), Optical constants of solid methane, NASA CP-3077, 327–339; Thompson and Sagan (1990), Color and chemistry on Triton, *Science 250*, 415–418.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John W. Salisbury
Department of Earth and Planetary Sciences,
Johns Hopkins University
Baltimore, MD 21218 Tel. 301-338-7048
CO-INVESTIGATORS: None.
PROPOSAL TITLE: Mid-Infrared Spectroscopic Investigation

ABSTRACT:

a. Growing interest in the mid-infrared (2.5-25 μm) has led to either a thermal infrared spectrometer or multispectral scanner planned for Mars Observer, EOS, and the Russian Vesta probe, and proposed for a lunar orbiter mission. Meanwhile, ground-based infrared measurements are underway of Mercury, the Moon and asteroids. These developments show the need for both a library of mid-infrared spectral signatures of minerals and rocks, and an understanding of different environmental effects on those signatures. It is the purpose of this project to help provide this needed capability.

b. This is a new proposal. Results of the previous grant are summarized on pages 2-5 in the body of the proposal.

c. During the first year of this new grant we will use the integrating sphere on our laboratory spectrometer to finish measurement of quantitative directional hemispherical reflectance spectra of sedimentary and metamorphic rocks that can be used to accurately predict emissivity. The characterization of these rocks will be completed and a spectral library of rocks published. We will interpret the body of spectral data obtained so far to develop new applications of remote sensing data, such as determination of particle size of soils using the spectral contrast of the reststrahlen bands, and evaluation of the effects of grain coatings. We will also use the new field spectrometer to measure environmental effects on spectral emissivity. Finally, we will cooperate with other NASA investigators to broaden the research base in the mid-infrared.

d. Salisbury, J. W. and Walter, L. S., 1989, Thermal infrared (2.5 to 13.5 μm) spectroscopic remote sensing of igneous rock type on particulate planetary surfaces: Journal of Geophysical Research, v. 94, p. 9192-9202.

Salisbury, J. W., D'Aria, D. M., and Jarosewich, E., 1991, Mid-infrared (2.5-13.5 μm) spectral properties of powdered stony meteorites: Icarus (in press) and attachment 3.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gerald G. Schaber
(Name, Address, Telephone Number) U.S. Geological Survey, 2255 North Gemini Dr., Flagstaff, AZ 86001
(602) 527-7485;
FTS 765-7485

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Geology and Cratering History of Venus

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. **Objectives:** To continue ongoing research on the geologic evolution and impact cratering history of Venus by using all available radar image and ancillary databases, especially those from Magellan; to publish these results: and to integrate relevant findings into development of radar-geology unit descriptions and mapping procedures for NASA's Venus Geologic Mapping Program. In addition to formal papers describing topical research results, major products anticipated will include white papers describing "proposed" Venus geologic mapping procedures and maps showing the density distribution of impact craters on Venus by area, geologic unit, and elevation.

b. **Accomplishments**: New Proposal (See **References Cited** for published results of recent NASA-funded Venus research.)

c. **Work Plan**: (1st year - October 1, 1991- Sept. 30, 1992): (1) Continue research on the distribution, density, morphology, geology, and surface properties of impact craters on Venus and the processes that have modified and eliminated them; submit for formal publication a paper on the distribution of terrains of different apparent ages as determined by impact crater density. Additional formal papers will be prepared on the geologic evolution of Cleopatra crater, and the geology, formation, and surface properties of peak-ring craters on Venus; (2) As Program Scientist for NASA's Venus Geologic Mapping Program, G. Schaber will, in collaboration with Ken Tanaka (USGS; Venus Mapping Coordinator), NASA's Venus Geologic Mapping Steering Committee, and the Magellan Science Team, participate in the preparation of preliminary descriptions and interpretations of major geologic units or terrains to be evaluated during the early phases of NASA's 1:5,000,000-scale Venus Geologic Mapping Program; and (3) investigate the regional distribution and nature of major volcanic sources, assessing the local tectonic framework, relative ages, and dominant volcanic styles, eruptive volumes.

d. **Recent Publications (Complete references in References Cited in Text)**: Kozak and Schaber (1989); Arvidson et al. (1990); Head et al., (1990, 1991 a,b,c, in press a,b,c); Basilevsky and Schaber (1991); Phillips et al., (in press); Saunders et al. (1990; a,b in press); Schaber (1990a,b; 1991; in press); Schaber and Chadwick (1990); Schaber and Kozak (1990).

Proposal Summary

Principal Investigator: Robert M. Schmidt
Boeing Aerospace Company Mail Stop 87-60
P.O. Box 3999, Seattle, WA 98124-2499
(206) 773-0660

Co-Investigators:
Title: Impact Cratering Mechanics

Abstract (a. overall objectives; b. accomplishments; c. proposed work; d. recent publications):

a. The objective of the current three-year program is to use a geotechnical centrifuge and related shock physics experiments to develop scaling rules for large-body impacts onto planetary surfaces. Three topics of interest to be run in parallel include the following:

1.) Atmospheric effects on impact cratering.
2.) Continuation of the present work to investigate rock and rock simulant targets.
3.) Stress wave propagation and shock photography in transparent target media.

b. It might be expected that large-scale (i.e. gravity dominated) impacts in jointed rock would produce larger craters than in porous targets (e.g. megaregolith), because energy and momentum coupling would be more efficient in the relatively nonporous rock. However, recent results (Schmidt, 1990) from experiments performed in rock targets and rock simulants suggest that cratering efficiency in jointed rock may be considerably smaller than that in porous targets. While the coupling may be better for the non-porous materials, the jointed rock or rock simulants seem to display much higher friction angles due to joint locking and kinematic incompatibility between blocks. The high friction angle reduces crater size for the jointed material. This may have significant implications for interpretations of planetary cratering records which are based on crater scaling laws. We have recently perfected a weakly cemented basalt to use a simulant for jointed rock as it exists in the field. The cohesive and tensile strength can be varied by two orders of magnitude from near zero to 300 bars. Cratering experiments using this materials have shown good reproducibility and crater size is a strong function of lithostatic confining pressure. Cratering and fragmentation results are given in the first two references below.

c. Preliminary tests are under way using carbon gauges embedded in the weakly cemented basalt during fabrication. Transient stress measurements will provide information on coupling and propagation. Water targets are also being used to investigate scaling relationships, especially with regard to stress wave propagation, rate of crater growth, and total time of crater formation. This allows photography of complex shock wave interactions for simulated layered targets with different sublayer conditions. This technique is being extended to other transparent targets such as plexiglas. Next, we will orient thin glass plates in a vertical plane to test for effects of the direction of "jointing" in our samples. Different configurations of explosive loadings will be evaluated to provide a more rectilinear pre-fracture pattern. Plate thickness will be varied relative to the impactor size. This will be done by varying both the projectile size and the plate thickness. To do this a larger two stage light gas gun, used previously in 1G experiments, is being considered for use on the centrifuge. This gun is capable of launching 1/4" projectiles, as compared to 1/16" impactors for the smaller. To investigate atmospheric effects a vacuum/pressure chamber has been fabricated for use on the centrifuge. This will facilitate experiments to isolate pressure effects from drag effects.

d. Schmidt R. M. and Housen K. R. (1991) Laboratory simulations of large scale fragmentation. *Lunar and Planetary Science XXII*, pp. 1185-1186, Lunar and Planetary Institute, Houston, TX.

Housen K. R. and Schmidt R. M (1991) Laboratory simulations of large scale fragmentation events, manuscript submitted to *Icarus* 2/12/91.

Schmidt R. M., Voss M. E. and Watson H. E. (1991) A compendium of data for impact cratering experiments performed at elevated gravity on a centrifuge and at 1G in the laboratory. Document D180-32314-1, Boeing Aerospace & Electronics Company, Seattle WA 98124-2207.

Schmidt R. M. (1990) Crater simulations in subscale jointed rock: Preliminary results, *Lunar and Planetary Science XXI*, pp. 1083-1084, Lunar and Planetary Institute, Houston, TX.

Schmidt R. M. and Holsapple K. A. (1989) Planetary ejection mechanisms, *EOS*, 70, No. 43, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Gerald Schubert

Dept. of Earth and Space Sciences
UCLA, 405 Hilgard Ave., L.A., CA 90024-1567
(213) 825-4577

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: THERMAL AND DYNAMICAL PROCESSES IN THE EVOLUTION OF PLANETS AND SATELLITES

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objective: Determine interior structures and thermal histories of planets and satellites. Characterize the modes of heat transport and deformation in the mantle. Relate surface tectonic features to mantle dynamics.

(b) Progress: Showed that Triton is unique in the solar system in that its internally generated heat makes a significant contribution to its surface energy balance. For example, internal heat flow on Triton can double the surface pressure of its nitrogen atmosphere. Modelled the thermal equilibration of the Earth following a giant impact and found that it occurs on a time scale of 1 to 10 million years. Calculated new structural models of the Martian interior. Explored the influence of the sulfur content of the core of Mars on the planet's thermal evolution and the generation of a planetary magnetic field. Concluded that the lack of a present Martian magnetic field is most consistent with a model of Mars in which the present core is completely liquid. Calculated fully 3-dimensional, highly nonlinear modes of mantle convection in spherical shell models of Mars and Venus. Found that cylindrical upwelling mantle plumes could be responsible for volcanic centers on Mars and Venus and that a cylindrical downwelling plume might explain the compressional features in western Ishtar Terra on Venus.

(c) Proposed Work: Construct thermal models of Triton's interior. Determine effects of a hemispherically asymmetric distribution of an insulating nitrogen surface condensate layer on Triton's surface heat flow. Investigate the effects of inhomogeneous heating by large impacts on the thermal histories of terrestrial planets. Develop thermal history models of Io's core and mantle to establish the feasibility of a present dynamo-generated magnetic field. Construct numerical models of mantle plumes with temperature-dependent viscosity. Apply the plume models to Mars and Venus to determine if major geologic features on these planets are associated with mantle plumes. Use the 3-dimensional spherical convection code to study convection and plume dynamics in Mars and Venus and finite element codes to relate mantle and lithosphere dynamics to surface tectonics.

(d) Summary Bibliography: (01/01/90-12/31/90): 5 papers published, 3 papers in press, 6 abstracts published, 5 oral presentations.

(e) Personnel: 1 faculty (part time), 1 graduate research assistant.

PROPOSAL SUMMARY/ABSTRACT

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone)

Peter H. Schultz
Brown University
Department of Geological Sciences
Box 1846
Providence, R.I. 02912
(401) 863-2417

CO-INVESTIGATORS:

PROPOSAL TITLE: Planetary Impact Processes

ABSTRACT:

a.) Objectives: 1.) To investigate the process and consequences of oblique impacts from the planetary geologic record, laboratory experiments, and theoretical analysis. 2.) To characterize the formation and evolution of impact craters in atmospheric environments through comparisons of the planetary impact record, impact experiments, and young terrestrial craters.

b.) Progress: Analysis of planetary surfaces, laboratory experiments, and terrestrial field studies have provided the following new results: 1.) Recognition of projectile decapitation by hypervelocity oblique impacts in the laboratory and in the planetary surface record (Mars and Moon). 2.) Increased time resolution (microsecond) of impact vapor and plasma cloud through high frame rate imaging, improved data collection techniques, and Langmuir probes. 3.) Spatial separation of jetting, vapor, ricochet, and target ejecta for oblique impacts, thereby allowing analyses of each component. 4.) Characterization of the separate effects of ambient pressure, dynamic pressure, and projectile wake effects on ejecta emplacement, cratering efficiency, and crater shape in laboratory experiments with parallel effects emerging for Mars and Venus. 5). New estimates on the rate and style of erosion around the low-gradient continuous ejecta of Meteor Crater and Odessa using ground-penetrating radar with implications for styles of ejecta emplacement and gradation rates on Mars.

c.) Proposed Research: Two major tasks are proposed. The first investigates the process and consequences of oblique impacts and will be accomplished through the following subtasks: 1.) Comparison of oblique impacts on the Moon, Mars, and Mercury with laboratory experiments as a means to separate impactor velocity, angle, and size; and 2.) characterization of impactor survival and shear heating in oblique laboratory impacts through contrasting effects of different projectile/target combinations, melt/vapor plating, intact capture, magnetic field and plasma generation, and spectral analyses. The second task continues the analysis of atmospheric effects on the cratering process through the following subtasks: 1.) Comparison of the effects of crater formation and emplacement styles on Mars, in laboratory experiments, and Venus; 2.) studies of contrasting ejecta emplacement styles recognized around selected terrestrial craters.

d.) Summary Bibliography:

Schultz, P.H. and Gault, D.E. (1991). In *Proc. Global Catastrophes* (in press).

Schultz, P.H. (1991a). Atmospheric Effects on Cratering Efficiency, *J. Geophys. Res.* (in revision).

Schultz, P.H. (1991b). Atmospheric Effects on Crater Shape. (*Icarus*, in revision).

Schultz, P.H. (1991c). Atmospheric Effects on Ejecta Emplacement. (Submitted to *J. Geophys. Res.*).

Grant, J. and Schultz, P.H. (1990), *Icarus 84*, 166-195.

Grant, J. and Schultz, P.H. (1991). Amount and Styles of Ejecta Erosion at Meteor Crater, Arizona. (To be submitted to *Geol. Soc. Am. Bull.*).

Crawford, D. and Schultz, P.H. (1991). Laboratory investigations of impact-generated plasma. *J. Geophys. Res.* (in revision).

Proposal Summary

PRINCIPAL INVESTIGATOR: *Richard A. Schultz*
Mackay School of Mines/168
University of Nevada, Reno
Reno, Nevada 89557-0138
(702) 784-4318

TITLE: Geologic Mapping of the Ophir Planum Region of Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(*a*) **Objectives.** Produce a 1:500,000 scale photogeologic map of the Ophir Planum region of Mars (MTM -10067). Geologic mapping of this area will clarify the sequence of faulting on the Ophir Planum plateau located at the junction of three Valles Marineris troughs. Analysis of these faults is necessary to reconstruct the structural history of Valles Marineris.

(*b*) **Progress.** Geologic mapping completed. New crater counts define a Late Hesperian age for Ophir Planum plateau and Early Hesperian age for Coprates Chasma floor. The geologic history and faulting sequence in the map area have been determined. Plateau grabens are found to be older than most downfaulting of the adjacent troughs and appear related to early stages of trough faulting. Coprates Chasma and similar troughs appear to be asymmetric rift grabens in cross section.

(*c*) **Work Plan CY 92.** Funding during this last phase of the project will support map revisions, follow-up travel to the MGM Flagstaff meeting, and review of other MGM maps.

(*c*) **Recent Publications.**

Schultz, R.A., Strike-slip faulting of ridged plains near Valles Marineris, Mars, *Nature*, *341*, 424-426, 1989.

Aydin, A. and R.A. Schultz, Effect of mechanical interaction on the development of strike-slip faults with echelon patterns, *Journal of Structural Geology*, *12*, 123-129, 1990.

Schultz, R.A. and H.V. Frey, A new survey of multiring impact basins on Mars, *Journal of Geophysical Research*, *95*, 14,175-14,189, 1990.

Frey, H.V. and R.A. Schultz, Speculations on the origin and evolution of the Utopia-Elysium lowlands of Mars, *Journal of Geophysical Research*, *95*, 14,203-14,213, 1990.

Schultz, R.A. and A. Aydin, Formation of interior basins associated with curved faults in Alaska, *Tectonics*, *9*, 1387-1407, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) David H.Scott
2255 N. Gemini Dr., Flagstaff, AZ 86001
602-527-7188; FTS 765-7188

Co-INVESTIGATORS: (Name Only) James M. Dohm

PROPOSAL TITLE: Geologic mapping of materials deposited on northwest flanks of Pavonis and Arsia Mons (1:500,000 scale).

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

---

a) Objectives: To map five 1:500,000-scale MTM quadrangles covering parts of Pavonis and Arsia Montes. The purpose of the geologic mapping is to determine the origin and probable composition of large, fanlike, concentrically ribbed sheet deposits on the northwest slopes of the volcanoes; stratigraphic relations between the deposits and lava flows of the Tharsis Montes Formation will be clarified.

b) New Proposal: (3-year term).

c) Work Plan FY 92: Complete geologic mapping of MTM quadrangles -05122 and -05127 on Arsia Mons; calculate H/L ratios and volumes of deposits.

d) Publications:

Scott, D.H., and Dohm, J.M., 1990, Faults and ridges: Historical development in Tempe Terra and Ulysses Patera regions of Mars: LPSC Cont. Proc., XX, p. 503-513.

Scott, D.H., and Tanaka, K.L., 1986, Geologic map of the western equatorial region of Mars: U.S. Geol. Surv. Misc. Inv. Series Map I-1802A, scale 1:15,000,000.

<u>PROPOSAL SUMMARY</u>

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
David H. Scot
USGS, 2255 N. Gemini Dr., Flagstaff, AZ 86001
602-527-7188; FTS 765-7188

Co-INVESTIGATORS: (Name Only)
Mary G. Chapman
James W. Rice, Jr.

PROPOSAL TITLE: Martian Lacustrine Basins and Reassessment of Fluvial History: Exobiological Implications.

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

---

a) **<u>Objectives and Justification</u>**: Two-part proposal: 1) To examine Viking Orbiter images and new topographic data sets for evidence of large bodies of ponded water that may once have been present on Mars; and 2) to re-examine small valley networks in the highlands to determine their stratigraphic age. Recent evidence indicates that water, upon which terrestrial life depends, has been present throughout Mars' history. Our Elysium basin study, for its terminal year (FY91), has been combined with this proposal.

b) **<u>Accomplishments</u>**: Work has been concentrated in the Amazonis and Utopia basins. Evidence of paleolakes includes terraces, raised platforms, and benches that may mark former lake shorelines; the "shorelines" largely occur at the same elevation within and between contiguous basins. The basins and their borders also contain other geomorphic indicators of a fluvial history. Some work has been extended into the Isidis basin. Mapping of the Elysium basin and its probable water sources is in a final stage and the map will be submitted for publication by the U.S. Geological Survey. Two papers have been published and an abstract has been submitted to LPSC 22.

c) **<u>Proposed Work FY92</u>**: Extend current investigations to other major basinal areas where paleolakes may have resided; continue studies of valley networks to determine their stratigraphic position, possible origins, and relevance as indicators of a fluvial episode limited to an early period in Mars' history. A field study of terrestrial paleolakes will be started.

d) **<u>Relevant Publications</u>**:

Scott, D.H., and Chapman, M.G., 1991, Mars Elysium basin: Geologic/volumetric analyses of a young lake and exobiological implications: LPSC 21 Proceedings, p. 669-677.

Scott, D.H., and Underwood, J.R., Jr., 1991, Mottled terrain: A continuing Martian enigma: LPSC 21 Proceedings, p. 627-634.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Eugene M. Shoemaker
USGS, 2255 N. Gemini Dr., Flagstaff, AZ 86001
602-527-7181; FTS 765-7181

CO-INVESTIGATORS: (Name Only) Carolyn S. Shoemaker

PROPOSAL TITLE: Studies of Australian Impact Structures

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objective: The objective of this study is to refine our understanding of the past flux of solid bodies in the neighborhood of the Earth. Australia is one of the most favorable regions of the world in which to find and identify impact structures. Our specific goals are 1) to accurately document the cratering record of Australia, 2) to obtain precise ages of the impact structures, where possible, 3) to search for evidence on the nature of the impactors, and 4) to use these results to reevaluate the flux history of terrestrial impacting bodies.

b. Progress: Detailed field studies were carried out on 3 large structures of known or probable Proterozoic age. Late Proterozoic ages are indicated by the field relationships for the Strangways and Lawn Hill structures; the Middle Proterozoic Fiery Creek Dome was demonstrated not to be of impact origin. The rate of production of terrestrial impact craters ≥ 20 km in diameter during the Proterozoic appears to have been somewhat less than that during the last 120 million years but consistent with the last 3.3 billion-year record of cratering on the Moon. Further samples were obtained to determine the ages of young meteorite craters. The recent rate of production of craters ≥ 1 km diameter by impact of iron meteorites on the continental area of Earth is estimated to be about 1 per 20,000 years. Studies of the siderophile elements in the meteorites and impactites from the Wolfe Creek crater and the Henbury crater reveal large fractionation of several noble metals relative to Ni.

c. Proposed work: The principal work planned for the coming field season is a reconnaissance to search for new impact structures in Queensland, New South Wales, and South Australia. Additional geologic mapping of the central uplifts of the Lawn Hill structure and the Connolly Basin will be undertaken, and a newly discovered small impact crater in Western Australia will be mapped at large scale. Collaborative study of key tektite localities in southeastern Australia is also planned.

d. Bibliography: Plescia, J., Shoemaker, E.M., and Shoemaker, C.S., 1991, Gravity survey of the Mt. Toondina impact structure, South Australia, in Abstracts of papers submitted to the Twenty-second Lunar and Planetary Science Conf., Houston, March 18-22, 1991: Houston, Lunar and Planetary Institute, p. 1079-1080. Shoemaker, E.M., and Shoemaker, C.S., 1990, Proterozoic impact record of Australia, in Abstracts of papers submitted to International Workshop on Meteorite Impact on the Early Earth, Perth, Australia, Sept. 21-22, 1990: Houston, Lunar and Planetary Institute, p. 47-48. Shoemaker, E.M., and nine other authors, 1990, Ages of Australian meteorite craters - A preliminary report, in Abstracts of papers submitted to 53rd Meeting of the Meteoritical Society, Perth, Australia, Sept. 17-21, 1990: Meteorites, v. 25, p. 409.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Robert B. Singer, Associate Professor
Planetary Sciences Department
Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721
(602) 621 4573

Composition and Distribution of Mars Surface Materials

ABSTRACT

A. Objective This is the third-year renewal of a three-year research program to improve our geologic understanding of Mars. Emphasis is placed on mineralogy and distribution of surface materials at the present time, from which current processes and geologic history are inferred. Primary data used are existing Earthbased spectral reflectance data and Viking multispectral images, along with terrestrial remote-sensing data of Mars-analog sites. Laboratory studies and development of data analysis techniques will be conducted as required for the proposed science. We continue to work towards an integrated analysis approach incorporating image data and spectroscopic data.

B. Progress The past year has seen continued good progress and publication. Please see the attached Progress Report for more details. 1) The spectrophotometric study of the Coprates/Valles Marineris region has included continued work on the nature and origin of low-albedo materials, a study of regional albedo changes, and the initiation of multiparametric mapping using Hapke-type photometric modelling. 2) Mars-analog basaltic pyroclastic and hydroclastic deposits have been extensively studied, using remote-sensing data from the Geologic Remote Sensing Field Experiment (GRSFE) as well as field geology, sample collection, and laboratory analyses. Our understanding of the origin and evolution of materials in these deposits has been significantly expanded. 3) Work has continued to confirm the discovery of the mineral scapolite on Mars, and to refine estimates of composition and regional abundance. Additional spectroscopic observations were obtained in 1990 by us (funded elsewhere) and by others to help deconvolve the spectral contributions of CO from the mineral phase. 4) Cooperative work has been initiated with H. McSween to study relationships between SNC meteorites and Mars primary crustal materials.

C. Proposed Work 1) Complete spectrophotometric analysis of the Coprates quadrangle, utilizing overlapping Viking Orbiter multispectral coverage with differing incidence and emission angles. Hapke parameters (e.g. single-scattering albedo, macroscopic roughness) will be solved for and used to provide geologic mapping of compositional and physical properties. 2) Complete the study of basaltic pyroclastic and hydroclastic volcanism and alteration on Earth and Mars, based on remote-sensing, field geology, and laboratory data. 3) Continue geologic investigation of scapolite on Mars, based on existing 1988 data and new 1990 observations. Refine our understanding of regional occurrence, abundance, and possible modes of origin of scapolite on Mars. 4) Spectroscopic and petrologic investigation of martian primary crustal materials, utilizing data for Mars and the SNC meteorites.

D. Recent Publications:

Dark Materials in Valles Marineris: Indications of the Style of Volcanism and Magmatism on Mars. J. Geophys. Res., 95, 14,399 - 14,413 (1990) (P.E. Geissler, R.B. Singer, B.K. Lucchitta).

Origins of the Mars-Like Spectral and Magnetic Properties of a Hawaiian Palagonitic Soil. J. Geophys. Res., 95, 14,427 - 14,434 (1990) (R.V. Morris, J.L. Gooding, H.V. Lauer, and R.B. Singer).

High-Resolution Reflectance Spectra of Mars in the 2.3-μm Region: Evidence for the Mineral Scapolite. J. Geophys. Res., 95, 14,463 - 14,480 (1990) (R.N. Clark, G.A. Swayze, R.B. Singer, J. Pollack).

Change Detection using Viking Orbiter Images of the Martian Canyons. Bull. A.A.S., 22, 1061 (1990) (P.E. Geissler and R.B. Singer).

Mapping Volcanic Pyroclasts in the Lunar Crater Volcanic Field, Nevada, Through Spectral Mixing Modelling, EOS (Trans. Am. Geophys. Union), 71, 1721-1722 and presented at fall AGU meeting (1990) (W.H. Farrand, R.B. Singer, and E. Merényi).

Oxidation of Basaltic Tempras: Influence on Reflectance in the 1μm Region. Submitted to Lunar and Planet. Sci., XXII (1991) (W.H. Farrand and R.B. Singer).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Laurence A. Soderblom
(Name, Address, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001
Telephone Number) (602) 527-7018

Co-INVESTIGATORS: Alfred S. McEwen
(Name Only)

PROPOSAL TITLE: Global Color and Surficial Geology of Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: This renewal is for the last year of a project to generate and analyze a suite regional-scale 2-color and 3-color digital maps derived from Viking Orbiter images that cover the martian globe over a range of seasons. With 1-km or better resolution, these new bases have about roughly 100 times the information density the Viking 2 approach global color mosaic (Soderblom et. al. 1978). The images being used were acquired during ideal seasonal and photometric conditions. Our scientific goals are to use this data base to elucidate the surficial geology of the planet. This includes analysis of multiple scattering by surface and atmosphere, of temporal changes in the surface color/albedo, and of relationships between the surficial material units and geologic units defined on the basis of morphology, age, and physical properties.

b. FY91 Progress: By the end of the current fiscal year, we will have completed the following: 1) generation of about 20 individual 2- and 3-color controlled digital mosaics (the data set so far identified has non-redundant coverage for about 95% of the surface and multiple coverage---more than one season or illumination condition---for about 50% of the surface); 2) analysis of a comprehensive ancillary photometric data base extracted for several thousand points within the mosaic set in order to derive a globally-fitted empirical photometric model for the suite of mosaics; 3) generation of 3 global mosaics (with varying degrees of coverage): Survey Mission coverage, Viking 1 coverage of the second Viking-observed martian year, and a single mosaic of the best, complete coverage for the entire globe; 4) organization and submission of the data bases for publication on CDROM under joint PGG and Mars Observer funding with PDS consultation and participation.

c. FY92 Work Plan: During the final year the focus will be on analysis and publication of results in the scientific literature. The first manuscript will be to a companion to the CDROMs (perhaps a USGS publication) describing the data base, the types of seasonal and spectral coverage included, the processing and analysis used to generate it (radiometry, geodesy, and photometry) and summary of first order scientific results. The second will be an analysis of the best-coverage global mosaic to derive maps of surface units based on color/albedo properties (statistical description of color/albedo units and global thematic maps, for example) and to study correlations of these maps with the digital geologic (in collaboration with Tanaka) and thermal inertia (in collaboration with Christensen) maps.

d. Relevant Bibliography: Soderblom, L. A. in press, Composition of the Martian Surface from Spectroscopic Observations, in Mars, eds. H Kieffer, M. Mathews, B. Jakowsky, and C. Snyder, University of Arizona Press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Names, Address, Telephone Number)	Sean C. Solomon 54-522, M.I.T. Cambridge, MA 02139 617/253-3786
CO-INVESTIGATORS: (Name Only)	

TITLE: Tectonic History of the Terrestrial Planets

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Our broad goal is to understand the comparative tectonic, volcanic, and thermal histories of the terrestrial planets.

(b) During the past year we estimated the lithospheric thermal gradient and heat flux on Venus and Mars from the elastic lithosphere thickness, initiated finite-element models of stress within and near large volcanoes to study the relation between stress and volcano evolution, developed finite-difference models of the thermal evolution of zones of lithospheric underthrusting and orogeny on Venus, and wrote syntheses of current understanding of the tectonic evolution of Mars and Venus.

(c) In the coming triennium our proposed work includes the continued development of finite element models of stress within and around large volcanic constructs on Mars and Venus to study the relation between volcanic processes and stress; the continued development of thermal and mechanical models for the evolution of mountain belts on Venus; the construction of models for the stresses and strains due to gravitational spreading of high terrain on Venus; the development of models for lithospheric deformation induced by mantle convective upwelling and downwelling to test hypotheses for the formation of ridge belts and other tectonic features on Venus; and the investigation of local to regional thermal stress as an influence on the formation of tectonic features on volcanoes and in large volcanic provinces on Mars and Venus.

(d) Solomon, S.C., and J.W. Head, Heterogeneities in the thickness of the elastic lithosphere of Mars: Constraints on heat flow and internal dynamics, *J. Geophys. Res.*, *95*, 11073-11083, 1990.

Solomon, S.C., and J.W. Head, Fundamental issues in the geology and geophysics of Venus, *Science*, in press, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Paul D. Spudis
Lunar and Planetary Institute
3600 Bay Area Blvd., Houston, TX 77058.
713-486-2193

Co-INVESTIGATORS: (Name Only) Philip A. Davis

PROPOSAL TITLE: Early Lunar Crustal Evolution

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a). We propose to use remote-sensing data (Earth-based spectral reflectance and spectral imaging and lunar orbital chemistry), cratering data, photography, lunar sample results, and Apollo landing-site geology to: (1) produce an interpretive petrological map of the lunar near side using a combined remote-sensing mineralogical and geochemical approach; (2) use lunar multi-ring basins as probes of crustal composition and structure; (3) study the origin and significance of low-K Fra Mauro basalt, a polymict lunar rock type of uncertain provenance; (4) determine the modes of emplacement of cumulate xenoliths in some selected terrestrial basalt flows and apply this knowledge to determining the probable conditions of xenolith occurrence in lunar mare basalt flows; and (5) complete global 1:5 million scale geologic mapping of the Moon by producing a new geologic map of the central lunar near side.

b). Full proposal, building on previous work.

c). In the first year, we will assemble the imaging spectrometer data (task 1) as it becomes available into the Lunar (La Jolla) Consortium data base format in Flagstaff, register the images to previous petrologic maps (Davis and Spudis, 1985, 1987), and determine first-order correlations. Our initial focus will be on the lunar central near side highlands, where we have previously detected a petrological boundary (Davis and Spudis, 1987). We will complete the Crisium basin work (task 2) and begin data collection for Humorum. We will begin study of the Apollo 16 LKFM and VHA impact melts (task 3) and complete our study of the Apollo 15 aphanitic melts. We will make our initial visit to the Hualalai xenolith site (task 4) and begin to compile field data for the xenolith occurrences. Finally, we will compile a first draft of the new geologic map of the lunar near side (task 5).

d). Spudis P.D., Hawke B.R. and Lucey P.G. (1989) Geology and deposits of the lunar Nectaris basin. Proc. Lunar Planet. Sci. Conf. 19, Cambridge Univ. and Lunar and Planet. Inst. Press, p. 51-60.

Spudis P.D., Taylor G.J., McCormick K.A., Ryder G., Keil K., and Grieve R.A.F. (1990) Clasts in lunar impact melts and the origin of low-K Fra Mauro basalt (abstract). Lunar Planet. Sci. XXI, p. 1188-1189.

McCormick K.A., Taylor G.J., Keil K., Spudis P.D., Grieve R.A.F., and Ryder G. (1989) Sources of clasts in terrestrial impact melts: Clues to the origin of LKFM. Proc. Lunar Planet. Sci. Conf. 19, Cambridge Univ. and Lunar and Planet. Inst. Press, p. 691-696.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Dr. Steven W. Squyres
Center for Radiophysics & Space Research
Cornell University, Ithaca, NY 14853 (607)255-3508

Co-INVESTIGATORS: (Name Only) Daniel M. Janes

PROPOSAL TITLE: Studies in Planetary Geoscience

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: The work proposed here addresses six questions dealing with the geologic evolution of planetary surfaces: (*1*) What is the distribution of ground ice on Mars? (*2*) What are the characteristics of the most ancient water-lain sediments on Mars? (*3*) How does mixing of dissimilar surface materials affect the ability to investigate planetary geochemistry via gamma-ray spectroscopy? (*4*) What are the observable consequences of explosive volcanic eruptions on outer planet satellites? (*5*) How does a planetary lithosphere respond to mantle convection and loading? (*6*) How can the morphology of viscous flows on planetary surfaces be related to their rheology?

(b) Progress: In the past year, we have (*1*) Fully tested a Mars photoclinometric code and used it to obtain a large number of topographic profiles across possible ice-rich features; (*2*) Developed a theoretical treatment of ice evaporation rates on Mars and reduced and analyzed Earth-based radar profiles across ancient aqueous sedimentation basins on the planet; (*3*) Completed a study of gamma-ray mixing effects and investigated techniques for overcoming the complexities introduced by mixing effects; (*4*) Investigated condensation in expanding vapor plumes on airless bodies and developed a smoothed particle hydrodynamical model of such plumes; (*5*) Made a number of major refinements to an existing model of lithospheric response to convection and loading.

(c) Proposed work: In the coming funding year, we propose to (*1*) Obtain additional photoclinometric profiles across relaxed topography on Mars, and use finite-element modeling to examine the rheologic properties of the martian megaregolith and their relationship to ice content; (*2*) Examine the spectral properties of ancient martian sediments and model the physical and chemical characteristics of their environments of deposition; (*4*) Model the hydrodynamics of liquid and vapor eruptions on icy satellites, and compare model results to features observed in Voyager and Earth-based data; (*5*) Apply our lithospheric response model to a variety of problems dealing with Venus, Mars, and icy satellites; and (*6*) Use finite-element techniques to investigate the relationship between the morphology of viscous flows on planetary surfaces and their rheology.

(d) Summary bibliography: 5 papers published, 1 paper in press, 4 papers submitted, numerous abstracts published. *e.g.*, Thomas, Squyres, and Carr, *J. Geophys. Res.* 95, 14, 345; Goldspiel and Squyres, *Icarus* 89, 392;

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

David J. Stevenson
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, California 91125
818/356-6108

Co-INVESTIGATORS:

PROPOSAL TITLE: Planetary Origin, Evolution and Structure

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Theoretical study of the origin, evolution and structure of planets and their satellites, with an emphasis on the modeling of physical processes that determine observable features (tectonics, heatflow, magnetic field, etc.) of these bodies.

(b) (i) Models for the heatflows of all the giant planets, showing that they must possess some deep-seated stable stratification. (ii) Quantitative demonstration that the current spin states of Jupiter and Saturn can arise from despinning due to a hydromagnetic torque that couples the protoplanet to a weakly conducting accretion disk. (iii) A demonstration that radar and other observations of Titan can be reconciled by a model in which the large hydrocarbon reservoir is stored in caverns and "magma chambers" beneath the water ice-rich surface. (iv) Assessment of particles on the surface and in the atmosphere of Triton. (v) Review of the current status of brown dwarf searches. (vi) Preliminary assessment of rheologies of ices on Triton.

(c) (i) Determination of thermodynamic conditions and partitioning behavior of silicate and iron clouds deep in Uranus and Neptune. (ii) Related modeling of a thin shell dynamo in Uranus and Neptune. (iii) Normal mode excitation in Jupiter and Saturn by "explosive boiling." (iv) Resurfacing of Ganymede during passage through a Laplace-like resonance. (v) Mantle convection modeling for Mars and Venus including partial melting and episodic volcanism. (vi) History of the atmosphere of Mars. (vii) Several smaller projects concerning satellites and terrestrial planets.

(d) Six papers published, three in press during last year supported in part by this grant.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Glen R. Stewart
LASP, Box 392, University of Colorado
Boulder, CO 80309-0392
phone: 303-492-3737

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Kinetic Theory Models of Planetary Rings

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The overall objectives are (i) to investigate the collisional evolution of satellite wakes observed in Saturn's rings and (ii) to determine the vertical structure of planetary rings that consist of a broad distribution of particle sizes. The goal of objective (i) is to develop a model based on kinetic theory that is capable of predicting the collisional evolution of satellite perturbations in planetary rings. Detailed comparisons with observations will be used to contrain the physical properties of ring particles in satellite wakes. The goal of objective (ii) is to develop a detailed model of the vertical structure, filling factor, velocity dispersions, and effective viscosity of observed rings and to provide the necessary dynamical input to constrain photometric models of Saturn's rings that are currently being developed by Dones, Showalter, and Cuzzi.

b) This is a new proposal. Related research by the principal investigator in previous years has developed the theoretical framework for modeling satellite wakes and multicomponent planetary rings.

c) Task (i) will use kinetic theory to derive a system of partial differential equations for the collisional evolution of particle streamlines in satellite wakes. These equations will be solved as an initial value problem by finite difference methods. Task (ii) will use analytical approximations to derive a tractable system of integral equations for ring structure from the kinetic theory of Araki and Tremaine. These equations are to be solved numerically for a realistically broad size distribution of ring particles, including the effects of large filling factor and self-gravity.

d) Shu, F.H. and G.R. Stewart, The Collisional Dynamics of Particulate Disks, Icarus **62**, 360-383, 1985. Brophy, T.G., G.R. Stewart, and L.W. Esposito, A Phase-Space Fluid Simulation of a Two-Component Narrow Planetary Ring: Particle Size Segregation, Edge Formation, and Spreading Rates, Icarus **83**, 133-155, 1990. Stewart. G.R., Collisional Damping of Satellite Wakes in Planetary Rings, Bull. Amer. Astron. Soc. **22**, p. 1045., 1990 Stewart, G.R., Nonlinear Satellite Wakes in Planetary Rings I. Phase Space Kinematics, preprint, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert G. Strom
Department of Planetary Science
University of Arizona
Tucson, Arizona 85721
(602) 621-2720

CO-INVESTIGATORS:

PROPOSAL TITLE: Geophysical and Geological Investigations

ABSTRACT:

This renewal proposal is for the continuation of three main tasks. The first task involves the study of the Solar System cratering record including a reevaluation of the Callisto and Ganymede cratering record. The second task involves the continuation of the study of icy satellite geology and geophysics, including cryovolcanism and thermal histories. Task three is the continuation of developing and evaluating a martian climatological and hydrological model involving an ancient ocean(s) in the northern hemisphere and a concomitant ice sheet(s) in the southern hemisphere. This task is a joint coordinated effort between ourselves and Vic Baker's group. Our role in the this effort has primarily concentrated on the distribution and relative age of probable glacial features, and the physics of glaciers and ice sheets under martian conditions. Because the funding request for last year was reduced by over 25% we have had to delay and extend parts of some tasks as stated in the cover letter accompanying the revised budget.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Kenneth L. Tanaka
(Name, Address, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff,
Telephone Number) (602) 527-7208 FTS 765-7208 AZ 86001

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Tectonism in the Ancient Martian Crust

ABSTRACT: **(Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)**

a. Objectives and Justification: Most commonly noted extensional structures on Mars are narrow (1- to 3-km-wide) grabens, indicating that shallow mechanical discontinuities separate surface and basement structures. Martian wrinkle ridges have been proposed to be the result of thin- or thick-skinned deformation. Geophysical models have been constructed to describe the stress fields that explain the grabens and ridges, which are mostly Amazonian and Hesperian in age. On the Thaumasia plateau (the southeastern part of Tharsis), possible rift zones and asymmetric ridges tens of kilometers wide and as much as several hundred kilometers long appear to be deep-seated structures. These features are mainly Noachian in age. To improve our understanding of tectonism in the ancient Martian crust, I propose to (a) determine the broad structural history of Thaumasia, (b) study the kinematic history of major structures, and (c) analyze how Tharsis' style of structure and tectonism changed at the end of the Noachian.

b. Accomplishments: With colleagues, I have produced reports assessing overall structural and stress history on Mars and an analysis of Late Noachian and younger stress/structural history for Tharsis. These reports establish that early Tharsis (i.e., Thaumasia) activity is distinct from later tectonism. I have also begun mapping the Coprates rise (the eastern end of Thaumasia); R.A. Schultz and I find that the rise is probably a compressional structure with 2-4 km of relief that developed during the Late Noachian.

c. Work Plan for FY 91-92: Complete kinematic analysis of the Coprates rise. Begin mapping the entire Thaumasia province and establish its overall structural history. Analyze broad, shallow rift zones that cut the Thaumasia plateau.

d. Summary Bibliography: Bandert, W.B., Golombek, M.P., and Tanaka, K.L. (in press) Stress and Tectonics on Mars: *Mars* (H.H. Kieffer, B.M. Jakosky, and C.W. Snyder, eds.). Tanaka, K.L., Golombek, M.P., and Banerdt, W.B. (accepted for publication pending revision) Reconciliation of Stress and Structural Histories of the Tharsis Region of Mars: *J. Geophys. Res.* Tanaka, K.L. and Schultz, R.A. (1991) Late Noachian development of the Coprates rise, Mars (abs.): *Lunar Planet. Sci. Conf. XXII*, pp. 1379-1380.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Peter C. Thomas
RAND, 1700 Main St., Santa Monica, CA 90407-2138
(310) 393-0411

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: "SHAPES, SURFACES, AND INTERIORS OF SATELLITES AND ASTEROIDS"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives.

1) Complete the derivation of accurate digital shape models of six irregularly shaped satellites 2) Use these models to investigate the history and mechanisms of ejecta redistribution on small satellites subject to significant tidal and rotational effects on local gravity.

3) Investigate the structural features of small objects using the shape models and accurate 3-d coordinates of surface features.

4) Generate normal albedo maps of five small satellites.

5) Model the development of asteroid shapes due to impacts, debris reaccumulation, and possible scale dependence of the shaping mechanisms.

b) Progress

Developed software for: limb and stereo determination of numerical shape models of irregularly shaped objects of resolution 2x2°; digital mapping of surface features, including crater densities; taking photometric data; and doing geophysical calculations of surface potential energies, moments of inertia, and stresses. Generated preliminary digital shape models of Phobos, Deimos, Proteus, and Epimetheus. Made preliminary surface potential energy maps of Phobos during its orbital evolution.

c) Work this year

Complete the digital shapes of the six small satellites, make digital geologic maps of all, normal albedo maps of two, and finish study of tidal effects on ejecta distribution on small satellites.

d) Summary Bibliography

Thomas, P. C. 1989. The shapes of small satellites. *Icarus 77*, 248-274.

Dermott and Thomas 1990. Shapes, masses and interiors of satellites, *Adv. Space. Res. 10*, 165-172.

Thomas, P. C., 1990. Small satellites and asteroids: Scale variation of topography and shapes, NASA TM 4210 130-132.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Donald L. Turcotte
Dept. of Geological Sciences, Snee Hall
Cornell University, Ithaca, NY 14853-1504
(607) 255-5267

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Implications of Convection Within the Moon and the Terrestrial Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The principal objective of the proposed research is to utilize the data from the Magellan Mission to constrain models for the thermal and chemical evolution of Venus. The focus of our efforts will be on rates of crustal formation (volcanism), crustal thickness, mechanisms of crustal recycling, and the origin of topography and gravity anomalies.

b. During the past year we proceeded with our efforts to model the thermal evolution of Mars and Venus. We also carried out a series of small projects motivated by data from the Magellan project.

c. (1) A series of parameterized convection calculations will be carried out in order to model crustal growth and recycling and lithospheric structure on Venus.

(2) Models for crustal recycling will be developed to better understand the process.

d. D.L. Turcotte, A heat-pipe mechanism for volcanism and tectonics on Venus, J. Geophys. Res. 94, 2779-2785 (1989).

D.L. Turcotte and J. Huang, Implications of crustal formation on Mars for parameterized convection calculations, Lunar Planet. Sci. XXI, 1266-1267 (1990)

<u>PROPOSAL SUMMARY</u>

PRINCIPAL INVESTIGATOR: G. Leonard Tyler (415-723-3535)
Center for Radar Astronomy (Durand Bldg - Room 232)
Stanford University
Stanford, CA 94305-4055

ASSOCIATE INVESTIGATOR: Richard A. Simpson

ABSTRACT:

(a) Overall Objectives: Radiowave scattering is an effective and important method for remotely studying planetary surfaces; on cloud covered bodies it is the *only* means by which surface mapping on a global scale can be carried out. The radio waves interact most strongly with surface structure having dimensions comparable to, and slightly larger than, the radio wavelength (centimeters to a few meters for modern radar systems). But it is precisely this scale range which has been most difficult for theorists to incorporate in their scattering models. As a result, interpretation today relies heavily on rather simple tools and concepts now more than twenty years old -- tools which are totally inadequate for explaining important phenomena such as high angle scattering and wavelength dependence. With missions such as Magellan now in progress and Cassini on the horizon, it is essential that we improve our interpretive base.

Recent advances in numerical techniques and computer technology, as well as some changes in analysis direction, offer the promise of new interpretive techniques. Numerical codes developed for scattering studies supported largely by the Departments of Defense and Energy are now becoming generally available. At the same time computers themselves have been improved to the point where those commonly available can handle the enormous arrays and millions of operations necessary to solve these problems. One of our early objectives has been to survey the software available for numerical electromagnetics, obtain and convert those programs which seemed most promising for planetary applications, and test them on simple problems which have known (or easily derived solutions). Our current and future objective is to develop surface models useful in the planetary context, apply the new tools, and compare the results with measurements and planetary data sets.

(b) Progress Report: (i) Although no single code is useful in a *wide* range of planetary problems, the Numerical Electromagnetic Code (NEC) appears to be promising for several important applications. It calculates charges, currents, and radiation patterns from structures defined in terms of wires and/or surface patches. Tests on canonical objects (cubes, cylinders, and spheres) show good agreement with theory. Recent progress has been interrupted by a change in computer systems, but porting the 10000 lines of FORTRAN code to a RISC workstation has been successful. (ii) Scattering by icy surfaces has become a subject of considerable interest recently with reports of intermittent anomalous radar scattering from Titan and early development of the Cassini Radar Mapper. We have examined the potential for conducting bistatic radar experiments using Cassini (and also Mars Observer and Galileo) with an objective of inferring centimeter to meter-scale surface properties and texture from the characteristics of the bistatic echo.

(c) Task Summary for Next Year: We propose to begin using NEC for scattering studies and broadening the range of problems it can address. We will also complete our analysis of bistatic planetary experiments.

(d) Summary Bibliography: One abstract published in NASA TM; chapter on radar determination of Mars' surface properties for *Mars* (Univ. Ariz. Press, in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James R. Underwood, Jr.
(Name, Address, Telephone Number) Department of Geology, Kansas State University
Manhattan, KS 66506-3201
913-532-6724

Co-INVESTIGATORS: (Name Only) None

PROPOSAL TITLE: Photogeologic Studies of Selected Features on Mars: Claritas Fossae

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. Overall objectives and justification of work.

1. Investigate the character, geologic history, and significance of Claritas Fossae system and its coincident rise.
2. Investigate the relation between the Claritas Fossae system and other major tectonic systems with which it is associated, i.e. those of Thaumasia Fossae to the south and Noctis Labyrinthus to the north.
3. Investigate relatively small-scale volcanic centers in, or marginal to, the Claritas Fossae system.
4. Coordinate the response to the reviews of map and text of Galileo Regio (Jg-3) quadrangle, as part of Galilean Satellite Geologic Mapping Program.
5. Serve as a member of Program Development Committee for Planetary Geosciences.
6. Serve as a member of Ad Hoc Panel for NASA's 1:5,000,000 Venus Geologic Mapping Program.

B. Progress

1. Requested of USGS Flagstaff 1:2,000,000-scale photomosaic base maps of all of Claritas Fossae, including its intersection with Noctis Labyrinthus to the north and Thaumasia Fossae to the south.
2. Mapping at the 1:2,000,000 scale is underway.
3. Draft maps of the two 1:500,000 Claritas Fossae quadrangles are being reviewed and revised.
4. Final revision and author review of the Galileo Regio quandrangle, Ganymede, is being completed.
5. Attended the semi-annual Planetary Geosciences Program Development Committee meeting , January 8-9, 1992 at Ball Aerospace, Arlington, Virginia.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Professor Joseph Veverka
310 Space Sciences Bldg.
Cornell University
Ithaca, NY 14853

CO-INVESTIGATORS: (Name Only)
Dr. Paul Helfenstein

PROPOSAL TITLE: "Study of the Effects of Photometric Geometry on Spectral Reflectance Measurements"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) General: Investigate how spectrophotometric properties of planetary materials depend on photometric geometry by refining and applying radiative transfer theory to data obtained from 1) spacecraft and telescope observations of planetary surfaces; 2) goniometric studies of laboratory analogs; and 3) computer simulations. Assess physical interpretation of photometric parameters in the context of planetary surface geological properties and processes.

Specific: To further test and extend Hapke's photometric model; to apply the model to observations of planetary/satellite surfaces and to laboratory analogs.

b) PROGRESS DURING LAST THREE-YEAR CYCLE:

1) Continued refinement of Hapke fitting techniques, including efficient methods of deriving parameters for individual terrains, means of accounting for thin atmospheric hazes, and use of two-term Henyey-Greenstein (HG) phase functions.

2) Studied impact of using a 2-term HG phase function (rather than a 1-term) in applications of Hapke's theory. In general, using a 2-term function leads to decreased estimates of macroscopic roughness θ.

3) Demonstrated ability to measure phase functions of regolith particles out to phase angles of 160°.

4) Developed two-component regolith mixing model and applied it successfully to interpretation of Oberon color photometry.

c) PROPOSED WORK FOR NEXT THREE-YEAR CYCLE:

1) Apply mixing model to satellite data to characterize "end members" in different satellite systems.

2) Extend 2-component mixing model to multi-component case; derive mixing equations for parameters other than $\bar{\omega}_0$ and g; investigate tests to discriminate between "checkerboard" and "intimate" mixing models.

3) Continue laboratory measurements of regolith particle phase functions out to 160°. Use lunar data (including from Galileo) to constrain actual phase function of lunar regolith particles.

4) Use Galileo data to refine lunar Hapke parameters given by Helfenstein and Veverka (1987).

5) Compile, analyze, and distribute comprehensive data set of Hapke parameters for satellites (average and terrain specific); derive and provide corresponding simplified analytic approximations to full Hapke functions.

d) SUMMARY BIBLIOGRAPHY

Helfenstein and Veverka (1991), *Icarus 90*, 14-79.

Verbiscer et al. (1990). *Nature 347*, 162-164, and 7 other publications listed in Summary Bibliography on page 27.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Professor Joseph Veverka
310 Space Sciences Building
Cornell University, Ithaca, NY 14853
607-255-3507

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: "Physical Studies of Planetary and Satellite Surfaces"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

Aim: Continue study of physical properties of planetary and satellite surfaces with emphasis on photometry, comparative morphology, and regolith processes.

PROGRESS REPORT

Recent Progress:

1) Completed whole-disk photometric study of Triton using Voyager 2 images.
2) Completed several comprehensive investigations of color and photometry of icy satellites of Saturn (Mimas and Enceladus) and Uranus (Oberon).
3) Completed studies of Neptune's small satellites using Voyager 2 data.
4) Extended Hapke's theory to anisotropic multiple scattering and applied technique to Enceladus and Triton.
5) Completed roughness analysis of Ariel.
6) Published several comprehensive review papers.

Proposed Work for Coming Year:

1) Complete detailed photometric study of Triton terrains and hazes using disk-resolved data.
2) Characterize newly discovered photometrically anomalous area on Triton.
3) Continue studies of frosts on Callisto and Ganymede to determine scattering properties for comparison with frosts on other satellites.
4) Complete color/photometry investigations of terrains on Ariel.
5) Continue investigations of small satellites concentrating on refined analysis of Phoebe, Hyperion, and Amalthea data.
6) Pursue photometric and radiometric studies of individual areas on Io, using Voyager data.

Summary Bibliography:

Verbiscer and Veverka (1990) (*Icarus 88*, 418-428).
Hillier et al. (1990). (*Science 250*, 417-421); and 16 other papers listed in recent bibliography on page 14.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Dr. William R. Ward
Jet Propulsion Laboratory
(818) 354-2594 FTS 792-2594

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Dynamical Evolution of the Solar System

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a). Tasks 1-4 concentrate on problems of the dynamical evolution of solar system bodies; particularly, the role of Secular spin-orbit resonances in the behavior of planetary obliquities. Tasks 5-9 continue a program to model aspects of solar system formation, especially the role of planetnebula tidal interactions. Task 1 develops a theory of resonance overlap for secular spin-orbit resonances. Task 2 updates models of the Mars obliquity history in the light of new work on secular orbit theory. Task 3 explores a possible resonant constraint on giant planet contraction models. Task 4 develops a stream-line model of horseshoe orbit drag that can be used to study torque saturation. Task 5 investigates the influence of density wave torques on end-stage accretion time scales. Task 6 models the effects of disc tides on nebula structure. Task 7 explores the role of disc tides in establishing and maintaining orbit-orbit resonances among accreting protoplanets. Task 8 studies density waves in disc composed of small planetesimals. Task 9 describes current efforts to improve torque models.

(b). A chapter on long-term dynamical evolution of Mars was written for the upcoming book from U. of A. A paper on possible resonance obliquity for Mars has been submitted to Nature. Two papers have been published in Ap. J., one on the rapid formation of giant planet cores, the other on orbital migration of protoplanets due to tidal torques. Several talks and university seminars were delivered during the last year.

(c). Long-term evolution of a spin axis making repeated passages through overlapping secular resonances will be studied and applied to Mars, the earth and Jupiter. The torque saturation of a horseshoe orbit region will be modeled. Several papers in progress on density wave effects in the solar nebula will be brought to completion.

(d). Ward, W. R., On the rapid formation of giant planet cores, Ap. J. Lett, 345, L99-L102, 1989. Ward, W. R., and Hourigan, K., Orbital Migration of protoplanets, Ap. J., 347, 490-495, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Stephen G. Warren
Dept. Atmospheric Sciences AK-40, Univ. of Washington, Seattle, WA 98195. 206-543-7230

Co-INVESTIGATORS: (Name Only) Conway B. Leovy

PROPOSAL TITLE: Optical properties of CO_2-ice and CO_2-snow in the ultraviolet, visible and infrared

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The spectral absorption coefficient of pure CO_2 ice will be measured in the weakly absorbing regions of the near-ultraviolet, visible and infrared, 0.15-100 μm wavelength. We will use our recently developed method of growing thick clear samples of CO_2 ice. The spectral absorption coefficient is needed for understanding the reflection, absorption, transmission and emission of radiation by particulate media containing CO_2 ice. We will use it to model the spectral albedo and emissivity of clouds and surface frosts in the polar regions of Mars. These in turn we will use to determine a strategy for remote sensing of optical thickness, particle size, water-ice content and dust content.

b) (previous grant, June 1989-present) We have succeeded in growing clear samples of 40 mm optical path in a thermally isolated chamber which can be cooled to any desired temperature > 20 K. We can grow samples at any temperature below about 170 K and of thickness 1.6-107.5 mm. Most of the necessary sources, optics and detectors for transmission spectroscopy for 0.15-4.8 μm have been procured, or designed and fabricated, and tested.

c) Samples of five different thicknesses and two different temperatures will be grown, and their transmission compared to a reference will be measured. This will be done using a grating monochrometer for 0.15-4.8 μm and a Fourier-transform interferometer for 2.5-100 μm. The measurements can be reduced to absorption coefficient and index of refraction by linear regression.

d) S. G. Warren, 1986: Optical constants of carbon dioxide ice. *Applied Optics, 25,* 2650-2674.

S.G. Warren, W.J. Wiscombe and J.F. Firestone, 1990: Spectral albedo and emissivity of CO_2 snow in Martian polar caps: Model results. *J. Geophys. Res., 95,* 14717-14742.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) Thomas R. Watters
National Air and Space Museum
Smithsonian Institution
Washington, DC 20560 (202) 357-1424

Co-INVESTIGATORS: (Name Only) Ted A. Maxwell

PROPOSAL TITLE: Geologic and Tectonic Evolution of Southwest Lunae Planum

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

ABSTRACT:

a) This proposal is intended to be considered for a 1-year renewal of the study of the geologic and tectonic evolution of a portion of southwest Lunae Planum. This proposed research involves understanding the origin of certain structural and erosional features that will be mapped and analyzed at the 1:500,000 scale of the Mars Transverse Mercator (MTM) photomosaic maps. The objectives of the proposed research are to: 1) provide detailed geologic maps of southwest Lunae Planum using MTM 05077, 05072 and 00072; 2) constrain the nature and timing of tectonic events in southwest Lunae Planum; and 3) constrain the nature and timing of resurfacing events in Hebes and Echus Chasma.

b) During the past year the mapping of MTM 05077 and 05072 has been completed and work has been initiated on MTM 00072. This map will be completed at the end of this funding year. A wrinkle ridge-fault scarp transition that occurs in MTM 05072 has been investigated and wrinkle ridge crosscutting relationships in 00072 are being be analyzed.

c) In the fourth year of this study, funds are requested to partially support work related to the review of other MTM maps and to attend the mapping meetings.

d) Watters, T.R., The origin of periodically spaced wrinkle ridges on the Tharsis Plateau of Mars, J. Geophy. Res., in press, 1991.

Watters, T.R. and R.A. Craddock, Nature and origin of wrinkle ridges in the floor material of Kasei Valles, Mars, LPSC XXII, 1475-1476, 1991.

Watters, T.R., M.J. Tuttle and D. Simpson, Wrinkle ridge-upland scarp transitions: Implications for the mechanical properties of the deformed materials, LPSC XXII, 1477-1478, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Stuart J. Weidenschilling
Planetary Science Institute
2421 E. 6th Street, Tucson AZ 85719
602/881-0332

CO-INVESTIGATORS: (Name Only)

Clark R. Chapman
Donald R. Davis

PROPOSAL TITLE: Aerodynamic and Gasdynamic Effects in Cosmogony

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The goal of this program is to understand the role of aerodynamic and gas-dynamic phenomena in the formation of the planetary system from the primitive solar nebula. Its scope includes interactions of the nebular gas and bodies ranging in size from dust grains to protoplanets. This contract also provides partial support for C.R. Chapman's duties as Editor of *JGR-Planets*.

(b) Funding not yet received. Under the previous contract, we carried out numerical and analytical investigation of resonances with PR drag as an analog of gas-drag-stabilized resonances in the solar nebula. We constructed numerical models of coagulation and settling of dust in the solar nebula with "generic" turbulence, and examined effects of turbulent velocities on the rate of dust evolution.

(c) We will evaluate the scenario for rapid formation of Jupiter-zone planetesimals by H_2O enhancement, develop a 2-D dust coagulation model for both vertical and radial variation of particle size, and also determine effects of passage through interior resonances with Jupiter in the presence of gas, to evaluate effects on the formation of the asteroids.

(d) Physics of planetesimal formation, S.J. Weidenschilling, B. Donn and P. Meakin, in *Formation and Evolution of Planetary Systems*, H. Weaver and L. Danly, Eds., Cambridge Univ. Press, pp. 131-150 (1989). Radial mixing of material in the asteroidal zone, T.V. Ruzmaikina, V.S. Safronov, and S.J. Weidenschilling, in *Asteroids II*, R. Binzel *et al.*, Eds., U. of Arizona Press, pp. 681-700 (1989). Formation of planetesimals in the solar nebula, S.J. Weidenschilling and J. Cuzzi, to appear in *Protostars and Planets III* (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Stuart J. Weidenschilling
Planetary Science Institute
2421 E. 6th Street, Tucson AZ 85719
602/881-0332

CO-INVESTIGATORS: (Name Only)
Donald R. Davis

SCIENTIFIC COLLABORATOR: Francesco Marzari

PROPOSAL TITLE: Accretion and Evolution of Solar System Bodies

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Goals: The purpose of this research program is to study physical and dynamical processes involved in the formation of the planets and smaller bodies in the solar system, using analytic and numerical techniques. The focus of the present proposal is the use of a new numerical simulation code to model the accretional evolution of a planetesimal swarm interacting over a range of heliocentric distances.

(b) Recent Progress: We have tested our numerical code against a new analytic coagulation problem with "runaway" growth, and confirmed its accuracy in that case. We added algorithms for treating large planetesimals (embryos) as discrete bodies, and performed simulations of accretion in multiple interacting heliocentric distance zones. A major paper describing our code and methods was completed and accepted for publication.

(c) Proposed Research: We will apply our code to model accretion of the cores of the giant planets in the outer solar system. We will also model accretion in the outer solar system. We will also model accretion in the asteroid zone, including effects of a proto-jovian core, and examine scenarios for early removal of mass from the asteroid zone.

(d) Summary Bibliography: Stirring of a planetesimal swarm: The role of distant encounters, S.J. Weidenschilling, *Icarus* **80**, 179 (1989). Multizone accretional evolution of planetesimal swarms, D. Spaute, D.R. Davis, S.J. Weidenschilling, *Adv. Space. Res.*, **10**, (3) 109 (1990). Accretional evolution of a planetesimal swarm: I. A new simulation, D. Spaute, S.J. Weidenschilling, D.R. Davis, and F. Marzari, *Icarus*, in press (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number): Paul R. Weissman
Jet Propulsion Laboratory, Mail stop 183-601
4800 Oak Grove Drive, Pasadena, CA 91109
(818) 354-2636 FTS 792-2636

CO-INVESTIGATORS: (Name Only): None

PROPOSAL TITLE: Cometary Physics and Dynamics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Physical and dynamical studies of comets are important to studies of the origin and evolution of the solar system, of the cratering histories of the planets and their satellite systems, of the role of comets in supplying the volatile inventories of the terrestrial planets, of the role of comet vs. asteroid impacts on the Earth in initiating biological extinctions, and in planning for future NASA missions to comets. This task uses a variety of modeling techniques to perform computer based studies of the dynamics of comets in the Oort cloud and the thermal evolution of cometary nuclei, comparing results to observations wherever possible.

b. A study of the estimated angular momentum of the Oort cloud was completed. It was shown that most of the angular momentum in the cometary cloud is the result of the action of external perturbers, and that the angular momentum extracted from the outer proto-planets during the formation of the solar system is consistent with current hypotheses regarding planetary formation. Thermal modeling of comet Kopff in support of the CRAF mission was undertaken. It was shown that the obliquity of the nucleus could lead to highly asymmetric gas production rates at large solar distances, and could result in substantial cometary activity soon after CRAF rendezvous, at 4 AU from the Sun or greater. Also, the nucleus obliquity has considerable effect on the choice of suitably cold surface and subsurface sampling sites, in the event that such an experiment is carried on a cometary mission.

c. In the coming year, work will continue on the development of a new Oort cloud dynamical simulation program including the effects of stars, GMC's and galactic tides. Thermal modeling of short-period comets Tempel 2 and Wild 2 in support of the CRAF mission will continue. In addition, thermal modeling of Chiron and other outer solar system bodies will begin.

d. Weissman, P. R., The Oort cloud, Nature **344**, 825-830, 1990. Weissman, P. R., The angular momentum of the Oort cloud, Icarus **89**, 190-193, 1991. Stern, S. A., Stocke, J., and Weissman, P. R., An IRAS search for extra-solar Oort clouds, Icarus, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) George W. Wetherill
Department of Terrestrial Magnetism
Carnegie Institution of Washington
5241 Broad Branch Road NW, Wash., DC 20015
(202) 686-4370

Co-INVESTIGATORS: (Name Only) None

PROPOSAL TITLE: Accumulation of the Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Investigations are being made into numerical and theoretical problems of planetary system formation, together with dynamical studies of the present Solar System relevant to planetary origin. The long range goal of this work, complemented by extensive work elsewhere, is to quantitatively model major processes and events of Solar System history that can be compared with observational data.

b. (1) Extended modelling of the final stage of planetary growth to simultaneously include the asteroidal and terrestrial planet regions.
(2) Extended calculations of runaway growth of planetesimals to include both eccentricity and inclination changes, and solar-embryo-planetesimal 3-body effects.
(3) Completed and published work demonstrating the validity of my somewhat unusual quasi-Lagrangian approach to runaway growth calculations by comparison with analytical solutions of the coagulation equation.
(4) Published a comprehensive review article concerning the formation of the Earth, its relationship to the origin of the Solar System, and to the initial chemical and physical state of the Earth.

c. During the proposed three year period, particular emphasis will be placed on:
(1) further exploring the relationship between terrestrial planet, asteroid, and meteorite origin and the gas content of the nebula;
(2) extending runaway embryo growth calculations into the final stage of terrestrial planet evolution;
(3) continuing the effort to relate the residual small body population to the early lunar and terrestrial cratering records;
(4) identifying the relationship between variants of current Earth accumulation models regarding the impact, thermal, and chemical history of the early Earth.

d. Wetherill, G. W. Comparison of analytical and physical modelling of planetesimal accumulation. Icarus 88, 336-354, 1990.
Wetherill, G. W. Formation of the Earth. Ann. Rev. Earth Planet. Sci. 18, 205-256, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)
Dr. Fred L. Whipple
Smithsonian Institution Astrophysical Observato
60 Garden Street, Cambridge, MA 02138
(617)495-7200 or FTS 830-7200

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: Study of the Physics of Cometary Nuclei

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a) This study of comets concerns the basic nature, origin, aging and differences, if any, of long-period (LP) comets versus short-period (SP) comets. The broader objective is to improve our understanding of comets as a part of the evolution of the Solar System and particularly their possible contributions to the Earth and life on the Earth. These concepts would be considerably altered were the short-period comets shown to be formed in a different part of the primitive solar nebula than the long-period comets.

b) Recently the author has developed an activity index measuring the observed increase of a comet's brightness from a state of relative inactivity at great solar distances to its maximum activity near perihelion. Early results fail to suggest aging among LP comets or other than a common nature for comets generally. Small comets appear statistically to be as active as larger ones.

c) The current effort is the development of a volatility index for comets, to measure the variation in a comet's activity at the time of its maximum brightness near perihelion. The purpose is to provide another comparative criterion for comet aging and nature, short-period versus long-period etc. The current intent is to continue the present studies and to concentrate on seeking criteria that measures ages and aging among the SP comets and LP comets.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. J.L. Whitford-Stark
(Name, Address, Telephone Number) Geology Dept. Sul Ross State University
Alpine, TX 79832 (915)-837-8083

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Correlation of eruption conditions and compositions of lunar lavas

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

---

a) The objectives of the proposed research are to document variations in eruption conditions as related to composition of lunar lavas. The composition will be defined in terms of spectral types as outlined by Pieters. The study will be restricted to flows containing sinuous rilles since these are the most readily identified. The work will involve the construction of a database containing the locations, dimensions, lava type, and stratigraphic ages of the rilled flows. This database will hopefully show if there are any variations in eruption conditions between very low, low, intermediate, and high titanium lunar lavas as a function of their ages. Although sinuous rilles have been studied in detail in the past, there have been no previous attempts to make correlations with composition or age.

b) New proposal

c) The rilles will be mapped and their locations noted, along with the spectral type of the enclosing lava. The dimensions of the rilles will be noted along with their stratigraphic ages. This will be compiled in a database and analyzed.

d) Whitford-Stark, J.L. 1982 Factors influencing the morphology of volcanic landform an Earth-Moon comparison. Earth Science Reviews 18, 109-168.
Whitford-Stark, J.L. 1990, Lunar Maria. Magill's Survey of Science: Earth Science Series p. 1408-1413.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James G. Williams
JPL, 238-332
Pasadena, CA 91109
(818) 354-6466, FTS 792-6466

TITLE: Solar System Dynamics - Asteroids

a. Objectives: 1) Discover, define, and study asteroid families, the fragments of former collisions, to examine the interiors of former parent bodies. Physical properties data indicate the degree of diffferentiation of the parent body. Size and (imperfect) velocity distributions may be recovered. 2) Theoretical studies of the dynamical evolution of the solar system aid understanding. For example, improvements in the secular perturbations calculations permit new families to be recognized and old ones to be refined.

b. Progress: 1) A paper has been submitted which lists, illustrates and discusses families. General properties and discussions of specific families are given. The search method and statistical filtering are described. 2) A paper on the Alexandra family has been submitted. Alexandra is one of the more important families. It shows considerable structure including a disk. 3) Up to the end of FY'90 astrometric positions were published for 2 comets and 7 planet crossers. 4) Up to the end of FY'90 - a new value of the lunar GM was derived from a joint solution of lunar and planetary range data.

c. Proposed Work: 1) Follow up work on the best families is proposed including size distributions, center-of-mass velocities, and taxonomy. 2) The families need to be extended to higher numbered asteroids. 3) The taxonomy work will be extended to additional data sets when they are available. 4) Theoretical work will be done as needed.

d. Summary Bibliography: 1) 2 papers submitted to Icarus. 2) Astrometric positions were published in the Minor Planet Circulars through the end of FY'90.

PROPOSAL SUMMARY

Principal Investigator: Professor Jack Wisdom
Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139
(617) 253-7730

Proposal Title: SOLAR SYSTEM DYNAMICS

ABSTRACT

(a) We propose to continue our investigations of dynamical processes in the solar system. Our goal is to gain a better understanding of our solar system from the dynamical processes which have shaped it and govern its motions, particularly in the light of recent advances in our understanding of non-linear dynamical systems.

(b) We have developed a new algorithm for the numerical integration of the planetary n-body problem which is more than an order of magnitude faster than conventional methods. We have used this new method to carry out several new billion-year integrations of the outer planets which confirm our earlier results that the motion of the planet Pluto is chaotic.

(c) We shall continue our investigations of the dynamics of the solar system. Our new integration method, together with the new Supercomputer Toolkit, will allow us to tackle many problems which were last year out of reach: the evolution of the whole solar system on 100-million year timescales to test the result that the inner planets evolve chaotically, a thorough examination of test-particle stability throughout the solar system, with particular emphasis on the outer solar system, and the detailed study of the transport of meteorites and comets to the vicinity of the Earth. We will continue our studies of the rotational dynamics of satellites, as well as our studies of the tidal evolution of satellite orbits.

(d) Wisdom, J. and Holman, M. (1991) "Symplectic Maps for the N-Body Problem", submitted.

Polvani, L.M. and Wisdom, J., with DeJong, E. and Ingersoll, A. "Simple Dynamical Models of Neptune's Great Dark Spot." *Science* **249**, 1393 (1990).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Charles F. Yoder
Jet Propulsion Laboratory 183-501
4800 Oak Grove Dr., Pasadena, CA 91109
(818) 354-2444 FTS 792-2444

CO-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: DYNAMICAL STUDIES

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. The basic objective of this research is to use dynamical arguments to obtain constraints on the origin and present states of planets, asteroids and planetary satellites. The principal emphasis shall continue to center on my study of orbit-orbit, spin-orbit resonance locks and tidal heating mechanisms. This proposal requests continued funding.

B. IR observations (supplied by P. Nicholson and K. Matthews) of the Saturnian, coorbiter satellites were analyzed and combined with earlier data sets to infer their mean density: 0.65 ± 0.08 gm/cm^3. A plausible range of Mars structural models were used to infer the effects of core size, elasticity and composition on Mars' nutations, polar motion and rotation, 3) Lunar structural models combining Apollo seismic P and S wave profiles of the upper mantle and LLR constraints on core size and Love # k_2 to reveal a potentially significant low S-wave velocity zone below 800 km,

C. A paper on Mars shall be written describing the plausible range of structural parameters and the feasibility of constraining these models from a dedicated geodetic mission. A paper reviewing earlier lunar research on core-mantle compling mechanisms and recent work related to the interpretation of the lunar k_2 detected using laser ranging data shall be written. The ring-torques affecting the coorbiter dynamics (both orbit expansion and libration amplitude change) shall be reexamined.

D. Bonderies, N. and C. F. Yoder (1990) Phobos gravity field and its influence on its orbit and physical librations, Astron. and Astrophys., 233, 235-251.

Yoder, C. F., et al. (1989) Orbits and Masses of Saturn's Coorbiting Satellite, Janus and Epimetheus, Astron. J., 98, 1875-1889.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) James R. Zimbelman, CEPS/NASM, Smithsonian Institution, Washington, DC 20560
(202) 357-1424

Co-INVESTIGATORS: (Name Only)

PROPOSAL TITLE: 1:500,000 Scale Geologic Mapping of the Tharsis Montes on Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objective: Interpretation of the geologic history of materials in the Tharsis Montes region of Mars (17.5°N to 12.5°S, 100°W to 125°W) through geologic mapping of geomorphic characteristics, superposition relationships, and tectonic features on all three volcanoes. The map units will be used to evaluate the contribution from geologic materials to remotely sensed physical properties of the region.

b) Prior year: Base map materials for MTMs -10122, 10102, and 10107 were received at NASM on 1/22/91. Preliminary mapping of Arsia Mons at a scale of 1:2M was completed in preparation for detailed mapping (as reported in Zimbelman, 1991). Submission of maps for MTMs 10102 and 10107 is anticipated by summer, 1991.

c) Proposed Work: 1) Ascraeus Mons: Submit maps of MTMs 10102 and 10107 for review, to be published as one sheet. 2) Arsia Mons: Complete mapping of MTMs -10117 and -10122, once the base materials for -10117 have been delivered. These maps will also be submitted for publication as one sheet. 3) Pavonis Mons: Complete preliminary mapping at a scale of 1:2M, to support later detailed mapping. 4) Tharsis Montes: Compare mapping results from all three volcanoes in a synthesis paper, to be submitted to the Proceedings of the 22nd Lunar and Planetary Science Conference.

d) Bibliography: 1) Zimbelman, J.R. (1991) Preliminary 1:500,000-scale geologic mapping of Arsia Mons, Mars, Lunar and Planetary Science XXII, pp. 1551-1552, Lunar and Planetary Institute, Houston.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: M.T. Zuber
Geodynamics Branch, Code 921
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

(301) 286-2129

CO-INVESTIGATORS: None

PROPOSAL TITLE: Planetary Geophysics and Tectonics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The broad objective of the proposed work is to gain insight into the mechanical structures and stress histories of the lithospheres of the terrestrial planets, with emphasis on Mars and Venus.

(b) During the past year we have: (1) developed a model to constrain the geometry and depth of the magma chamber of the Martian volcano, Olympus Mons; (2) investigated models for the isostatic compensation of Aphrodite Terra, Venus; (3) developed procedures to measure tectonic wavelengths from radar images and interpreted these measurements in terms of the structure of the Venus lithosphere; and (4) participated in the development of a 40^{th} degree and order gravitational field model for Mars.

(c) During the next year we will: (1) Develop numerical models of compressional ridge formation to address the nature of ridge belts on Venus and wrinkle ridges on Mars; and (2) investigate the relationship between the state of stress of volcanic edifices and magma chamber mechanics through the development of analytical and numerical models of caldera formation.

*(d) Zuber, M.T., and L.L. Aist, The shallow structure of the Martian lithosphere in the vicinity of the ridged plains, *J. Geophys. Res.*, *95*, 14215-14230, 1990.

Zuber, M.T., Ridge belts: Evidence for regional- and local-scale deformation on the surface of Venus, *Geophys. Res. Lett.*, *17*, 1369-1372, 1990.

Zuber, M.T., and P.J. Mouginis-Mark, Caldera subsidence and magma chamber depth of the Olympus Mons volcano, Mars, Appendix 1.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE December 1992	3. REPORT TYPE AND DATES COVERED TECHNICAL MEMORANDUM
4. TITLE AND SUBTITLE DIRECTORY OF RESEARCH PROJECTS - PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM		5. FUNDING NUMBERS
6. AUTHOR(S) HENRY HOLT, EDITOR		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA OFFICE OF SPACE SCIENCE AND APPLICATIONS SOLAR SYSTEM EXPLORATION DIVISION		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, DC 20546		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-4428
11. SUPPLEMENTARY NOTES		
12a. DISTRIBUTION/AVAILABILITY STATEMENT UNCLASSIFIED - UNLIMITED SUBJECT CATEGORY 32		12b. DISTRIBUTION CODE

13. ABSTRACT *(minimum 200 words)*

THIS PUBLICATION PROVIDES INFORMATION ABOUT CURRENTLY FUNDED SCIENTIFIC RESEARCH WITHIN THE PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM. THE DIRECTORY CONSISTS OF THE PROPOSAL SUMMARY SHEET FROM EACH PROPOSAL FUNDED UNDER THE PROGRAM DURING FISCAL YEAR 1992. THE SHEETS PROVIDE INFORMATION ABOUT THE RESEARCH PROJECT, INCLUDING TITLE, PRINCIPAL INVESTIGATOR, INSTITUTION, SUMMARY OF RESEARCH OBJECTIVES, PAST ACCOMPLISHMENTS, AND PROPOSED NEW INVESTIGATIONS.

14. SUBJECT TERMS PLANETARY EXPLORATION, PLANETARY GEOLOGY, PLANETARY GEOPHYSICS			15. NUMBER OF PAGES 152 16. PRICE CODE A08
17. SECURITY CLASSIFICATION OF REPORT UNCLASS	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASS	19.SECURITY CLASSIFICATION OF ABSTRACT UNCLASS	20. LIMITATION OF ABSTRACT UNLIMITED