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NASA Technical Memorandum 10288

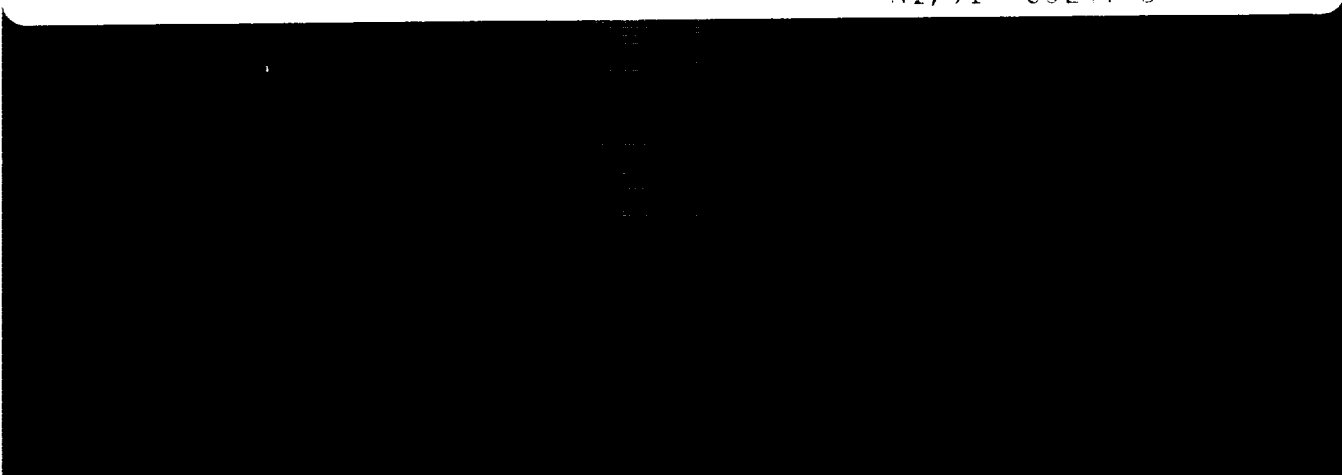
Directory of Research Projects, 1991

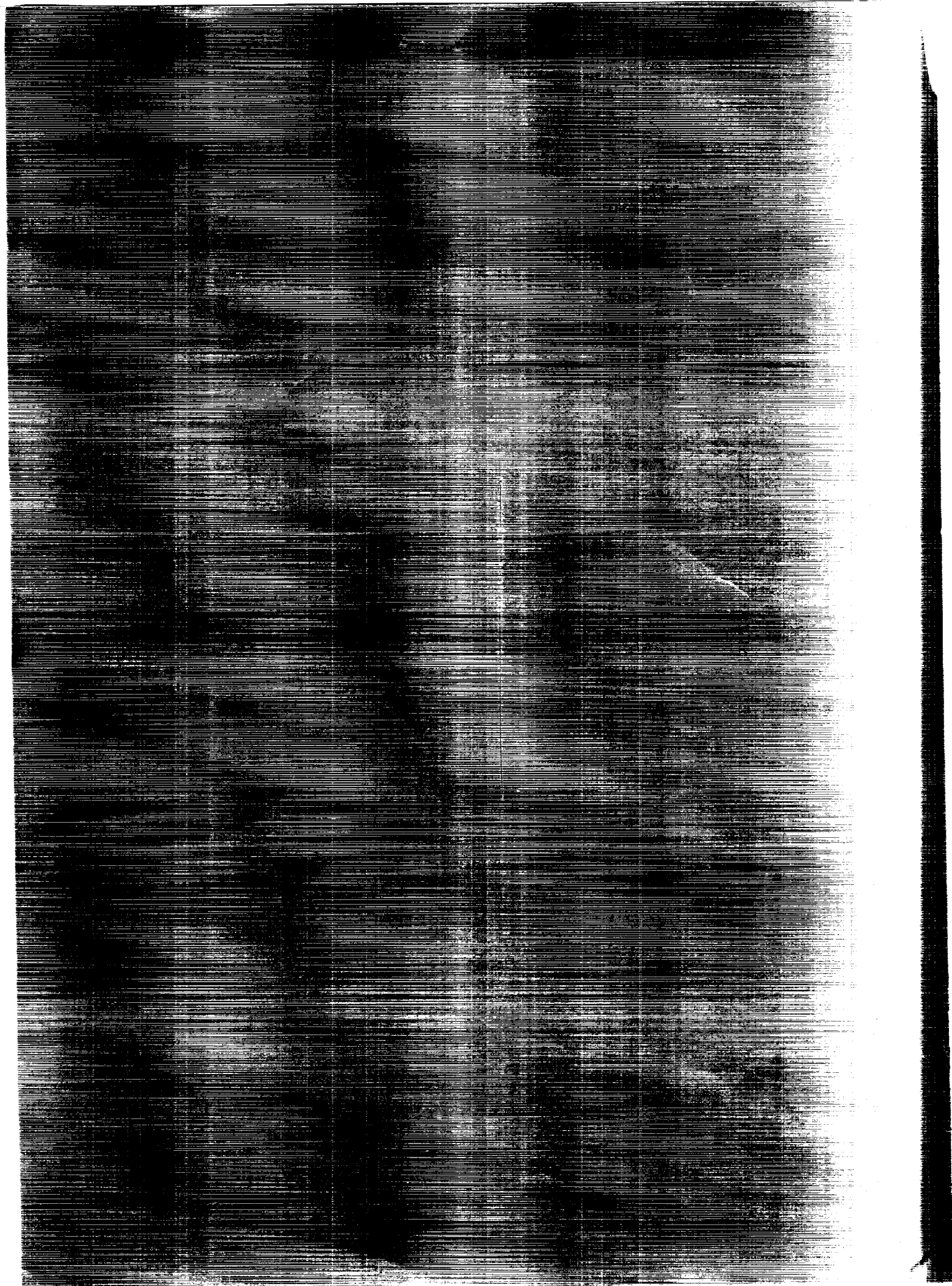
Planetary Geology and Geophysics Program

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NASA Technical Memorandum 4288

Directory of Research Projects, 1991

Planetary Geology and Geophysics Program

Ted A. Maxwell, *Editor*

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



National Aeronautics and
Space Administration

Office of Management

Scientific and Technical
Information Program

1991

INTRODUCTION

This Directory of Research Projects provides information about currently funded scientific investigations within the Planetary Geology and Geophysics (PGG) Program. The Directory consists of the proposal summary sheet from each proposal funded under the PGG Program during fiscal year 1991, covering the period October 1, 1990 - September 30, 1991. The summary sheets provide information about the research project including: title, principal investigator, institution, summary of research objectives, past accomplishments, and proposed new work. This Directory is intended to inform scientists in the PGG Program about research projects supported by the program, and can be utilized by others as a PGG Program information source.

Research projects funded under the PGG Program cover a broad range of topics including: geological mapping, studies of surface features and their origin from imaging results, theoretical and analytical studies of lithosphere - atmosphere interactions, geophysical studies of planetary interiors and surface features, studies of dynamics of planetary and ring formation, remote sensing studies including theory, reflectance characteristics and analysis of observed spectra, and both experimental and terrestrial analog studies of the impact process. In addition, the program is responsible for all aspects of planetary cartography, and provides funding for several facilities in the Planetary Geosciences.

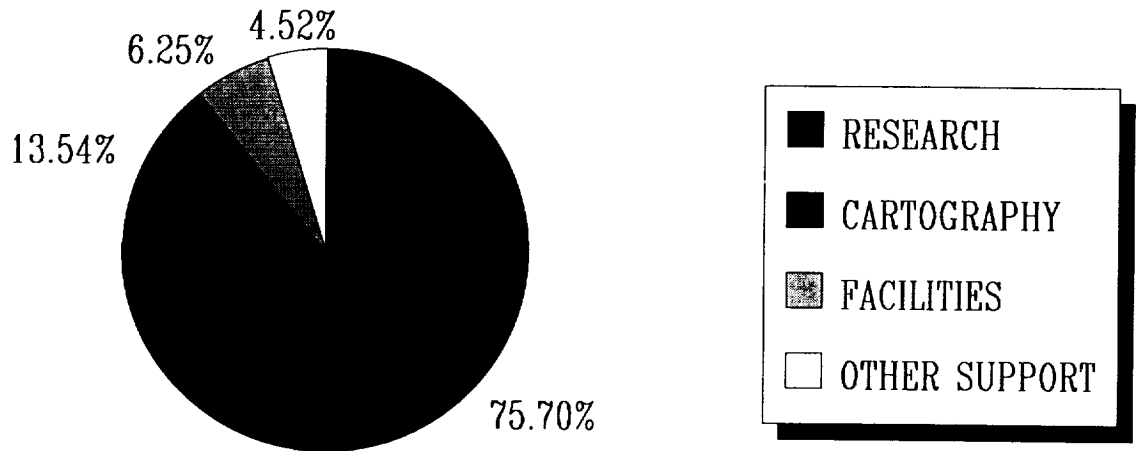
Statistical information about the PGG Program is presented on the next two pages. The following pages consist of an alphabetical listing of Principal Investigators for fiscal year 1991, and the remainder of the Directory consists of the project summaries.

For additional information about the Planetary Geology and Geophysics Program, contact one of the persons below:

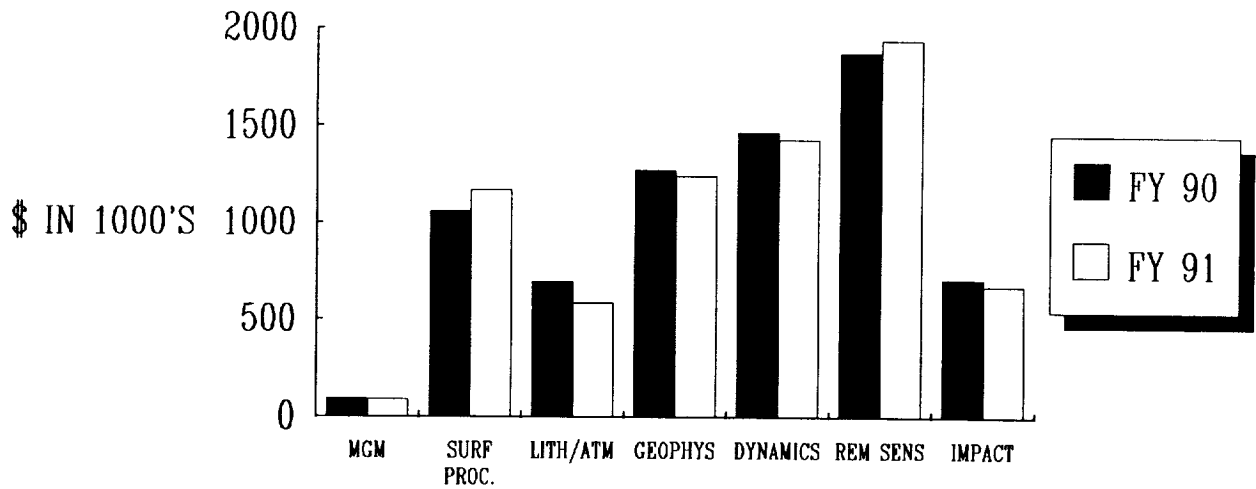
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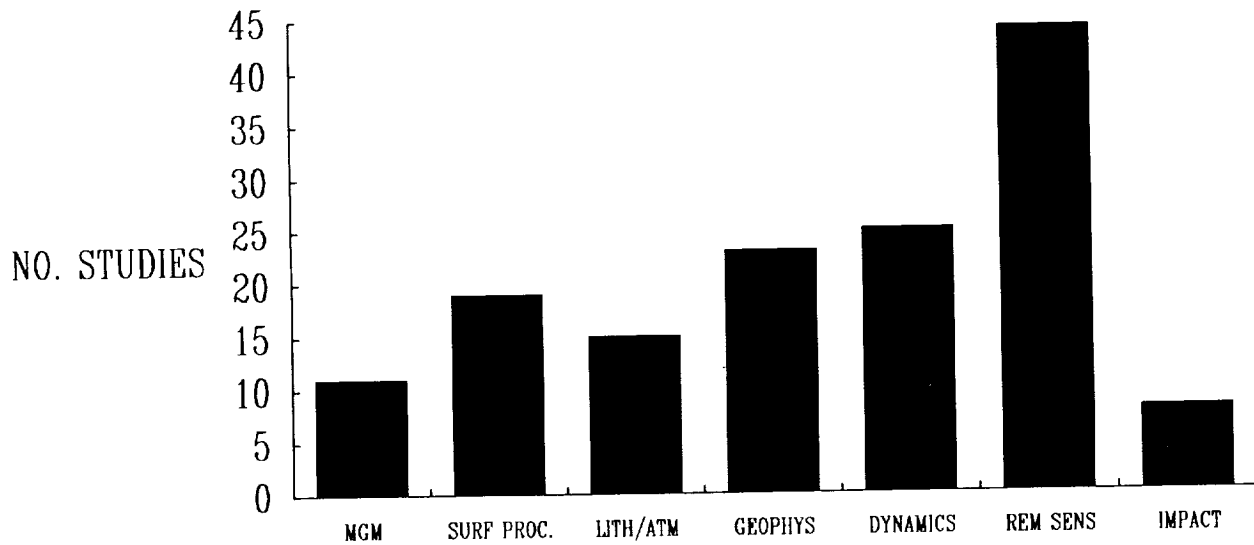
PLANETARY GEOLOGY AND GEOPHYSICS



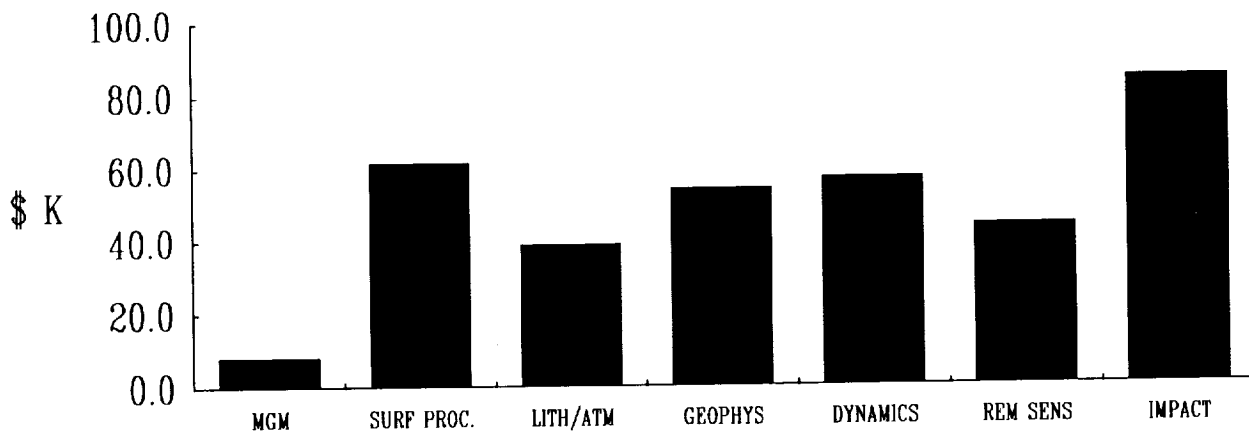
PGG - FUNDING ALLOCATION



PGG - INVESTIGATIONS BY TOPIC



PGG - MEAN GRANT SIZE





PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM
 PRINCIPAL INVESTIGATORS, FISCAL YEAR 1991

INVESTIGATOR	INSTITUTION
Adams, John B.	U WA
Ahrens, Thomas J.	Cal Tech
Arvidson, Raymond E.	Wash U
Baker, Victor R.	U AZ
Baloga, Stephen M.	JPL
Banerdt, W. Bruce	JPL
Batson, Raymond	USGS Flagstaff
Bell, Jeffrey F.	U HI
Boring, John W.	U VA
Boss, Alan	Carnegie Inst. of Wash.
Bridges, Frank	U CA, Santa Cruz
Brown, Robert H.	JPL
Buratti, Bonnie	JPL
Burns, Joseph A.	Cornell
Burns, Roger G.	M.I.T.
Campbell, Donald B.	Cornell
Carr, Michael H.	USGS Menlo Park
Chapman, Mary G.	USGS Flagstaff
Christensen, Philip R.	AZ St U
Clark, Roger N.	USGS Denver
Clow, Gary D.	USGS Menlo Park
Condit, Christopher	U MA, Amherst
Craddock, Robert	Smithsonian
Crisp, Joy A.	JPL
Croft, Stephen K.	U AZ
Crumpler, Larry S.	Brown
Cuzzi, Jeffrey	NASA/ARC
Davies, Merton E.	RAND Corp.
Davis, Donald R.	PSI
Davis, Philip A.	USGS Flagstaff
De Hon, Rene A.	NE LA U
Dermott, Stanley F.	U FL, Gainesville
Durham, William B.	LLNL
England, A. W.	U MI
Eshleman, Von R.	Stanford
Esposito, Larry W.	U CO
Fanale, Fraser P.	U HI
Fink, Jonathan	AZ St U
French, Richard G.	Wellesley
Frey, Herbert	NASA/GSFC
Gaffey, Michael J.	RPI
Gaskell, Robert W.	JPL
Goguen, Jay D.	JPL
Golombek, Matthew P.	JPL

PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM
 PRINCIPAL INVESTIGATORS, FISCAL YEAR 1991

INVESTIGATOR	INSTITUTION
Gooding, James L.	NASA/JSC
Greeley, Ronald	AZ St U
Greenberg, Richard J.	U AZ
Hager, Bradford	M.I.T.
Hapke, Bruce	U Pittsburgh
Harris, Alan W.	JPL
Hartmann, William	PSI
Hawke, Bernard Ray	U HI
Head, James W., III	Brown
Holsapple, Keith A.	U WA
Holt, Henry E.	N AZ U
Hood, Lon L.	U AZ
Howard, Alan D.	U VA
Jakosky, Bruce M.	U CO
Jeanloz, Raymond	U CA, Berkeley
Johnson, Robert E.	U VA
Johnson, Torrence V.	JPL
Kaula, William	UCLA
Kieffer, Susan W.	AZ St U
King, John S.	SUNY, Buffalo
King, Trude	USGS Denver
Kirk, Randolph L.	USGS Flagstaff
Komar, Paul D.	OR St U
Lebofsky, Larry A.	U AZ
Lee, Steven W.	U CO
Levy, Eugene H.	U AZ
Lissauer, Jack J.	SUNY, Stony Brook
Lucchitta, Baerbel	USGS Flagstaff
Lucey, Paul G.	U HI
Lunine, Jonathan I.	U AZ
Malin, Michael C.	Malin Space Sciences Systems
Mao, Ho-Kwang	Carnegie Inst. of Wash.
Martin, Terry Z.	JPL
Matson, Dennis	JPL
Maxwell, Ted A.	Smithsonian
McCord, Thomas B.	U HI
McEwen, Alfred S.	USGS Flagstaff
McFadden, Lucy-Ann	U CA, San Diego
McGill, George E.	U MA, Amherst
McKay, Christopher	NASA/ARC
McKinnon, William B.	Wash U
Melosh, H. J.	U AZ
Metzger, Albert E.	JPL
Moore, Henry J.	USGS Menlo Park
Mouginis-Mark, Peter J.	U HI

PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM
 PRINCIPAL INVESTIGATORS, FISCAL YEAR 1971

INVESTIGATOR	INSTITUTION
Murray, Bruce C.	Cal Tech
Nash, Douglas B.	San Juan Research Inst
Nellis, William J.	LLNL
Nicholson, Philip D.	Cornell
Olson, Peter	Johns Hopkins
Orenberg, James B.	San Francisco St U
Ostro, Steven J.	JPL
Paige, David A.	UCLA
Parmentier, E. M.	Brown
Peale, Stanton J.	U CA, Santa Barbara
Phillips, Roger J.	SMU
Pieters, Carle M.	Brown
Plescia, Jeffrey B.	JPL
Pollack, James B.	NASA/ARC
Porco, Carolyn C.	U AZ
Price, Katherine H.	DePauw U
Richter, Frank M.	U Chicago
Sagan, Carl	Cornell
Salisbury, John W.	Johns Hopkins
Saunders, R. Stephen	JPL
Schaber, Gerald G.	USGS Flagstaff
Schmidt, Robert M.	Boeing
Schubert, Gerald S.	UCLA
Schultz, Peter H.	Brown
Schultz, Richard	U NV, Reno
Scott, David H.	USGS Flagstaff
Sharpton, Virgil L.	LPI
Shoemaker, Eugene M.	USGS Flagstaff
Singer, Robert B.	U AZ
Soderblom, Laurence A.	USGS Flagstaff
Solomon, Sean C.	M.I.T.
Squyres, Steven W.	Cornell
Stevenson, David J.	Cal Tech
Strom, Robert G.	U AZ
Tanaka, Kenneth L.	USGS Flagstaff
Thomas, Peter C.	Cornell
Tittemore, William C.	U AZ
Turcotte, Donald L.	Cornell
Tyler, G. Leonard	Stanford
Underwood, James R., Jr.	KS St U
Veverka, Joseph	Cornell

PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM
PRINCIPAL INVESTIGATORS, FISCAL YEAR 1991

INVESTIGATOR

INSTITUTION

Ward, William R.	JPL
Warren, Stephen G.	U WA
Watters, Thomas	Smithsonian
Weidenschilling, Stuart	PSI
Weissman, Paul R.	JPL
Wetherill, George W.	Carnegie Inst. of Wash
Whipple, Fred L.	Smithsonian Astro. Obs.
Williams, James G.	JPL
Williams, Steven H.	LPI
Wisdom, Jack	M.I.T.
Wu, Sherman	USGS Flagstaff
Yoder, Charles F.	JPL
Zimbelman, James	Smithsonian
Zisk, Stanley	U HI
Zuber, Maria T.	NASA/GSFC

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:

a. Objectives:

We are carrying out experimental research on mechanical and thermodynamic aspects of shock and impact cratering and accretionary processes in 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 of the outer solar system. 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 in the laboratory 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 seismic velocity deficits beneath impact and explosion craters.

b. Accomplishments:

1) We have carried out the first experimental studies of the solubility of Ar in carbon glass in order to both understand how noble gases become dissolved in carbonaceous material in the solar nebulae and to provide sample material to conduct impact devolatilization experiments.

4) conduct further analysis of the equation of state of meteorites and serpentine (in the very high pressure range (> 130 GPa) where anomalous compression is indicated), and construct a model which describes the release isentropes in terms of the equation of state and thermodynamic properties of MgO and H₂O. We also propose to study shock temperatures of serpentine and glassy carbon.

5) conduct further experiments on the cracking and hence density and seismic velocity deficit induced by shock waves in both hemispherical and planar geometry in dry and wet rocks. We expect to examine the data prescribing the regions of velocity deficits beneath such craters as the Ries and Meteor crater and determine what constraints these anomalies can place on the impact process.

d. References

1. Lange, M. A. and Ahrens, T. J., 1987, Impact experiments in low temperature ice, *Icarus*, **69**, p. 506-518.
2. Tyburczy, J. A. and Ahrens, T. J., 1988, Dehydration kinetics of shocked serpentine, *Proceedings of the 18th Lunar and Planetary Science Conference*, Cambridge Univ. Press, p. 435-442.
3. Schmitt, D. R. and Ahrens, T. J., 1989, Shock temperatures in silica glass, *J. Geophys. Res.*, **94**, 5851-5871.
4. Tyburczy, J. A., Krishnamurthy, R. V., Epstein, S., and Ahrens, T. J., 1990, Impact induced devolatilization and hydrogen isotopic fractionation of serpentine: Implications for planetary accretion, *Earth Planet. Sci. Lett.*, in press.
5. Tan, H. and Ahrens, T. J., 1989, Shock-induced polymorphic transition in quartz, carbon, and boron nitride, *J. Appl. Phys.*, **67**, 217-224.
6. Ahrens, T. J., O'Keefe, J. D., and Lange, M.A., 1989, Formation of planetary atmospheres during accretion, in *Origin and Evolution of Planetary and Satellite Atmospheres*, ed. S. K. Atreya, J. B. Pollock, and M. S. Matthews, U. Arizona Press, p. 328-385.

PROPOSAL SUMMARY

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

CO-INVESTIGATORS(S):

TITLE: Impact Cratering Calculations

ABSTRACT:

a. Objectives

To describe and understand the physics of impact cratering, both normal and oblique, on planetary surfaces composed of solid silicates, ices, and their regoliths, as well as impacts into planetary atmosphere 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, ejecta distributions (with regard to size, velocity, energy content, and sorting), and condensation physics of impact produced vapor as well as the impact production of aerosols from the liquid and solid state.

b. Accomplishments

1) We have conducted the first two-dimensional numerical calculation of the normal and oblique impact of a bolide with an exponential atmosphere in a gravity field. The bolide dimension is comparable with the scale height to the atmosphere. For normal and oblique impact the geometry is axi-symmetric and planar (an approximation), respectively. For the case of axi-symmetric impact, we can determine atmospheric energy coupling (5%). Moreover, our results for atmospheric blast wave energy coupling compare favorably to the existing similarity solutions.

2) We have produced an initial planetary accretion model for the early Earth. We combined our experimental data on the impact velocity required to induce a proto-atmosphere via shock devolatilization with the physical model of Abe and Matsui, which describes the thermal regime of the accreting Earth, and with initial calculations (of Holloway) of the oxidation state of the atmosphere coexisting with a hot chondritic assemblage. We estimate the mass of the primary reservoir of un-shocked material and compare this with the inferred reservoir now producing the mantle ^3He flux. We also estimate the bolide energy required to completely blow-off the proto-atmosphere.

3) We conducted cratering calculations over a wide range of effective projectile characteristic dimensions (a) which trades-off with planetary gravity (g) upon scaling using the inverse Froude number, ag/U^2 . Here U is impact velocity. The crater transition depth, D_T , is calculated in terms of the gravity and strength crater scaling relations and we derive an expression which permits

evaluating mean planetary crustal strength from the gravity to strength crater transition depth. Mean crustal strengths of ~5 and 10 kbar are derived for the Earth and Mars, and Mercury and the Moon, respectively, from our present equations and Pike's crater correlations.

4) New techniques for handling very fine impact ejecta were developed and impact produced aerosol-sized ejecta mass yields are determined for low velocity impacts in limestone. The experiments yield 10^{-4} to 10^{-3} , mass fraction, of $1 < \mu\text{m}$ aerosols. This is comparable with earlier experiments of Gault et al., but significantly less than the yields required by the Alvarez et al. extinction scenario.

5) Both the flammability of surface biomass initiated by a K/T impactor and the heating of crustal volatiles from impact required to mobilize molten volcanic rock from a large bolide have also been investigated.

c. Proposed Program

1) Conduct atmospheric impact cratering calculations to determine the mass of atmosphere ejected and lost from a planet (with different mass and base temperature exponential atmospheres) upon impact of different density, diameter, and velocity bolides.

2) Conduct further research on the depth of excavation and crater shape upon impact of large and high-speed bolides on planetary surfaces. The major effect we expect to study is the scaling appropriate for high velocity impacts where shock-induced vaporization accounts for a major fraction of the crater volume. The scaling developed on the basis of chemical explosive tests and experimental impact craters produced by projectiles impacting below 10 km/sec is not expected to be strictly valid in the vaporization regime.

3) We propose to study very large body impacts with a newly written self-gravitating smooth particle hydrodynamic code. We expect to examine partitioning of energy and momentum for different velocity, impact angle and equation of state, as well as the degree of planetary melting and devolatilization.

4) We propose to determine the amount and distribution of aerosol-sized impact ejecta for different targets at different impact velocities.

5) We propose to extend previous work and construct a chemical planetary accretion model which both accounts for the thermal regime of the accreting surface (magma ocean), the radiation budget of the overlying atmosphere and the chemical phase equilibrium between the molten rock and the overlying atmosphere containing phases composed of C, H, O, and S.

d. References

1. Ahrens, T.J., O'Keefe, J.D., and Lange, M.A., 1989, Formation of atmospheres during accretion of the terrestrial planet, *Planet and Satellite Atmospheres: Origin and Evolution*, ed. S. Atreya, J.B. Pollack, and M.S. Matthews. U. Ariz. Press, Tucson, AZ., p. 328-385.
2. Lange, M.A. and Ahrens, T.J., 1989, Atmospheric blow-off during accretion of the terrestrial planetary atmospheres, submitted to *Icarus*.

Chouffe, J.D. and Ahrens, T.J., 1989, Impact produced condensate and droplet size distributions, submitted to *Icarus*.

Chouffe, J.D. and Ahrens, T.J., 1989, Impact production of CO₂ by the K-T extinction bolide and the sudden heating of the Earth, *Nature*, 338, 247–249.

Ahrens, T.J., 1989, Water storage in the mantle, 342, 122–123.

Ahrens, T.J., 1989, Earth accretion, in *Origin of the Earth*, eds. J. Jones and H.E. Newson, Oxford, U. Press., in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Raymond E. Arvidson Telephone No. (314) 889-5609
(Name, Address, Washington University, Earth & Planetary Sciences, Campus Box 1169
Telephone Number) One Brookings Drive, St. Louis, MO 63130

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

PROPOSAL TITLE: "Analysis of Remote Sensing Data for the Surfaces 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. Objectives: Compilation of GRSFE data base for publication by Planetary Data System on 8 CDROMs for community use. Analyses of relevant Goldstone, Arecibo, Viking remote sensing data to determine surface properties of Venus and Mars and to infer resurfacing histories. Analyses of GRSFE data to test validity of radiative transfer models for visible through microwave remote sensing observations:
- B. Accomplishments: Flew GRSFE and acquired 5 gigabytes of data in July and September, 1989. Began generation of GRSFE archive. Helped generate pre-Magellan review of aeolian processes on Venus and led effort to develop pre-Magellan crater resurfacing models. Calibrated and analyzed Goldstone Venus data. Evaluated martian surface properties using IRTM and multi-emission angle VIS data. Analyzed multi-emission angle ASAS images over Lunar Crater Volcanic Field, Nevada, to test Hapke function.
- C. Proposed Work: Complete GRSFE archive, publish through PDS on 8 CDROMs for community release at special GRSFE session at spring 1991 AGU. Continue analyses of surface properties of Mars and test of models using GRSFE data.
- D. Publications: Arvidson et al, 1990, LPSc XX Proceed., 557-572; Arvidson et al, 1989; Rev. Geophys., 27, 39-60; Arvidson, Encyc. Physical Sci. Tech., 78-98; Guinness and Arvidson, JGR, in press; Gooding, Arvidson, et al, Mars book chapter, in press; Greeley and Arvidson, Earth, Moon, Planets, submitted.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Victor R. Baker
(Name, Address, Telephone Number) Department of Geosciences, University of Arizona
Tucson, AZ 85721 - (602) 621-6003

Co-INVESTIGATORS: William D. Sellers
(Name Only) Virginia C. Gulick

PROPOSAL TITLE: Martian Paleohydrological Cycles

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:** 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.
- B. **Progress:** This new proposal extends a prior Planetary Geology and Geophysics project concerned with the geomorphology of channels and valleys on Mars. Progress in that study included: (1) Discovery of the ocean-land-atmosphere mechanism for cyclic climatic change on Mars (Baker et al., 1990), (2) Development of the hydrothermal model to explain Martian valley formation (Gulick and Baker, 1989), (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:** 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.
- D. **Publications:**
Baker, et al., 1990, Ancient ocean-land-atmosphere interactions on Mars: Global model and geological evidence: Lunar and Planet. Sci. Conf. 21, p. 40-41.
Gulick, V.C., and Baker, V.R., 1989, Fluvial valleys and martian paleoclimates: Nature, v. 341, p. 514-561.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Stephen M. Baloga
Jet Propulsion Laboratory
MS. 183-501
4800 Oak Grove Dr.
Pasadena CA, 91109
(818) 354-2039

CO-INVESTIGATORS: Joy A. Crisp, Jeffrey B. Plescia

PROPOSAL TITLE: QUANTITATIVE STUDIES IN PLANETARY VOLCANISM

OBJECTIVES: The overall objective is to improve the quantitative understanding of physical processes in planetary volcanism, particularly 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 lava flows and apply the results to lava flows on selected volcanoes on Mars, 2) To develop new energy balances for explosive eruption columns on Mars that incorporate Stefan-Boltzmann radiation and particle losses and investigate the role of large scale fumarolic activity in the formation of selected surface features on Mars, 3) To develop quantitative constraints on the source of magma supply from lava flow and flow fields on Mars, and 4) To determine whether the composition of lobate and sheet flows on Io is sulfur or silicate.

PROGRESS : Corresponding to the above objectives, recent progress has been: 1) Published two papers on heat losses from lava flows during emplacement. Completed data analysis of topographic influences during flow emplacement for Puu Oo 1983-1984 eruption. Derived equations for flow over an irregular or random topography. Submitted one paper to Phys. Rev. Lett. on methods for an "inversion" problem to determine rheology from kinematics 2) Reformulated the original equations for buoyant plumes and obtained energy integrals. Solved the system of equations for buoyant plumes in a neutral atmosphere, but issuing from extended sources, such as large scale volcanic sources.

PROPOSED WORK: Corresponding to the above objectives, 1) Incorporate recent fluid mechanics developments for flow over irregular topography into existing models for lava emplacement; Complete statistical analysis of terrestrial data on the response of flowing lava to topographic changes; Compare theoretical predictions with terrestrial and planetary data, 2) Complete the investigation of the role of large scale fumarolic (buoyant plume) activity in the formation of channel-like forms on the flanks of certain volcanoes on Mars; Complete new energy balances for volcanic plumes and re-assess existing thoughts on explosive volcanism on Mars, 3) Investigate major magmatic supply and flow emplacement factors that could produce systematic trends in surface expression of lava flow fields on Mars.

SUMMARY BIBLIOGRAPHY : Crisp, J. and S. Baloga, (1990) Lava flows with two thermal components, JGR, 95, 1255-1270; S. Baloga, (1990), Indirect solution of supplemented conservation laws, submitted to Phys. Rev. Lett; Crisp, J and S. Baloga, A method for estimating eruption rates of planetary lava flows, to appear in Icarus; S. Baloga and L. Glaze, 1990, Exact and approximate solutions for buoyant plumes in a neutral atmosphere (draft); Several abstracts related to this proposal appear in the Appendix E of this progress report.

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, with three papers accepted for publication; (ii) completed the study of early thermal gradients on Europa using lithospheric strength envelopes and observations of extensional tectonic features, with a paper accepted for publication.
- C. In the remaining two years I propose to do the following: (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 thermomechanical modelling framework for further extending these studies; (ii) investigate tectonic deformation processes and subsurface structure on Io using realistic rheological assumptions and broad-scale topographic data; and (iii) continue the investigation of the effects of mantle dynamics on surface stress fields in planetary lithospheres, and perform regional studies of the state of stress in selected areas on Venus at moderate resolution in order to refine regional models of the lithosphere and upper mantle of Venus.

D. Selected References:

- Banerdt, W. B., and M. P. Golombek, The evolution of Tharsis: Implications of gravity, topography, and tectonics, *Lunar Planet. Sci. XXI*, 42-43, 1990.
- 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. Rev.* in press, 1990.
- 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, 1990.
- Esposito, P. B., G. Balmino, W. B. Banerdt, B. G. Bills, G. F. Lindal, W. L. Sjogren, M. A. Slade, and D. E. Smith, Gravity and Topography, in *Mars*, H. Kieffer, B. Jakosky, and C. Snyder, eds., University of Arizona Press, Tucson, Arizona, in press, 1990.
- Golombek, M. P., and W. B. Banerdt, Constraints on the subsurface structure of Europa, *Icarus*, **83**, 441-452, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jeffrey F. Bell
(Name, Address, Planetary Geosciences
Telephone Number) 2525 Correa Road, Honolulu, HI 96822
(808) 948-6488 (after 5/1/90: (808) 956-6488)

Co-INVESTIGATORS: Klaus Keil
(Name Only) _____

PROPOSAL TITLE: SPECTRAL STUDIES OF POSSIBLE ASTEROIDAL 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 (0.3-5.0 μ m) 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. Investigated use of Hapke scattering theory to determine asteroid composition; measured spectra of shocked ordinary chondrite material; measured first spectrum of meteoritic troilite.

c. Obtain lab spectra of rare and newly discovered chondrite classes; compare asteroid and meteorite spectra via principal component analysis; determine mineralogy of S asteroids including Galileo flyby candidates; continue to study asteroid families for clues to interior structure of parent bodies.

d. 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). Bell, J. F., "A Probable Asteroidal Parent Body for the CV or CO Chondrites." *Meteoritics* 23, 256-257 (September 1988).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: J. W. Boring, Dept. of Nucl. Engineer. & Engineer. Physics, University of Virginia
(Name, Address, Telephone Number) Charlottesville, VA 22903-2442/804-924-3213

Co-INVESTIGATORS: R. E. Johnson
(Name Only)

PROPOSAL TITLE: Laboratory Reflectance Spectra of Irradiated Ices: Applications to Europa

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 make laboratory studies of the spectrum of light reflected from solid H₂O that has been bombarded by keV ions. The measurements will use as experimental parameters: (1) Temperature and method of growth of the ice film. (2) Temperature during ion bombardment. (3) Type and energy of incident ion. (4) Fluence (dose) of ions. The results of these measurements will aid in our understanding of the physical processes that affect the reflectance spectrum and will provide baseline information for understanding the reflectance of sunlight from icy planetary objects such as the Galilean moon Europa.
- b) Progress: In our first measurements of the reflectance of visible and UV light from ice it was found that changes in the spectra could be effected by ion bombardment and may be due to: (1) Compounds formed from implanted species, such as S. (2) Compounds formed from the H and O atoms of the ice as a result of chemical bond breaking induced by the incident ions. (3) Changes in the topography of the surface as a result of sputtering by the ions. The results of these studies made it apparent that we had to make a systematic study of the effects produced by each of the important experimental variables listed above, and of equal importance it is necessary to be able to compare the reflectance of the ice to that for some surface of known spectral reflectance (such as a standard mirror). We are presently in the process of making these systematic studies.

c) Proposed work

In earlier work we have seen that the implantation of keV S atoms into the ice has only a small effect on the reflectance. This is understandable since the depth of penetration is only $\sim 200\text{\AA}$. It may well be that in the case of Europa the implanted S exists to much larger depths because of reworking of the surface by various processes. We will explore the effects of an increased depth of implantation by performing successive growth of thin layers of ice followed by ion bombardment. It will also be necessary to compare these results to the reflectance properties of SO_2 and mixtures of SO_2 with H_2O . Another critical need in these measurements is for extending our reflectance studies into the infrared where vibrational transitions in existent molecules tends to produce characteristic reflectance features. We are presently working on the adaption of our experimental system for the IR studies. Of equal importance will be the requirement that we establish through detailed studies the effects on ice reflectance that can be produced by various changes in the conditions under which the ice is grown, even in the absence of ion bombardment.

d) Summary Bibliography

1 invited presentation

1 paper on the systematic studies of ice reflectance, in preparation.

e) Personnel

1 graduate asst.

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:* Numerical calculation of the formation and early evolution of the solar nebula, including the most important physical processes: three dimensional (3D) hydrodynamics, self-gravitation, radiative transfer, and complete gas thermodynamics. The models seek to improve our understanding of the dynamics and thermodynamics of the solar nebula, and hence our understanding of basic physical processes and conditions of crucial importance for planetary formation.

(b) *Progress:* (1) The main activity has been improving the accuracy of the hydrodynamical portions of the numerical code. A 1D code has been developed, starting from first principles, that includes all necessary corrections to make the van Leer scheme truly second order accurate in space and in time. Other important changes include an improved volume definition, consistent advection, and geometrical corrections needed for curvilinear coordinates. With these changes, the code does extremely well on the pressureless collapse test, and has proven to be truly second order accurate through convergence testing. (2) Tidal disruption of inviscid protoplanets has been shown to be negligible for Mars-sized bodies or larger, and important for lunar-sized bodies only for $v_\infty \sim 0$, severely limiting the importance of tidal disruption for planetary accumulation.

(c) *Proposed work:* (1) The main focus will be code improvement. The changes made in the 1D code must be included in the 2D and 3D codes and thoroughly tested; in addition, the 2D rotating sphere test case and the 3D fragmentation test problem must be run with the new codes. (2) With the new code, a new set of 3D models of solar nebula formation will be undertaken, including other improvements such as multiple collapse and central protosun heating. (4) The source of nonaxisymmetry in collapsing solar nebula models will be investigated through an equation linking nonaxisymmetric velocities to infall velocities. (3) If circumstances permit, a postdoctoral fellow may investigate the reality of protostellar core instabilities, which would affect the nebular heating derived from the protosun.

(d) *Summary bibliography* (3/89 - 3/90, third year, PI only): 11 papers published or submitted, 5 abstracts, 6 oral presentations. Two representative publications:

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

A. P. Boss, Protostellar Formation in Rotating, Interstellar Clouds. VIII. Inner Core Formation, *Astrophysical Journal*, **346**, 336-349, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Frank G. Bridges
(Name, Address, Dept. of Physics
Telephone Number) University of California
Santa Cruz, CA 95064 (408) 459-2893

Co-INVESTIGATORS: D. Lin
(Name Only)

PROPOSAL TITLE: Structure of Saturn's Rings: Collision
Properties 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.)

For the past few years we have studied zero-impact parameter collisions of water ice particles using a 1-D compound pendulum and measured the coefficient of restitution, the mass transfer and the sticking of particles in low velocity collisions. We now propose a series of measurements to study the collisional properties of such particles in collisions with two degrees of freedom. Over the last year we have developed a new pendulum instrument which allows particle motion in both x and y directions. With this pendulum we can study collisions in glancing incidence. We are now able to determine how the coefficient of restitution, erosion processes and the cohesive forces between particles change with impact parameter in low velocity collisions. Such measurements are crucial for understanding the dynamics of Saturn's rings.

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

PROPOSAL TITLE: Testing solid-state greenhouse models using thermal IR eclipse observations of icy satellites.

ABSTRACT:

- a) **OBJECTIVES:** To use existing observations of eclipses of the Galilean satellites in the thermal infrared to test and refine the solid-state greenhouse model. To advance understanding of surface and near-surface temperature distributions of icy satellites and to provide important input to thermal-history calculations for icy satellites. Our main objective is to modify and use our existing solid-state greenhouse models to interpret observations of the full-disk thermal flux during eclipse immersions and emersions of Europa and Ganymede. This will enable us to obtain estimates of the penetration scale length for sunlight on icy satellites and thus to more accurately model the surface and near-surface temperature distributions of satellites such as Europa and Enceladus. This is essential for determining upper boundary-layer temperatures of icy satellites. Preliminary models constructed by us have shown that recognition of and understanding the nature and scope of the solid-state greenhouse effect is quite important to understanding icy-satellite thermal histories and their geological evolution.
- b) **PROGRESS:** Analysis of eclipse data on Europa shows evidence for a solid-state greenhouse; subsurface temperature enhancements of $\sim 30\text{-}40^\circ\text{K}$ are suggested. Our models have been generalized to include variable thermal parameters, and we have incorporated that generalized thermal modeling code into the most accurate and detailed numerical model of Jovian satellite eclipses produced to date. We have also modeled the detailed heating profile with depth due to insolation using a two-stream radiative transfer approach. Finally we have measured the solid-state greenhouse effect in glass beads and are applying the results to our icy-body greenhouse models.
- c) **PROPOSED WORK:** We will publish our work on eclipse constraints for SS greenhouses on Europa and our lab work with glass beads. We have also applied the SS greenhouse model to the problem of Triton's geysers and will continue that study, aiming to publish the results this year. We will continue to study the effect on profiles of solar energy deposition with depth from differing regolith parameters (porosity, albedo, grain size etc.), and will initiate lab studies of the SS greenhouse effect in water ice using water-ice beads at low temperature in a vacuum.
- d) **SUMMARY BIBLIOGRAPHY:** Brown, R. H. and D. L. Matson (1990). Constraining solid-state greenhouse models using thermal-infrared eclipse observations. *Icarus*, in preparation; Dissly, R., R. H. Brown and D. L. Matson, "Laboratory measurements of the solid-state greenhouse effect in glass beads" *Icarus*, in preparation;



Research and Technology Resume

1 TITLE <p style="text-align: center;">ALBEDO PATTERNS OF THE SATURNIAN SATELLITES</p>	2 DATE PREPARED
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3 PERFORMING ORGANIZATION <p style="text-align: center;">JET PROPULSION LABORATORY 4800 OAK GROVE DRIVE PASADENA, CA 91109</p>	4 NUMBER/CODE <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding: 2px;">a. PROPOSAL</td> <td style="width: 50%; padding: 2px;">b. CURRENT</td> </tr> </table>	a. PROPOSAL	b. CURRENT
a. PROPOSAL	b. CURRENT		
5 CONTRACT/GRANT NO <p style="text-align: center;">NAS 7-918</p>			

6 INVESTIGATOR'S NAME <p style="text-align: center;">B.J. Buratti</p>	TEL NO <p style="text-align: center;">(818) 354-7427</p>	7 DATE <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding: 2px;">a. STARTING</td> <td style="width: 50%; padding: 2px;">b. ANNIVERSARY</td> </tr> </table>	a. STARTING	b. ANNIVERSARY
a. STARTING	b. ANNIVERSARY			

8 NASA ALT TECH MONITOR'S NAME <p style="text-align: center;">S. Baloga</p>	TEL NO <p style="text-align: center;">(818) 354-2219</p>	9 INSTITUTION CATEGORY AND CODE <p style="text-align: center;">FC</p>
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FISCAL YEAR	STATUS	WORKFORCE (WY)			FUNDING (In K)		
		IN-HOUSE	S/C	IMS	R D	TOTAL	
10 PRIOR	a	b	c	d	e	f	
11. CURRENT		0.15	XXXX	XXXX	20	20	
12 BUDGET		0.15	XXXX	XXXX	25	25	
		0.20	XXXX	XXXX	42	42	

13 DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography.)

A. STRATEGY: The objective of this task is to quantify and explain the albedo and color variations on the five inner medium-sized Saturnian satellites. We will investigate the interaction of the E-ring with their surfaces and other exogenic processes as a possible explanation form some of the albedo markings.

B. PROGRESS: (1) Completed and published color and albedo maps of the five Saturnian satellites: Enceladus, Mimas, Tethys, Dione, and Rhea. (2) Compared the maps with the expected results from differential micrometeoritic gardening and found that this mechanism may be more important than accretion of the E-ring in explaining the albedo patterns of these bodies. (3) Derived surface properties of Ganymede and Callisto, and found that Callisto has a marked hemispheric dichotomy in surface texture; Ganymede does not. Fundamental photometric quantities were also derived.

C. PROPOSED WORK: (1) Perform detailed correlation between albedo and color of Saturnian satellites as a function of distance from apex of motion and expected impact gardening rates. (2) Obtain measurements of planetary surface materials at small phase angles.

D. SUMMARY BIBLIOGRAPHY: Buratti, B. (1989). B.A.A.S. 21, 983.
 Buratti et al. (1990). Icarus 83, in press.
 Buratti, et al. (1990) Icarus, accepted.
 Buratti (1990) Icarus, submitted.

E. PERSONNEL: 1 Senior researcher, 1 student.

TECHNICAL MONITOR	TYPED NAME AND SIGNATURE	DATE
APPROVING OFFICIAL	TYPED NAME AND SIGNATURE	DATE

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Joseph A. Burns
(Name, Address, Space Sciences Bldg., Cornell Univ., Ithaca, N
Telephone Number) 14853-6801

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 affect planetary rings, particularly narrow ones and faint ones, since they are subject to a different hierarchy 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.** We identified periodicities in the integrated azimuthal brightness of Saturn's F ring; we associate these with the gravitational perturbations of the inner shepherd and several as-yet undiscovered moonlets. We determined the history of dust particles ejected from Phobos as they become charged and influenced by the solar wind's convected magnetic field. We evaluated the regions of potential spacecraft hazards due to material trapped in the vicinities of asteroids and Saturn's E ring. We added collisions into a numerical simulation of a narrow perturbed ring.

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; passage of grains through planet's shadow). We will model the generation and evolution of faint rings, including Saturn's E ring and the Uranian dust sheet.

d) R. A. Kolvoord, J. A. Burns and M. R. Showalter (1990). Periodic features in Saturn's F ring: Evidence for nearby moonlets. *Nature*, in press. [Attached]

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.*, in press. [Attached]

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Roger G. Burns
(Name, Address, Telephone Number) Dept. of Earth, Atmos. & Planetary Sci. 54-816
Mass. Inst. of Tech., Cambridge, MA 02139
tele. #(617)253-1906 FAX #(617)253-6208

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Electronic Spectra of Materials Simulating Planetary Surfaces:
Mars 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) Objectives. Pyroxenes and olivines are the most common and abundant ferromagnesian silicate minerals occurring in primary igneous rocks extruded onto the surfaces of terrestrial planets. Iron cations in them contribute significantly to remote-sensed reflectance spectra of planetary surfaces, particularly in the 1 micron and 2 microns wavelength regions where crystal field (CF) transitions in Fe^{2+} ions form the basis for identifying olivine and pyroxene compositions and structure-types. During extrusion of basaltic magma onto the surfaces of Venus, Mars and Earth, however, these Fe^{2+} ions are vulnerable to oxidation by atmospheric CO_2 and O_2 . The ferric iron may remain as Fe^{3+} ions in the pyroxene structure or form a veneer of ferric oxides. Either state of ferric iron could obscure the diagnostic olivine and pyroxene Fe^{2+} CF spectral features. To assess the effects of aerial oxidation on ferromagnesian silicates, visible-near infrared reflectance, Mossbauer and several surface-sensitive spectral measurements are required to characterize atmospheric degradation products of olivines and pyroxenes.

(b) Progress. Acid-weathering of olivines and pyroxenes associated with oxidative weathering of sulfides on Mars produces nanophase FeOOH and Fe_2O_3 phases which may contribute to bright-region spectra. Ferric iron, occurring either as structural Fe^{3+} or disseminated as Fe_2O_3 in olivines, orthopyroxenes and hedenbergites, drastically interferes with the Fe^{2+} CF bands in the visible-region spectra of these ferromagnesian silicates.

(c) Proposed Research. A variety of techniques, utilizing visible-near infrared and 4.2K Mossbauer spectra, and surface-sensitive Auger, ESCA and conversion electron spectroscopic methods, are to be used to characterize reaction products of (1) pigeonites, augites and Mg-Fe disordered orthopyroxenes after thermal oxidation; (2) olivines and pyroxenes reacted with hot CO_2 ; and (3) oxysilicates formed from Fe^{2+} -OH-bearing minerals (clay silicates, micas, amphiboles) by heating in vacuum and CO_2 atmospheres. Characterization of such products will lead to a better understanding of how surfaces of Venus, Mars and Archean Earth have been modified by chemical reactions with their atmospheres.

(d) Publications. See works by R.G.Burns with K.S.Bartels, D.S.Fisher, S.L.Martinez, T.C.Solberg and/or D.W.Straub in: *Lunar Planet. Sci.*, XXI, 145, 147, 736, 1215, & 1217 (1990); *idem*, XX, 44, 129, & 299 (1989); *Proc. 19th LPSC*, 313 (1989); *Mineral. Mag.*, 53, 135 (1989); *ACS Symp. Ser.*, 415, 262 (1989); *JGR*, in press; Chs. in *Remote Geochemical Analysis: Elemental and Mineralogical Composition* (accepted).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald B. Campbell
(Name, Address, Telephone Number) _____
Space Sciences Building
Cornell University
Ithaca, NY 14853

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) Several small studies of the moon and Venus are being proposed which will continue and build on several areas of the current work. Current and soon to be acquired radar data sets for the moon and Venus will be used for: 1) studies of crater surrounds, volcanic flows and other features on Venus utilizing the polarization properties of the reflected signal; 2) continued studies of the scattering mechanisms and surface properties associated with lunar impact craters, rilles, volcanic flows, domes, etc. by means of high resolution radar imaging and studies of the polarization properties of the reflected signal. For Venus, the measurements of the polarization properties may help to distinguish impact from volcanically formed craters in the Arecibo imagery and will also complement Magellan's results since the spacecraft's radar transmits and receives a single linear polarization.

b) Work to date during the current year has concentrated on the production and analysis of images covering $50 \cdot 10^6 \text{ km}^2$ of the southern hemisphere of Venus and on a study of the polarization properties of the area around Sif and Gula Montes in Western Eisela Regio. Terrain in the southern hemisphere have been categorized, mainly by comparison with images of the northern hemisphere from the Venera 15/16 spacecraft, and the size-frequency distribution measured for the possible impact craters. The average crater density, 0.8 per 10^6 km^2 , in the imaged area of the southern hemisphere appears to be significantly lower than the average value of 1.3 per 10^6 km^2 obtained from the Venera 15/16 data for the northern most quarter of the planet.

c) It should be possible to make significant progress during the new proposal period in most of the goals outlined in a). More analysis will be needed of the data obtained for Venus at Arecibo in 1988 to obtain the polarization properties but this is already underway. Initial high resolution radar observations of the moon are scheduled for this coming June and so data should be available to make significant progress in the lunar part of the proposal.

d) "Styles of Volcanism on Venus: New Arecibo High Resolution Radar Data", D.B. Campbell, J.W. Head, A.A. Hine, J.K. Harmon, D.A. Senske and P.C. Fisher, Science, 246, 373, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael H. Carr
(Name, Address, U. S. Geological Survey, MS 946
Telephone Number) Menlo Park, CA 94025
FTS 459-5174

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Deuterium and the 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 over-all objective is to better understand the role that water has played in the geologic and climatic history of Mars. Recent measurements of the D/H in the Mars atmosphere show that the Mars atmosphere is 5.1 times more enriched in deuterium than the Earth's. This has previously been interpreted as indicating that either Mars lost most of its initial inventory of water early in its history or that little water has interchanged with the atmosphere. Both interpretations conflict with geologic evidence. One objective of this proposal is to reconcile the deuterium measurements with the geologic evidence. The second objective is to further explore the implications of the presence of valley networks with respect to climatic and ground conditions.

(b) Different geologic processes were examined to determine their possible effect on the D/H in the atmosphere. It was concluded that a variety of geologic processes would have periodically introduced large amounts of water into the atmosphere, thereby periodically resetting its D/H ratio. Between such events the D/H in the atmosphere would have increased if there was limited interchange between the poles and the atmosphere. The D/H ratio in the atmosphere, therefore, tells us little, if anything, about the amount of water outgassed from the planet.

(c) Future plans. (i) Explore further the fate of water that pooled in the lakes that must have formed at the ends of the large flood features, (ii) document evidence that valley networks cannot have formed exclusively by groundwater sapping, (iii) assemble unpublished estimates of early erosion rates on Mars, (iv) better define conditions on early Mars that affect the stability of ground water.

(d) Recent relevant publications. Carr, M. H., D/H on Mars: Effects of floods, volcanism, impacts and polar processes (submitted to Icarus). Carr, M. H., 1989, The early environment of Mars, EOS, v. 70, p. 1172.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Mary G. Chapman
(Name, Address, U.S.G.S., 2255 No. Gemini Dr., Flagstaff, AZ 86001
Telephone Number) 602-527-7043; FTS 765-7043

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Geologic Maps of the Granicus Valles Area, 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 and Justification. The objective of this proposal is to produce interpretive detailed geologic maps of the Granicus Valles area, Mars. These maps will be at 1:500,000 scale, based on photomosaics of quadrangles MTM 25227, 30227, and 30222, which are composed of good to excellent images. The maps will assist further research whose goal is to (1) compare estimated original volumes of erosional features with those of surrounding flow deposits to determine genetic relations, and (2) study meander reaches on Granicus Valles to provide information concerning bedrock lithology and gradient. These additional goals will be pursued with the use of photoclinometry and measurements of meander-length sinuosity.

b. New Proposal.

c. Work Plan for FY 91. Mapping of MTM 30222, followed by photoclinometric and meander analyses. Begin work on MTM 30227 in the same fashion.

d. Summary Bibliography. Publications pertinent to this project include Tanaka et al. (in press) U.S. Geol. Survey Misc. Inv. Ser. Map I-2147 (1:5,000,000-scale geologic map of Elysium region); Harden, 1990, Geol. Soc. Amer. Bull., v. 102, p. 233-242; Christiansen, 1989, Geology, v. 17, p. 203-206; Mouginis-Mark, et al., 1984, Earth, Moon, and Planets, v. 30, p. 149-173.

PROPOSAL SUMMARY

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

CO-INVESTIGATORS: Dr. Donald Anderson

PROPOSAL TITLE: Thermal-Infrared Spectroscopy for Planetary Surfaces

ABSTRACT:

- a) The objective of this proposal is to study the thermal-infrared spectral properties of minerals, rocks, and natural surfaces, with the emphasis on development of quantitative models to determine the composition of planetary surfaces. This objective will be accomplished in four tasks designed to: 1) characterize the thermal-infrared spectra of a suite of candidate planetary materials in emission; 2) develop quantitative methods for component identification and abundance determination from thermal-infrared spectra; 3) study the spectral properties of komatiites and basalts; and 4) study the spectral properties of natural geologic surfaces, weathering products, and soils to develop analytical tools to interpret planetary observations.
- b) New proposal. Major accomplishments on related, previously funded work include: 1) acquisition of mineral and rock samples in emission; 2) detailed studies of spectral properties of weathering coatings of varying thickness using rock samples collected in the Mojave and southwestern Arizona; 3) analysis of the effects of composition and vesicularity on volcanic glasses; 4) development of full emission spectra sample chamber and emissivity algorithms; and 5) preliminary investigation of Mie and Chandrasekhar (Hapke) theory radiative transfer models;
- c) The results of this work will include: 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. The emphasis will be on the relationship of thermal-IR spectra to the composition and physical properties of the surface and underlying rock; 2) development of quantitative, radiative transfer models to model and deconvolve thermal-IR spectra of mixtures; 3) detailed investigation of the spectral properties of a wide range of 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.
- d) Relevant Publications:
 - 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.
 - Barbera, P.W., P.R. Christensen, S.M. Peacock, 1990, The geology of the Kelso-Baker Region, Mojave Desert, California: Analysis of Thermal Infrared Multispectral Scanner Data, submitted to *Geology*.
 - Barbera, P. W., Geology of the Kelso-Baker region, Mojave Desert, California Using Thermal Infrared Multispectral Scanner Data, Masters Thesis, Arizona State University, 1989.
 - Thliveris, S., Geology and desert varnish studies using TIMS data: Marble Mountains, California, Masters Thesis, Arizona State University, in review.
 - Christensen, P.R. and S. Thliveris, Thermal-infrared spectral observations of coated surfaces, *Lunar Planet Sci. XX*, 155-156, 1989.
 - Reyes, D., and P.R. Christensen, Mid-infrared spectra of komatiite vs. basalt, *Proc. Lunar Planet. Sci. Conf.*, 21, 1990.
 - Ondrusek, J., J.H. Fink, and P.R. Christensen, Mapping textural variations on silicic lava flows with thermal infrared spectrometry, *Reports of Planet. Geology and Geophys. Program*, in press, 1990.

PROPOSAL SUMMARY

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

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

PROPOSAL TITLE: Thermal Conductivity Measurements for Planetary Surfaces

ABSTRACT

- a) The objectives of this proposal are: 1) to determine the dependence of thermal conductivity on the physical properties of a surface, including particle size, porosity, packing, and bonding; 2) to develop an analytical model of thermal conductivity of particulate surfaces; and 3) to relate thermal conductivity measurements to remote sensing observations. The thermophysical properties of Mars have been extensively mapped, and thermal observations have also been made of the Earth, the Moon, the asteroids, and the outer satellites. These observations can be related to the physical properties of the surface through laboratory measurements of thermal conductivity. This effort will conduct a systematic investigation of the full range of expected planetary surface conditions, including mixtures of particle sizes, non-spherical particles, and bonded grains. Pore size and geometry, grain-grain contacts, and inter-grain bonding play the dominant role in controlling thermal conductivity at low pressures. It is proposed that these properties be investigated in relationship to conductivity measurements, and a model of their relative contributions be developed. These experiments and the resulting model will be particularly important for interpreting Mars Observer Thermal Emission Spectrometer observations to characterize martian surface properties.
- b) Results to date include the development of the complete laboratory apparatus to perform the necessary conductivity measurements. This setup provides for a full range of pressure, gas composition, and temperature measurements to be conducted.
- c) Future work will begin laboratory measurements, including: 1) collection of a uniform matrix of thermal conductivity measurements at Mars pressures covering the full range of particle sizes and mixtures of particle sizes; 2) scanning electron microscope (SEM) observations of particle size, porosity, pore geometry, grain-grains contacts, and bonding which will be related to thermal conductivity; 3) an analytical model of thermal conductivity in particulate materials; 4) measurements of mixtures of particle sizes, which will be used to study natural surfaces; and 5) a determination of the effects of bonding and particle shape on thermal conductivity.
- d) Relevant Publications
Presley, M.A. and P.R. Christensen, The distribution and origin of duricrust on Mars, *Lunar Planet Sci. XX*, 868-869.
Christensen, P.R., 1986, Regional dust deposits on Mars: Physical properties, age, and history, *J. Geophys. Res.* **91**, 3533-3545.
Jakosky, B.M., 1986, On the thermal properties of martian fines, *Icarus*, **66**, 117-124.
Jakosky, B.M., and P.R. Christensen, 1986, Global duricrust on Mars: Analysis of remote sensing data, *J. Geophys. Res.* **91**, 3547-3559.
Pye, K. and D.H. Krinsley, 1984, Petrographic examination of sedimentary rocks in the SEM backscattered electron detectors, *J. Sed. Pet.* **54**, 877-888.
Krinsley, D. and R. Greeley, 1986, Individual particle and martian aeolian action - A review, *Sed. Geology*, **47**, 167-189.

PROPOSAL SUMMARY

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

CO-INVESTIGATORS: None
(Name Only)

Quantitative Remote Sensing of Mineral Abundance Using Reflectance
TITLE: 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, we completed papers on the discovery and abundance of scapolite on Mars, the ice abundance and non-ice component on Callisto, and began analysis of new high spectral resolution data on Callisto, Europa and Ceres. The scapolite on Mars has been controversial, but we have completed a careful CO atmospheric removal and additional work on the abundance, and find scapolite is consistent with the 2.36 and 3.8- μm spectral regions. The scapolite abundances are reasonable at 8wt% or less, but still have profound implications for martian geology. The USGS digital spectral library and about 50,000 lines of spectral analysis software are being distributed to the scientific community.

c. The surface composition of outer solar system satellites and Mars will be analyzed with new IRTF high spectral resolution data. The new analysis algorithms will be used in the above analyses, and their efficiency and accuracy improved. More optical constants will be derived for geologically important minerals to be used in the above analyses.

d. Clark, R.N., G.A. Swayze, R.B. Singer, and J.B. Pollack: High Resolution Reflectance Spectra of Mars in the 2.3- μm Region: Evidence for the Mineral Scapolite, *JGR* Submitted, 1990.

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

Calvin, W.M., and Clark, R.N., 1990, Modeling the Reflectance Spectrum of Callisto 0.22 to 4.1 μm , *Icarus* in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gary D. Clow
U.S.G.S., 345 Middlefield Rd., MS-946
Menlo Park, CA 94025; (415) 329-5179

CO-INVESTIGATORS: Robert M. Haberle
(Name Only)

PROPOSAL TITLE: Ice Sublimation Rates at the Surface of Mars

ABSTRACT:

(a) **Objective:** Many geomorphic features on Mars have been explained in terms of processes involving water ice. The disposition of surface and near-surface ice is strongly influenced by sublimation rates, but previous estimates of these rates are very uncertain. Our objectives are to 1) achieve a better understanding of water-vapor transport mechanisms under Martian conditions, 2) develop simple parameterizations for near-surface vapor transport specifically for Mars, and 3) calculate sublimation rates for a range of conditions to help elucidate the nature of the many putative ice-related features on the surface of Mars. The results will have implications for the polar caps, glaciers, snowpacks, lakes, frozen ground, global water cycle, and atmospheric evolution.

(b) **Progress:** 1) A comprehensive model for heat and water-vapor transfer in the Martian atmospheric boundary layer has been completed. The model includes both wind-driven and free-convection processes. 2) Parameterizations have been partially completed. 3) We have readdressed Kahn's model of atmospheric evolution in light of the new evaporative cooling rates.

(c) **Work Plan FY91:** Calculate evaporation rates on Mars for a number of situations to 1) provide constraints on lifetimes of possible lakes, glaciers, and a northern hemisphere ocean; estimate the mean residence time of water molecules within these features; 2) reassess the stability of the residual polar caps; 3) reassess the role of the northern residual polar cap in supplying water to the northern hemisphere atmosphere; 4) reassess the stability relationships of a water-ice condensate at VL-2; and 5) provide better constraints on the limiting pressure at which transient pockets of liquid water could form on Mars.

(d) **Summary Bibliography:**

Clow, G.D. and R.M. Haberle, 1990. Free convection in the Martian atmosphere, In *Lunar and Planetary Science XXI*, Lunar and Planetary Institute, Houston, 210-211.

Clow, G.D. and R.M. Haberle, 1990. Characteristics of the Martian atmospheric surface layer, In *Lunar and Planetary Science XXI*, LPI, Houston, 209.

Clow, G.D. and others, 1988. Climatological observations and predicted sublimation rates at Lake Hoare, Antarctica, *J. Climate*, 1, 715-728.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert A. Craddock
(Name, Address, CEPS/NASM 3101, Smithsonian Institution
Telephone Number) Washington, DC 20560 202-357-1457

Co-INVESTIGATORS: Larry S. Crumpler, Ted A. Maxwell, and
(Name Only) James R. Zimbelman

PROPOSAL TITLE: GEOLOGIC MAPPING OF THE CHRYSE PLANITIA
REGION/VIKING 1 LANDING SITE 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) This proposal is for a 1-year study to map the Chryse Planitia region of Mars around the Viking 1 landing site at 1:500,000 scale. Geologic mapping at this scale will help determine: 1) What is the depositional, erosional, and structural history of the Chryse Planitia region, 2) How representative is the Viking 1 landing site of the Chryse Planitia region, and 3) Remaining questions that could be answered by a return mission to Chryse Planitia (or the martian surface).

(b) This proposal is for an approved, but as yet unfunded, study. Significant developments in the past year include recognition of the complementary nature of efforts between research lead by Craddock at the Smithsonian Institution and Crumpler at Brown University and a bilateral agreement of co-investigation in the proposed study area.

(c) New funding will enable studies of the surface physical properties of Chryse Planitia, as well as the timing and stratigraphy of units within one of Mars' deepest basins. During the first part of the year, work will concentrate on mapping the geologic units of the region, determined by superposition, crosscutting relations, and (limited) crater counts. These units will be compared to measurements of the surface physical properties made from high resolution Viking Infrared thermal mapper (IRTM) and Earth-based radar data. The latter part of the year will be concentrate on determining the extent of the surface physical properties, their similarities with other areas on Mars; and their implications on rover/sample return missions.

(d) Greeley, R. and Craddock, R.A., Geologic Map of the Southern Mangala Valles Region of Mars (MTM -20147). In review. Craddock, R.A. and Zimbelman, J.R., Yorktown and Lexington: Distant Objects as Viewed by the Viking 1 Lander. Lunar Planet Sci. XX, 193-194, 1989. Craddock, R.A., Rationale for a Mars Rover/Sample Return Mission to Chryse Planitia and the Viking 1 Lander. Lunar Planet. Sci. XXI, 234-235, 1990.

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: RHEOLOGY OF PLANETARY LAVA FLOWS

A.Objectives The objectives are to investigate the effects of cooling and crystallization on the rheology and morphology of lava flows on the Earth and Mars, and to determine the relationship between the crystallinity of a solidified lava flow and the rheology of the flow during emplacement.

Fundamental research on the basic physics of crystallization and its effect on magma rheology is required to make new progress in the interpretation of lava flows. The results of the study of crystallinities of terrestrial flows and the combinations of theoretical models will be applied to martian lava flows to infer eruptive, compositional, and rheologic parameters.

B.Accomplishments A mathematical model was developed for the cooling of lava flows with two thermal components. This model was applied to martian flows to estimate eruption rates. Viscometry and crystallinity measurements of the Mauna Loa basalt were made. Invited lectures on lava flow modelling were given at the UCSB and California Institute of Technology Geology Departments.

C.Proposed Work: (1) Make sensitivity tests and apply extensions of the two-component thermal model that add temporal and spatial dependence to the fraction of exposed core, core temperature, crust thickness, and/or flow thickness of Hawaiian basaltic flows, (2) Complete the measurement and analysis of crystal size distributions in the 1984 Mauna Loa flow and estimate rates of crystal growth and nucleation, (3) Measure dimensions and thicknesses of leveed and sheet flows on Mars and apply theoretical models for lava flow emplacement to constrain eruptive and rheologic parameters, (4) Determine the thermal budget of the 1984 Mauna Loa flow, and (5) Analyze laboratory viscometry data of the Mauna Loa samples.

D. Summary bibliography: J. Crisp and S. Baloga, 1990. A model for lava flows with two thermal components, JGR, v.95, pp.1255-1270. J. Crisp and S. Baloga, 1990. A method for estimating eruption rates of planetary lava flows, Icarus, in press. J. Crisp, 1990. Constraints on eruption rates and cooling of three lava flows at Alba, NASA MEVTV Workshop on the Evolution of Magma Bodies on Mars, San Diego, CA, January 15-17, 1990, pp.10-11.

PROPOSAL SUMMARY

PRINCIPLE INVESTIGATOR:
(Name, Address,
Telephone Number)

Steven K. Croft
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721
(602) 621-2720

CO-INVESTIGATORS:

None

TITLE:

MARTIAN COLLAPSE TERRAINS

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: To constrain models for the origin of the closed depressions in the vicinity of Valles Marineris on Mars. Specifically to use geological and geophysical data to evaluate whether karst-like terrains on Mars formed in a thick permafrost layer or in a deposit of carbonate rocks. The layers in which the collapse depressions and canyons formed date to very early times in the geological history of Mars. Determination of the origin of the layers will provide constraints on the early state of the martian atmosphere and hydrosphere: composition, temperature, circulation, presence of liquid water, and decline.

b. Progress Report: Completed mapping of the Hebes Chasma Quadrangle.

c. Tasks: Review assigned maps and revise Hebes Map when reviewed.

d. Bibliography: Croft, S.K. (1989) Spelunking on Mars: The carbonate-tectonic hypothesis for the origin of Valles Marineris. In MEVTV Workshop on Tectonic Features on Mars, LPI Tech. Rept. #89-06, p.21-24. Croft, S.K. (1990) Geologic Map of the Hebes Chasma Quadrangle, VM 500K 00077. Rep. Planet. Geol. Geophys. Prog-1989, submitted.

Proposal Summary

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

Co-investigator: R.A.Craddock

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

Abstract:

- (a) **Objectives.** Three objectives are defined: (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) 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 proposal for renewal of an approved, but as yet unfunded, study. Significant developments in the past year include recognition of the complementary nature of efforts between the research efforts lead by Crumpler at Brown University and lead by Craddock at Smithsonian Institution and a bilateral agreement of co-investigation in the proposed study area.
- (c) **Proposed Work.** (1) The initial phase will consist of a determination of the geologic history in the central part of the Chryse Planitia based on mapping of terrane and stratigraphic units and tectonic features in the MTM 20047 and 25047 1:500,000 scale photomosaic sheets. (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 (a) regional Viking IRTM data and (b) models of the origin and probable erosional characteristics of plains on Mars. (3) On the basis of (1) and (2), we will (a) assess how much of what Viking Lander 1 determined about the local surface might apply to Mars in general , 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: Jeffrey N. Cuzzi
(Name, Address, Telephone Number) NASA Ames Research Center, M.S. 245-3
Moffett Field, CA 94035 (415) 604-6343

Co-INVESTIGATORS: Richard H. Durisen, Mark R. Showalter, Luke
(Name Only) 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.)

- 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 run ballistic transport evolutions with both Goldreich - Tremaine and Araki - Tremaine viscosity laws. Our recent simulations of inner ring edges include both angular and velocity distributions of ejecta, and have been run for roughly 10 million "actual" years. they show development of structure very reminiscent of that seen in the A and B rings. 2. We are studying the ring "irregular" structure and determining the distribution of spatial frequencies in them with a Burg 2 maximum entropy algorithm. Initial results clearly show the presence of characteristically 80 - 100 km spatial structure in the inner B ring. 3. We have implemented multiple scattering in our non-classical "ray-tracing" radiative transfer model, and have applied it to the A ring brightness asymmetry. 4. We concluded our study of the E and G rings of Saturn, and are preparing a paper on the results. We have revised and resubmitted a paper on constraining particle sizes using fluctuations in stellar occultation data. 5. We have initiated studies of nonlinear dynamics in regions surrounding ringmoons or moonlets using a mapping technique.
- c) We will improve the gridding of our ballistic transport evolution code to resolve structural features of widths seen in the real rings. We will include the different angular and velocity distributions resulting from disruptive impacts, and/or from Saturn family projectiles. We will spectrally analyze scans of the entire B and inner A rings to constrain the characteristic spatial scales and their variation with location in the rings. We will complete the implementation of multiple scattering in our non-classical ray tracing code, and use the code to constrain possible variations in particle packing fraction across the rings. We will derive and implement perturbations in particle inclination, and second-order perturbations in eccentricity, for inclusion into our mapping algorithm.
- d) Cuzzi, J.N., and R.H. Durisen (1990), *Icarus*, in press; Dones, L., M.R. Showalter, and J.N. Cuzzi (1989) in "Dynamics of Astrophysical Disks", J. Sellwood, ed., Cambridge Univ. Press; Durisen, R.H., et al. (1989), *Icarus*, 80, 136-166; Flynn, B.C., and J.N. Cuzzi (1989), *Icarus*, 82, 180-199; Horn, L.J., et al. (1989); *B. A. A. S.* 21, 928.

PROPOSAL SUMMARY

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

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

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 distribution of both particle and gas phases in the early stages of the protoplanetary nebula.
- b) In this year, we have improved our Schmidt number model (characterizing particle diffusion) to account for a spectrum of eddy sizes and realistic geometries, and for simultaneous settling under gravity, and have begun to explore the possibility that "centrifuging" causes preferential diffusion of particles in the centimeter-to-meter size range. We have performed a variety of simulations of the gas viscosity with two different viscosity models, and have identified the sensitivity of the more complex model to damping of turbulence by the particle phase. We have performed model runs comparing the nebula behavior for a range of qualitatively different viscosity profiles. We have demonstrated with several sample runs that radial transport associated with the two-phase aspects of the nebula is robust and competes with previously suggested processes for both net mass transport (material moves 0.1 - 1 AU relative to the gas in the time it takes for growth of planetesimals), and with volatile transport at "condensation fronts" (we generate a Jupiter core of condensed water in 10^5 - 10^6 years). We have begun to consider the implications of our model for proto-satellite nebulae which surrounded the growing gas giant planets. We have improved the numerics of our code in several ways to make it more accurate and efficient. We proposed for, and were granted, 150 Cray hours on the Ames National Aerodynamic Simulator. We presented the work to the AIAA and the Protostars and Planets conference, and have one manuscript complete and another (as well as part of a book chapter) in preparation.
- c) We will continue to model the behavior of protoplanetary and proto-satellite disks, with a range of particle sizes, densities, and nebula pressure gradients. We will begin 2-D modeling of "condensation fronts". We will study the damping effects of the particles on the turbulence with our two-equation viscosity model. We will implement several different treatments of the particle viscosity, ranging from simple particle disk models to fluidized-bed models, in our modeling of dense particle disks. We will further improve our Schmidt number model to include particle "centrifuging" effects.
- d) Champney, J.M., and J.N. Cuzzi (1990) A turbulent two-phase model for nebula flows; AIAA paper 90-0211; 28th Aerospace Sciences Meeting, Reno, Nevada; Cuzzi, J.N., J.M. Champney, and A.R. Dobrovolskis (1980) Particle-gas dynamics in the protoplanetary nebula; presented at Protostars and Planets III, Tucson, March 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald R. Davis 602-881-0332
(Name, Address, Planetary Science Institute
Telephone Number) 2421 E. 6th St., Tucson AZ 85719

Co-INVESTIGATORS: Stuart J. Weidenschilling
(Name Only) Eileen J. Ryan

PROPOSAL TITLE: Understanding Asteroid Collisional History Through
Experiments and Numerical 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) This program investigates the collisional evolution of asteroids and the process of catastrophic disruption by collision through theoretical modeling, laboratory experiments and development of scaling laws. We carry out collisional disruption experiments in order to obtain the experimental data necessary to develop numerical algorithms for collisional outcomes and to test scaling laws. We develop and apply numerical models of the collisional evolution of asteroids, considering observational constraints such as the size and rotation distributions, the number of dynamical families, Vesta's basaltic crust, etc. in order to understand which asteroid characteristics are the product of their collisional history and which are primordial in origin.
- b) Under the experimental area, we reduced and analyzed experimental data on the fragmentation of aggregate targets and on the mass-velocity distribution of fragments. We collaborated with Melosh and Asphaug in developing and testing a 2-D hydrocode program with finite strength effects included. This tool will enable us to test scaling laws for collisional outcomes. We developed and published an interpretation of new data on the size distribution of different asteroid taxonomic types based on their collisional properties. A new model for the spin rate of partially dispersed cores was developed, completing our comprehensive algorithm for asteroid collisional spin changes. This algorithm was incorporated into our numerical code and applied to study the simultaneous size and spin evolution of asteroids. We prepared and submitted a manuscript describing this new model and the effects of collisions on asteroid rotation rates.
- c) In the experimental area, we will carry out collisional disruption experiments to study the effects of target structures and projectile/target strength differences on collisional outcomes. We will also carry out experiments in association with colleagues designed to test pressure strengthening effects in our scaling laws. We will apply the 2-D hydrocode model to study the size scaling of collisional outcomes and to model the mass-velocity distribution of the fragments. For asteroid collision we propose to study the collisional "context" of asteroids 951 Gaspra and 243 Ida, two small asteroids that will be observed up close by the Galileo spacecraft. We will determine the collisional history of asteroids that satisfies all observational constraints using our integrated size-spin model.
- d) In the past year we produced, revised or contributed to 9 book chapters, papers or manuscripts, 3 abstracts and made 3 oral presentations. Recent papers are: (1) "On Collisional Disruption: Experimental Results and Scaling Law," D. R. Davis and E. V. Ryan, Icarus **83**, 156-182 (1990); (2) "On the Size Distribution of Asteroid Taxonomic Classes: The Collisional Interpretation," D. R. Davis, in Asteroids, Comets and Meteors III, Lagerkvist et al., eds., Jan. 1990; (3) "Asteroid Collisional Evolution I: Angular Momentum Splash: Despinning Asteroids Through Catastrophic Collisions," submitted to Icarus, Oct., 1989.

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: Kenneth L. Tanaka
(Name Only) Jeffrey B. Plescia

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 proposal are to obtain and to use photoclinometric-profile data for a variety of tectonic features on Mars to estimate (1) from grabens, the thickness of the faulted layer, the amount of extension and strain, and the variation of these parameters with time and space; (2) from pit chains, mechanisms for pit formation and the relations between pit formation, local regolith thickness, and graben formation; and (3) from wrinkle ridges, the amounts of regional crustal shortening and strain, and their relation to the local geologic setting.

(b) Accomplishments: We have completed a detailed photogeologic study of the sequence of tectonism at Alba Patera. We have examined the morphometry of 170 grabens within Alba Patera and estimated the depth to the mechanical discontinuity that initiated faulting to be 1.6-2.3 km. Six hundred pit-spacing measurements and several trough depths within Alba Patera indicate an average regolith thickness of 1.6 km. The depths indicated by pit-spacing, trough, and graben data are consistent with proposed cryosphere thicknesses at midlatitudes. We have also estimated the total extension across southern Alba Patera to be about 0.4%. We have obtained in excess of 400 profiles across wrinkle ridges in Lunae Planum and Amazonis Planitia, which indicate a total shortening of 1.6 km across Lunae Planum and, therefore a total compressional strain of between 0.2 and 0.5%.

(c) Work Plan (FY91): Task 1: to determine the amount and timing of extension and the thickness of the faulted layer north of Alba Patera and within Mareotis, Tempe, and Acheron Fossae. Task 2: to examine genetic relations of associated collapse and erosional features in these areas. Task 3: to define the magnitude and timing of regional crustal shortening and the amount of strain around the southern and western Tharsis regions as reflected in wrinkle ridges.

(d) Recent Bibliography: Davis, P.A., and Golombek, M.P., Discontinuities on the shallow Martian crust at Lunae, Syria, and Sinai Plana: J. Geophys. Res., in press; Tanaka, K.L., 1990, Tectonic history of the Alba Patera-Ceraunius Fossae region of Mars: Proc. 20th Lunar Planet. Sci. Conf., 515-523; Moore, H.J., and Davis, P.A., 1990, Analyses and morphology of a lava flow, Ascreaus Mons, Mars: Lunar Planet. Sci. XXI, 805-806; Plescia, J., 1990, Photoclinometric analysis of wrinkle ridges on Lunae Planum: Lunar Planet. Sci. XXI, 967-968; Golombek, M.P., Suppe, J., Narr, W., Plescia, J., and Banerdt, B., 1990, Does wrinkle ridge formation on Mars involve most of the lithosphere?: Lunar Planet. Sci. XXI, 421-422; Davis, P.A., and Tanaka, K.L., 1990, Shallow crustal discontinuities in the Alba Patera-Tempe Terra region of Mars: NASA Tech. Memo., Reports Planet. Geol. and Geophys. Program - 1989, in press.

PROPOSAL SUMMARY SHEET--ABSTRACT

PRINCIPAL INVESTIGATOR:

Dr. Rene A. De Hon
Department of Geosciences
Northeast Louisiana University
Monroe LA 71209
(318) 342-2188

CO-INVESTIGATORS: None

PROPOSAL TITLE: Fluvial and Lacustrine Depositional Patterns and
the Martian Landscape

ABSTRACT:

A. OBJECTIVES: This proposal is for studies of martian sedimentary depositional systems. The broad based objective is the identification of potential sites of significant sedimentary materials of regional extent deposited by water or ice at the terminus of distributary systems as lake/sea/ocean sediment.

B. ACCOMPLISHMENTS: New Proposal--but--This study is continuation of studies into sediment distribution systems and local sediment systems in channels, local basins, and alluvial fans or deltas. Previous studies have focused on lacustrine sites of deposition and depositional patterns at the terminus of some outflow systems.

C. TASKS:

Primary tasks are to study regional patterns of valley systems with emphasis on the final sites of deposition. Of chief interest are the Chryse basin, Hellas basin, Deuteronilus--Acidalia region, and northwestern Elysium--Utopia region. In addition to searching the clastic depositional systems, an alternative approach is to search for the signature of weathering characteristics indicative sedimentary precipitates.

D. RECENT PUBLICATIONS OR PRESENTATIONS:

De Hon, R.A. 1987, Ring furrows: Inversion of topography in martian highlands: Icarus 71, 287-297.

De Hon R.A., 1989, Flood surge in martian outflow systems: Episodic flow: Lunar Planet. Sci. Conf. XX, p. 230-231.

De Hon R.A., 1989, Martian Lacustrine Plains: 4th Mars Conference, Tucson, p. 90-91.

De Hon R.A., 1990, Hydraulic routing of the Maja Outflow across Xanthe Terra: Lunar Planet. Sci. Conf. XXI, p. 266-267

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: Dr. Carl D. Murray
(Name Only) 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 under the action of drag forces, planetary perturbations and particle collisions in order (i) to determine those orbits that result in the transport of asteroidal particles to the Earth (ii) to determine the origin of the particles in the zodiacal cloud, and (iii) to interpret the IRAS dust data. (2) To measure the shapes of satellites in order to place constraints on their mean densities and internal structures. (3) To investigate the dynamics of resonance, particularly temporary trapping and chaotic motion, in the satellite systems of Saturn and Uranus, in order to determine the orbital, internal, and thermal histories of the satellites.

(b) New Proposal.

(c) First Year Work Statement. (1) We will determine the structure of the zodiacal cloud that would be produced by collisions amongst asteroids alone and compare that structure with the structure of the cloud observed by IRAS. (2) We will re-examine the shape of Mimas, complete our work on the shape of Enceladus, and measure the shape of Tethys. (3) We investigate the orbital evolution of the Saturnian satellites prior to the formation of the observed resonances between Mimas, Tethys, Enceladus and Dione.

(d) Recent Relevant Publications

- (1) Dermott, S. F., and Nicholson, P. D. 1989. IRAS Dust Bands and the Origin of the Zodiacal Cloud. *Highlights of Astronomy* 8, 259-266.
- (2) Dermott, S. F., and Thomas, P. C. 1988. The Shape and Internal Structure of Mimas. *Icarus* 73, 25-65.
- (3) Dermott, S. F., Malhotra, R., and Murray, C. D. 1988. Dynamics of the Uranian and Saturnian Satellite Systems: A Chaotic Route to Melting Miranda. *Icarus* 76, 295-334.

PROPOSAL SUMMARY

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

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

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) The Voyager spacecraft have now imaged icy moons of all four of the solar system's giant, low-density planets, and have revealed tectonic activity on all but the tiniest moons. The largest satellites whose surfaces are visible, Ganymede, Callisto, and Triton, probably have histories dominated by the activity of water and water ice. Activity on the smaller moons of Saturn and Uranus suggests important amounts of ices and liquids in the $\text{NH}_3\text{-H}_2\text{O}$ 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) In the past year we completed the proposed measurement of solids and partial melts in the $\text{NH}_3\text{-H}_2\text{O}$ system over the composition range 1 to 29 wt% NH_3 . We perfected techniques for fabricating samples of pure methane clathrate and made preliminary measurements of the strength of that material, finding it to have strengths comparable to those for pure water ice at 140 and 160 K. We reinvestigated certain effects in ice I related to phase transformation: we found a nonisotropic morphology of ice II inclusions in ice I samples that were partially transformed at warm temperatures; we found the anomalous pressure-independent failure of ice I at cooler temperatures is associated with the formation of small amounts of ice II, a process that may have analogies to deep-focus earthquakes on earth.

(c) In the coming year we will (1) measure the flow of $\text{NH}_3\text{-H}_2\text{O}$ ices at the very low strain rate of $3.5 \times 10^{-7} \text{ s}^{-1}$, (2) complete the survey of the strength of methane clathrate as a function of temperature, pressure, and strain rate, and (3) build a 1-GPa pressure vessel for the creep apparatus that will allow us to measure the creep properties of pure water ice VI.

(d) Durham, W. B. and S. H. Kirby, Planetary ices: A comparison of rheologies at $T < 200 \text{ K}$ (abstract), *Lunar Planet. Sci.*, XXI, 305-306, 1990. Kirby, S. H. and W. B. Durham, The ice I-II transformation under nonhydrostatic stress: New observations relevant to the mechanisms of bulk transformation, faulting and deep earthquakes (abstract), *EOS Trans. Am. Geophys. Union*, 70, 1316, 1989.

PROPOSAL SUMMARY

A.W. England, Principal Investigator
F.T. Ulaby, Co-investigator
Radiation Laboratory
Department of Electrical Engineering
and Computer Science
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: Von R. Eshleman, Professor
Center for Radar Astronomy
Stanford University
Stanford, CA 94305-4055

TITLE: Theoretical Studies of the Radar Properties of the Icy Galilean Moons of Jupiter

ABSTRACT: (a) We propose a final contract renewal period of six months to complete our research on the interesting radar backscattering properties of the three icy Galilean moons of Jupiter—Europa, Ganymede, and Callisto. In this time we propose to publish a Ph.D. dissertation and to prepare a paper for journal publication. The radar properties of these moons were once called anomalous because of their unusual brightness and polarization properties compared to those of rocky planets and moons and even those of common scattering objects such as metallic spheres. However, new evidence indicates that the radar backscattering from the Galilean moons may be typical of that from other icy surfaces. Since the Galilean moons are the most well studied icy surfaces, it is important to gain an understanding of the geophysical characteristics of their surfaces responsible for the unusual radar echoes. Using theoretical models for the backscattering and by comparing with data we hope to gain such an understanding or to at least determine what new information is needed.

(b) In the past year we have continued to develop the most successful model that has been proposed to explain the radar echoes from the Galilean moons, namely the buried-crater model. We have shown that this model is consistent with all the gross features in the non-coherent data. We have also completed our involvement, under NSF funding, in an experimental effort to obtain for the first time coherent radar data using the Arecibo Observatory in three separate campaigns in 1987, 1988, and 1989-90. We have processed much of that data and have made calculations based on the buried-crater model of the expected statistical correlation between the two orthogonal polarizations received. The data indicates that the correlation, if any, is below the noise level and our calculations are consistent with this. We have one set of data in which linear polarization was used instead of circular and that data indicates some correlation. However, it is not clear if this may be due to unwanted correlations introduced by the Arecibo antenna system or to unfavorable conditions for the use of linear polarization on that day of observing. We have done some additional tests that may help us to decide this matter.

(c) During the six month renewal period we are requesting, we propose to complete the reduction of the Arecibo data and our comparisons with the buried-crater model. We propose to develop the major theories that have been offered as explanations of the data into a common state of completion for comparisons with data and each other. It is important to determine which theories are most compatible with the data and to use them in designing new experiments. One such experiment that would provide valuable information would be to use the Galileo spacecraft with an Earth based radar in a bistatic mode to obtain the angular dependence of the radar scattering by these moons. Thus, we will develop the most viable models to calculate the full angular dependence of the radar scattering by an icy moon. We will also compare the geophysical implications of the various models. This work will lead to the completion of a Ph.D. dissertation in the next six months and to publication of a journal article.

(d) We have included an appendix showing some of our reduced coherent data, an abstract presented at the 1988 DPS meeting, and a reprint of a paper published in 1990 in the journal *Advances in Space Research*.

PROPOSAL SUMMARY

P.I. Larry W. Esposito
LASP CB 392
University of Colorado
Boulder, CO 80309-0392

Title: Dynamics of outer planet rings

ABSTRACT:

a. The Voyager occultations provide several uniform and high quality data sets for the rings of Saturn and Uranus. The spatial resolution is generally better than 100 m and the wavelengths of observation range from $.13\mu$ to 13cm. We propose to study and inter-compare these data and develop theoretical models for particle size and particle transport.

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.

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.

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 and differences among the main rings. We will include non-axisymmetric perturbations in our Markov process simulation of particle dynamics and apply it to explain sharp ring edges observed in Saturn and Uranus rings.

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

d. Summary bibliography (CY89): 3 papers published; 3 abstracts.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Fraser P. Fanale
(Name, Address, Planetary Geosciences Div., Hawaii Inst. of Geophysics
Telephone Number) Univ. of Hawaii, 2525 Correa Rd., Hon., HI 96822

Co-INVESTIGATORS: None
(Name Only) _____

PROPOSAL TITLE: Volatiles in Planetary Regoliths, NAGW 133

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 objectives are to investigate the evolution of volatile systems on planetary bodies and the interaction of volatiles with planetary surfaces.

(b) We completed a paper entitled "The Influence of CO Ice on the Activity and Near Surface Differentiation of Comet Nuclei". This paper concerns the effects of CO on the activity and the stratigraphy of comets. A previous computer model of a comet nucleus composed of two ices and nonvolatiles was used to compute temperature profiles, H₂O and CO fluxes and depths of CO ice as a function of heliocentric distance. Subsurface CO gas pressures and the size of putative H₂O ice grains emitted from the nucleus were also calculated. For the orbit of P/Halley it was found that CO gas production would exceed H₂O gas production beyond 2.5 AU from the sun and that CO ice would always be within 3 m of the surface. This paper has been accepted for publication in Icarus.

We also completed a paper entitled "The Evolution of the Water Regime of Phobos". We improved our original model (Fanale and Salvail, 1989) by including the effects of time varying obliquity, eccentricity and solar luminosity. Temperatures water fluxes and depths of ice were computed over geologic time for the entire range of latitudes and for two sets of porosities and pore sizes. The ice was assumed to be distributed either uniformly throughout Phobos or concentrated in a near surface layer, and three initial fractions of water were considered. If ice were initially concentrated in a near surface layer and if its initial mass fraction were .01, it was found that it would currently exist within 1 km of the surface at all latitudes for a planet of low permeability or at latitudes higher than about 50 for one of high permeability. This paper has been submitted to Icarus.

(c) We will investigate the possible evolution of short period comets into asteroidal objects by either removal of ice over a nonvolatile core or the formation of a permanent nonvolatile crust. This is motivated by statistics which show that SP comets and asteroids occupy separate regions of an A-E diagram. Our previous computer models will be used to compute temperatures, gas fluxes, ice ablation rates and the thickness of a nonvolatile crust, if applicable, in low eccentricity orbits characteristic of asteroids. Several grain emission mechanisms involving both cohering and non-cohering nonvolatile grains will be considered as well as different orbits to determine whether divergent behavior can be made to occur.

We will modify our computer model of the water regime of Asteroid Ceres to predict observational characteristics such as OH brightness, line profile, field of view geometry and velocities. This will allow proper comparison between observations and our model predictions.

We will perform laboratory work to determine whether alteration of the surfaces of meteorite parent bodies by vitrification and comminution may be affecting the reflectance spectra of optical surfaces of asteroids, leading to erroneous identification. The main criteria for a match between spectra has been analysis of absolute reflectance, band centers, band depth and continuum slope. The laboratory work will involve simulating processes taking place on asteroid surfaces by vitrifying and pulverizing meteorite samples and then observing and identifying the changes, if any, in the reflectance spectra. This will allow us to identify important processes occurring in asteroidal regoliths and to place limits on the dependability of some of the criteria for spectral matching between meteorites and asteroids.

(d) Fanale and Salvail (1984); Fanale and Salvail (1986).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Fraser P. Fanale
(Name, Address, Planetary Geosciences Div., Hawaii Inst. of Geophysics
Telephone Number) University of Hawaii, 2525 Correa Rd., Hon., HI 96822
(808) 948-6488

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Volatiles on Outer Planetary Satellites, NAGW 633

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 the volatile systems on the outer planetary satellites.

(b) We revised our paper on the "solid state greenhouse effect" to include results for vapor fluxes, volumetric rates of sublimation and condensation and the relative contributions of the various modes of energy transport, in addition to temperatures. Results were obtained for two values each of thermal conductivity, sunlight extinction coefficient and pore size. It was found that phase changes and mass transport greatly reduce the effect of sunlight penetration into water ice; however, the "solid state greenhouse effect" remains significant, making it more likely that liquid water exists several kilometers below the surface.

We also used an existing computer model to investigate the comet-like activity of minor planet Chiron, assuming it to be composed of a homogeneous mixture of H₂O and CO ices and nonvolatiles. Assuming that Chiron is fairly compact and cohesive, it was found that chemical differentiation would cause a water ice and dust layer to form that would increase steadily with time, together with a steady decrease in gas production. This surface layer keeps the CO interface nearly isothermal after the first few orbits, thus eliminating the cyclic heating associated with decreasing heliocentric distance as a cause of outbursts of activity. We are currently attempting to incorporate more observational data as constraints on our model.

(c) We will investigate the evolution of the thermal regime and the chemical and phase composition of Enceladus. It will be assumed initially that Enceladus has a Maxwell rheology with a porous insulating surface layer of low thermal conductivity and is composed of a homogeneous mixture of H₂O and NH₃. Temperatures will be calculated for the entire radius using an energy equation that includes the effects of heat conduction, phase changes, convection, sunlight penetration and tidal heating. An iterative procedure will be used to calculate the thickness of a rigid, elastic crust below a thin, porous surface layer and above a viscous Maxwell solid core. If temperatures in the interior reach 170 K, the H₂O - NH₃ eutectic, a liquid phase will form. The upward migration of the liquid phase due to buoyancy to the level of the elastic lithosphere and the thickness of the evolving liquid layer will be calculated as a function of time for the last 1 Gyr, since observations indicate resurfaced regions are at least that old. Cases will be computed using different fractions of H₂O and NH₃.

We will develop a model which will simulate the evolution of Triton's volatile system. Triton will be assumed to be composed initially of a homogeneous mixture of H₂O, CH₄ and N₂ ices and initially to have no atmosphere. Average diurnal temperatures will be computed for the surface and near surface interior for the entire range of latitudes. The fluxes of N₂ and CH₄ through the porous water ice will be computed and integrated over the surface to obtain the total outgassing rate. The thicknesses of the chemically differentiated layers of H₂O ice and H₂O + CH₄ ices will also be computed. These calculations will be repeated over time to obtain the atmospheric mass and surface pressure, which is assumed to be constant over the planet at any given time. The thickness of local CH₄ ice deposits will be calculated at locations where the vapor pressure is less than the atmospheric pressure. The above calculations will be repeated over seasonal or longer time scales until a steady state condition or one similar to the present atmosphere of Triton is attained. Cases will be computed for several unknown parameters such as the emissivity, the chemical fractions and the pore size of the layers.

(d) Fanale and Salvail, 1987; Fanale and Salvail, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Fraser P. Fanale, Planetary Geosciences Div.,
(Name, Address, HIG, Univ. of Hawaii, 2525 Correa Rd.
Telephone Number) Honolulu, HI 96822 (808) 948-6488

Co-INVESTIGATORS: Susan E. Postawko
(Name Only)

PROPOSAL TITLE: Volatile Migration and Phase Changes 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) Many factors have strongly influenced the volatile composition and evolution of the atmosphere and regolith on Mars. We will quantitatively evaluate the adsorption of CO₂ under varying conditions, and attempt to understand the evolution and distribution of CO₂ as a function of the total CO₂ available to the regolith-atmosphere-cap system.
- b) We have collaborated with Soviet and French scientists over the past year in analysis and interpretation of the Soviet Phobos spacecraft data of both Phobos and Mars. The results of many of these investigations were presented at the *Lunar and Planetary Sci. Conf.* in March. The preliminary calculations from our study of early internal heat flow versus an atmospheric greenhouse effect on Mars have been completed. Although our study of parametric space has been limited, the general characteristics of the system can be determined. We find that if the total available atmospheric plus regolith CO₂ was greater than about 4 bars, then for reasonable values of early heat flow an atmospheric greenhouse effect could have been the dominant process by which surface temperatures were kept high enough for liquid water to flow. If the total available CO₂ was less than about a bar, however, an atmospheric greenhouse plays almost no role, but high heat flow could have kept near-surface temperatures high enough for the valley networks to form by groundwater sapping. We have completed a study of possible formation mechanisms for the abundant large closed depressions seen in the Valles Marineris region of Mars, and have submitted a manuscript to *J. Geophys. Res.* We have proposed 4 new models as possible formation mechanisms: Early graben were flooded and the standing water developed a thick ice cover. The entire region was then covered with cratered plains materials, and the depressions formed when the underlying water and ice were removed. The other 4 models involve various methods of removing carbonates which may have been formed in the region due to an early, thick CO₂ atmosphere interacting with standing water. Our manuscript on the analysis of the 1971 and 1973 Goldstone radar data has been revised and is awaiting publication in *J. Geophys. Res.*
- c) In this next year we will measure the infrared reflectance spectrum of adsorbed CO₂ on various substrates. We expect to determine variations in adsorption with temperature and pressure with regard to selection of adsorption sites in the crystal structures of substrates. We propose, in this next year, to use our existing programs to perform calculations of the atmosphere-regolith-cap system on Mars for fixed obliquities and regolith masses, but for varying amounts of total CO₂. The purpose of this exercise is to quantitatively demonstrate the existence of a large reservoir of adsorbed CO₂ which must be buffering the atmosphere and caps. We will continue our collaboration with Soviet and French scientists in analysis of the Soviet Phobos spacecraft data. In particular, we intend to compare degree of hydration of the martian surface as indicated by the Phobos data to thermal inertia data from Viking in order to determine controlling factors in hydration. We will also continue to study spectra of asteroids and meteorites in an attempt to find a better spectral fit to the spectrum of Phobos. We propose to begin our study of the stratigraphy of the martian polar caps, using mathematical models to estimate the thickness of any dust layer and the rate at which water vapor would be expected to diffuse through this dust layer.
- d) Zent et al. (1987) Carbon dioxide: Adsorption on palagonite and partitioning in the martian regolith *Icarus* 71, 241-249; Fanale et al. (1982) Mars: The regolith-atmosphere-cap system and climate change *Icarus* 50, 381-407.

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: [NOTE: This new proposal seeks to replace NAGW 529 and NAGW 1343]: (1) Correlated longitudinal trends in rheology with composition for four well-documented Hawaiian lava flows, (2) sought similar trends by calculating rheologic properties for lava flows on Olympus and Ascreaus Mons, (3) found through 72 laboratory simulations that a wide range of lava flow surface structures can be formed by varying either the flow rate or cooling rate, and that transitions from one structure to another can be related to a single dimensionless number, (4) identified diagnostic patterns of vesicular and glassy texture in dacite and rhyolite domes and flows, (5) used hydrogen isotope measurements of dacite samples from two active lava domes to better define cycles of explosive and effusive activity, (6) developed a new model relating dike geometry to the thermal and rheologic properties of the host rock, (7) estimated rheologic properties of the Olympus Mons aureole deposit, (8) mapped surface structures on 3 rock glaciers in Colorado in order to test a new model for the deformation of rock and ice mixtures.
- c. Proposed Work: (1) Conduct new laboratory simulations to better define the parameters necessary to form specific lava flow structures, (2) correlate eruptive conditions that form surface structures with those that form large constructs visible on Viking and Venera images, (3) use experimental data to define "effective" rheologic parameters for lavas with solidifying crusts, (4) map the distribution of surface structures on lava flows of a range of compositions in Hawaii and the Cascades, and on Viking and Venera images, (5) calculate which surface textures are likely to form on martian and venusian lava flows, (6) use TIMS data from Medicine Lake Highland Volcano and Long Valley Caldera along with laboratory-derived spectra to identify the infra-red signatures of different lava textures and compositions.
- d. Relevant Publications:
Fink JH, Griffiths RW, Radial spreading of viscous gravity currents with solidifying crusts. *Journal of Fluid Mechanics* (in press).

Fink JH, Zimbelman JR (1989) Longitudinal variations in lava rheology: Puu Oo basalt flows, Kilauea Volcano, Hawaii, in Fink JH (ed) Lava flows and domes, *IAVCEI Proceedings in Volcanology* 2:157-173.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Richard G. French
Department of Astronomy
Wellesley College
Wellesley, MA 02181

CO-INVESTIGATOR: Dr. Mark Showalter

PROPOSAL TITLE: Dynamics and Structure of Planetary Rings

ABSTRACT:

(a) Objectives: Investigate the dynamics and structure of the narrow rings of Saturn and Uranus using stellar occultations, fit existing and expected Uranus occultation data with detailed kinematical models, compare theoretical models of ring width variations with observations, observe Neptune's ring arcs through occultations, and compare the stratospheres of Saturn, Uranus, and Neptune.

(b) Accomplishments: 1) Observations and preliminary analysis of occultation of 28 Sgr by Saturn system from McDonald Observatory using IR CCD camera and multichannel photometer; 2) Comprehensive search for weak normal modes in Uranus' narrow eccentric rings; 3) Improvement of Uranus ring orbit model to include weak dynamical effects; 4) Detailed inversion of Earth-based occultation observations of Uranus and Saturn upper stratosphere, using information obtained from Voyager solar and stellar occultations; 5) Search for faint rings and ring arcs in Uranus system using Voyager images and stellar occultation observations (in progress).

(c) Proposed Work: 1) Analysis of observations from McDonald Observatory of the occultation of 28 Sgr by Saturn and its rings, including a joint astrometric solution for the ring system based on both Earth-based and Voyager 1 and 2 ring occultation data. 2) Identification of weak dynamical effects in the Uranian ring system from fits for the ring orbits using an improved kinematical model. 3) Analysis of Uranus stellar occultations to be obtained during the summer of 1990. 4) Observational tests of processes that might generate the observed anomalous ring width variations of the four narrowest elliptical Uranus rings. 5) Observations of a stellar occultation by Neptune's ring arc system during the summer of 1991. 6) Comparison of upper stratospheric temperatures of Saturn, Uranus, and Neptune inferred from Voyager ultraviolet occultations with results of ground-based occultation observations.

(d) Summary Bibliography: Baron, French, and Elliot, "The Oblateness of Uranus at the 1 Microbar Level" (1989) *Icarus* 78, 119-130; Baron and French, "New Uranian Atmospheric Temperatures..." (1989) *BAAS* 21, 916; French et al., "The 3 July 1989 Occultation of 28 Sgr..." (1989) *BAAS* 21, 928; French, Nicholson, Porco, and Marouf, "Dynamics and Structure of the Uranian Rings" (1990). A chapter in *Uranus* (U. of Arizona Press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Herbert Frey
(Name, Address, Code 621, Goddard Space Flight Center
Telephone Number) Greenbelt, MD 20771 301-286-5450

Co-INVESTIGATORS: Richard A. Schultz
(Name Only)

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: Completed a new inventory of large multi-ring impact basins on Mars. Developed a model for the evolution of the northern lowlands in eastern Mars and for the growth of the Elysium tectono-volcanic complex in terms of the long-term evolution of two very large overlapping impact basins. Determined the resurfacing history of Tempe Terra and other regions, and showed that what are mapped as Noachian-age ridged plain in Memnonia and Argyre are actually Hesperian-age but so thin that older Noachian age cratered terrain shows through. (c) Proposed Work: Concentrate search for impact basins on Mars in the south polar regions where large circular topographic lows and major volcanic flows exist, in order to determine if the apparent paucity of large impact basins in the southern hemisphere is real or due to incomplete mapping. Undertake detailed structural and stratigraphic study of the dichotomy boundary in Acidalia, where the boundary departs significantly from a simple small circle, and compare with the boundary further east in Ismenius Lacus and Amenthes-Aeolis to assess whether endogenic or exogenic processes are responsible for the origin of the dichotomy in this part of Mars. Study additional *Nplr* units to determine the true crater retention age of the ridged plains and assess whether ridged plains are restricted to Early Hesperian and later times. (d) Publications: Schultz, R. A. and Frey, H. V., A New Survey of Multi-Ring Basins on Mars, in press, J. Geophys. Res., 1990. Frey, H. and Grant, T. D., Resurfacing History of Tempe Terra and Surroundings, in press, J. Geophys. Res., 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael J. Gaffey, Department of Geology,
(Name, Address,
Telephone Number) West Hall, RENSSELAER POLYTECHNIC INSTITUTE,
Troy, New York 12180-3590 (518)-276-6300

Co-INVESTIGATORS: _____
(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: The goal of this work is an improved 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 characterizations provide information on early conditions and processes at particular heliocentric distances, and provide a spatial context or constraints for data and models derived from meteorite studies. Our work involves lithologic 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 survey the S-type asteroids from the 52-color survey data and showed that a wide range of non-chondritic silicates ranging from pure olivines (dunites) to basalts are present on S-asteroids; 2) Discussed the consequences of the observed asteroid compositional patterns for early solar system conditions and for terrestrial planet accretion in papers for two proceedings volumes; 3) Showed a systematic difference in the infrared emissivities of the S & M-type asteroids relative to the other asteroid classes consistent with high surface metal abundances; and 4) Identified the presence of specific phyllosilicate mineral types in the surface materials of certain low-albedo asteroids.

c. Proposed Work: Asteroid rotational spectral analysis will include: (349) Dembowska [thermal history and achondritic affinities - preparation of publication]; (387) Aquitaina [investigation of spinel features and evaluation of links to the C3V chondrites]; Analysis of of CCD spectra of S-asteroids for detailed mineral chemistry. Laboratory studies will include: spectral effects of metamorphism and aqueous alteration of carbonaceous chondrites; and the spectral calibration of porphyrins and other organics in meteoritic assemblages.

d. Recent Publications: Gaffey, M.J. (1990) Implications of asteroid surface mineralogy for evolution of the inner belt. in Asteroids, Comets, Meteors III (H. Rickman, P. Magnusson, and C.-I. Lagerkvist, eds.), Uppsala University, Uppsala, Sweden, pp. 77-86; Gaffey, M.J., J.F. Bell, R.H. Brown and T. Burbine (1990) Mineralogical variations within the S-asteroid population. Lunar Planet. Sci. XXI, 399-400; Vilas, F. and M.J. Gaffey (1989) Phyllosilicate absorption features in main-belt and outer-belt asteroid reflectance spectra. Science 246, 790-792.

PROPOSAL SUMMARY

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

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

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) Development of a physical model and computer simulation of Voyager camera distortions and photometric corrections (Gaskell, 1990).
- (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. Work on modeling of camera distortions and photometric corrections will be completed. We shall also find the Voyager 1 camera focal lengths. 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 (to appear).
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).

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:

A 'Dense Atmosphere' Model for
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. A better model for light scattering in regoliths will also enable more accurate calculation of surface temperatures, the vertical deposition of heat important to solid-state greenhouse models, and exposure times for future spacecraft observations.

B. PROGRESS: Adaptation of lunar regolith particle size studies to light scattering calculations. Recognition that sorting is a 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 some common compositions. Preliminary generalizations deduced from completed calculations.

C. PROPOSED WORK: 1) Use the doubling method to rigorously calculate multiple scattering in an optically thick layer of these particles to generate a 'dense atmosphere' model for regolith scattering. 2) Study the breakdown of the independent scattering approximation and interparticle shadowing for a range of particle albedos and sizes by comparing 'dense atmosphere' models with measurements of laboratory samples of spheres of known sizes and compositions. 3) Develop and test the 'dense atmosphere' model for the case of binary mixtures of particles with very different scattering properties. 4) Determine particle size distributions and compositions that are consistent with photometry and polarimetry of planetary regoliths (e.g. Titania, Europa, the Moon). 5) Use the 'dense atmosphere' model evaluated at wavelengths lacking photometry and polarimetry to predict observable photometric and polarimetric characteristics to test the validity of the model and refine our knowledge of regolith physical properties.

D. SUMMARY BIBLIOGRAPHY: Goguen, J. D. et al. (1989), V-filter Photometry of Titania, Oberon, and Triton Icarus 77, 239-247.; Smith, B. A. et al. (1989), Voyager 2 at Neptune: Imaging Science Results, Science 246, 1422-1429; 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.

PROPOSAL SUMMARY

Principal Investigator: Matthew P. Golombek
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(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 in press on subsurface structure and thermal gradients on Europa from lithosphere deformation models of observed tension cracks. 2) Paper in press on mechanical discontinuities in the shallow crust of Mars. 3) Chapter in press for University of Arizona book on Mars, Stress and Tectonics on Mars. 4) Completed review article on tectonic processes on the terrestrial planets. 5) Derived model for the possible involvement of most of the lithosphere in the formation of planetary wrinkle ridges.

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, and evaluate the subsurface structure of grabens and pits around Alba Patera, based on their width, depth, size, spacing, and likely mechanical models. 2) Collect photoclinometric data of wrinkle ridges on Mercury and Mars, and further develop kinematic models that include the subsurface structure and tectonic shortening across them to better constrain lithospheric deformation on planetary surfaces. 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: Golombek, M. P., and Banerdt, W. B., in press, Constraints on the subsurface structure of Europa: *Icarus*, January 1990. Davis, P. A., and Golombek, M. P., in press, Discontinuities in the shallow Martian crust at Lunae, Syria, and Sinai Plana: *Journal of Geophysical Research*, August 1989. 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 review, Tectonic processes in the terrestrial planets: Review article in The Reference Encyclopedia of Astronomy and Astrophysics, September 1989. Banerdt, W. B., and Golombek, M. P., 1990, The evolution of Tharsis: Implications of gravity, topography, and tectonics (expanded abstract): *Lunar and Planetary Science XXI*, p. 42-43. Golombek, M., Suppe, J., Narr, W., Plescia, J., and Banerdt, B., 1990, Does wrinkle ridge formation on Mars involve most of the lithosphere? (expanded abstract): *Lunar and Planetary Science XXI*, p. 421-422.

PROPOSAL SUMMARY

**PRINCIPAL
INVESTIGATOR:**

James L. Gooding
SN21/Planetary Science Branch
NASA Lyndon B. Johnson Space Center
Houston, Texas 77058
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TITLE:

Thermodynamics and Kinetics of
Planetary Volatile/Regolith Interactions

ABSTRACT:

a. Objectives. Quantitatively assess regolith interactions with volatile compounds as geologic processes on Mars, comets, and other low-temperature planetary bodies. Use differential scanning calorimetry (DSC) and evolved gas analysis (EGA) to measure phase stabilities and reaction rates for interactions of water and other volatiles with candidate regolith materials.

b. Progress in FY1990. (1) Experimentally determined that vacuum-weathered sulfur (prepared and proposed as analog material for Io by D. B. Nash) possesses phase compositional properties that are intermediate between those of ordinary sulfur and polymeric sulfur. New DSC data confirmed previously suspected tendency of vacuum-weathered sulfur to behave as if enriched in the polymeric allotrope. (2) Completed theoretical assessment of the material concentrations of chemically reactive agents in Martian surface sediments, using data from the Viking biology experiments. Results showed that total concentrations of the reactive agents could not have been more than a few hundred parts per million (ppm) and were likely to have been < 1 ppm. (3) As lead author, completed final revisions for the chapter on "Physical and chemical weathering" to appear in the book, *MARS* (H. H. Kieffer, B. M. Jakosky, and C. W. Snyder, Eds.), to be published by the University of Arizona Press. Co-authors were R. E. Arvidson and M. Yu. Zolotov. (4) As co-author, completed paper on material properties of a Mars-like Hawaiian palagonitic soil (with R. V. Morris).

c. Proposed Work for FY1991. (1) Determine stability ranges for water-substrate complexes formed by interaction of water with selected geologic substrates at low temperatures (100-300° K). Based on phenomena previously observed by DSC during freeze-thaw cycling of soils, palagonite tuff, palagonitic soil, and smectite substrates will be used to simulate complexation under Martian conditions. Carbonaceous chondrites will be used to simulate complexation under conditions that might apply to the Martian moons (Phobos and Deimos) or cometary nuclei. Results will identify proportions of water inventories that might be sequestered in forms with thermal stabilities intermediate between those of ice and structural or adsorbed water in hydrated minerals. (2) Determine stability of hydrogen peroxide, H_2O_2 , with respect to catalytic decomposition or chemical reaction while in contact with Mars-analog materials, including palagonite- and smectite-bearing materials, sulfate and chloride salts. Emphasis will not be on formation of H_2O_2 but on the kinetics of its decomposition under Martian conditions. Results will help constrain the survivability of H_2O_2 as a major oxidant in models for surface chemistry on Mars. (3) Complete measurement of thermodynamic properties of sulfur evolved in vacuum as they might apply to surface materials on the Jovian satellite, Io (with D. B. Nash as collaborator).

d. Summary Bibliography (FY1990). (1) Gooding J. L. and Nash D. B. (1990) Submitted to *Reports of the Planetary Geology and Geophysics Program -1989*, NASA, Washington, DC. (2) Gooding J. L. (1990) op cit. (3) Gooding J. L. et al. (1990) In H. H. Kieffer et al. (Eds.), *MARS*, University of Arizona Press, in press. (4) Morris R. V. et al. (1990) *J. Geophys. Res.*, in press.

e. Personnel. Principal Investigator (25% time) and one support-contractor scientist/engineer (20% time) at JSC.

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

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CO-INVESTIGATOR:

Lisa Gaddis
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PROPOSAL TITLE: *Geological Studies in Planetology*

ABSTRACT

OBJECTIVE: The goals of this investigation are: 1) to study aspects of remote sensing important for Planetary Geology, including determination of the utility 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 strengths 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) the second task is to study volcanic geomorphology with the focus on: a) the surface appearance of ash deposits, and b) 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 areas on Mars including highland paterae.

PROGRESS: a) linear mixing models have been applied to TM data for the Kelso Dunes in conjunction with the Geology Remote Sensing Field Experiment (GRSFE), b) field work has been completed in Kelso to obtain samples to test the model, c) radar geologic mapping has been initiated for the GRSFE test site, applying planetary geologic mapping principles, d) data have been collected for volcanic ash deposits in South America, e) background information has been collected on komatiite lava flows on Earth in preparation for field work in the summer, 1990, and f) results of the terrestrial analog work have been applied to the study of highland paterae on Mars.

PROPOSED WORK: a) continue application of mixing model to the study of the Kelso dune field; extend work using AVARIS data, b) continue radar geologic mapping of GRSFE site; initiate TM mapping; compare results with field studies, c) complete studies of ignimbrite deposits in Bolivia, d) apply terrestrial analog studies to other highland paterae on Mars, e) initiate field studies of komatiite flows on Earth, and f) assess remote sensing characteristics of komatiites and other ultramafic lava flows.

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.* (in press).
- 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.
- Greeley, R., Christensen, P. and Carrasco, R., 1989, Shuttle radar images of wind streaks in the Altiplano, Bolivia, *Geology*, 17, 665-668.
- Greeley, R. and Crown, D.A., 1990, Volcanic geology of Tyrrhena Patera, Mars, *J. Geophys. Res.* (in press).

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

Ronald Greeley
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Arizona State University
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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: (new proposal)

PROPOSED WORK:

a) Use results from the general circulation model (GCM) for the martian atmosphere to predict surface wind direction and magnitude and compare the results with the distribution and orientation of aeolian surface features in a continuation of previous studies; will incorporate refinements to include assessment of maximum winds (as opposed to average winds) and consideration of threshold winds for different sizes of particles, extension of the study to the polar regions, consideration of past climates on Mars, and adaptation of a "drift potential" expression for Earth to the martian environment to assess the potential flux of windblown sand on Mars, b) analyze terrestrial parna deposits (mixtures of sand and "dust") as potential analogs to Mars; includes determining the size range of parna pellets, their evolution during transport by winds, their threshold velocities, and the morphology and geology of parna deposits in the southwest United States; results will be applied to the study of potential aeolian deposits mantling the southern cratered highlands of Mars and as associated with possible martian "paleo-lakes".

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. Skyeck, and J.B. Pollack, 1990, Martian aeolian features and deposits: Comparisons with general circulation model results (submitted).
- Lancaster, N. and R. Greeley, 1990, Sediment volume in the north polar sand sea of Mars, *J. Geophys. Res.* (in press).
- Lancaster, N., 1988, A bibliography of dunes: Earth, Mars, and Venus, *NASA CR-4149*, 113 p.

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

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Arizona State University
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SCIENTIFIC COLLABORATOR:

H.J. Melosh (Task 1)
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PROPOSAL TITLE: *Geological Studies of Outer Planet Satellites*

ABSTRACT

OBJECTIVE:

This proposal has three principal objectives: a) to assess the potential for impact-generated antipodal disruptions on icy satellites using computer models and photogeology, b) to determine the origin(s) and evolution of ridge and trough terrains on icy satellites and assess the similarities and differences in the process(es) shaping the terrain, and c) conduct global geological mapping for Io and Callisto. Meeting these objectives will enable better definition of the surface evolution for many of the outer planet satellites. Global geological maps of Io and Callisto will provide a framework for geological and geophysical studies and will be important bases for the forthcoming Galileo mission.

PROGRESS:

a) A program has been modified and adapted to run on the ASU VAX 11/750 to model the seismic disruption of terrains antipodal to large impacts. Runs have been evaluated for specific cases on the Moon, Mercury, and on several of the icy satellites, and a manuscript has been prepared of the results, b) a classification scheme has been developed for ridged and grooved terrains on icy satellites and working hypotheses have been formulated for the origin of the various classes, c) a geological map for Io has been reviewed, revised, and returned to the U.S. Geological Survey and is currently in the technical editing process, d) an initial draft of the Callisto geological map has been completed.

PROPOSED WORK:

a) complete the geologic map for Callisto, including preparation of unit descriptions, explanation and text, and submit to U.S. Geological Survey for review, b) modify the computer code for antipodal disruption to take into account non-spherical geometries of the objects being impacted, and c) complete the study of ridged and grooved terrain by testing the proposed hypothesis for the origin of the classes.

REFERENCES:

- Greeley, R., S.W. Lee, D.A. Crown, and N. Lancaster, Observations of industrial sulfur flows: Implications for Io, *Icarus*, in press.
- Greeley, R., D.A. Crown, R.A. Craddock, and G.G. Schaber, Geologic map of Io, 1:15,000,000, in review, *U.S. Geological Survey*.
- Pappalardo, R. and R. Greeley, 1990, Models for ridge and trough terrain on icy satellites and the origin of ridges in Elsinore Corona, Miranda, *Repts. Planetary Geology Geophysics Program* (in press).
- Watts, A., R. Greeley, and H.J. Melosh, 1990, The formation of "antipodal terrains" resulting from impact events, *J. Geophys. Res.* (ms submitted).

PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR:

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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. In addition, the general geomorphology of the area has been studied, and geological histories have been derived.

A 1:500,000-scale geologic map has been produced for the summit region of Hadriaca Patera (-30267), as presented at the August, 1989 Mars Geologic Mappers meeting in Flagstaff.

PROPOSED WORK:

Geologic mapping of the adjacent 1:500,000 sheet (-35267) will be undertaken for Hadriaca Patera. The summit region quadrangle will be carried into the review process.

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.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Richard Greenberg
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721
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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 study the dynamics of low-velocity encounters among orbiting bodies and transport processes that govern the spatial distribution of a swarm. We will review and intercompare models of the early planet growth stage. Research on meteorite origins and delivery processes will concentrate on the effect of initial injection onto Earth-bound trajectories. Outer-planet satellite work will concentrate on evolutionary paths for the Galilean satellites.

(d) Summary Bibliography: 14 papers and 8 abstracts of presentations.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bradford H. Hager
(Name, Address,
Telephone Number) Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
617/253-0126

CO-INVESTIGATORS: None
(Name Only)

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

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

Mantle convection controls the heat transport and tectonics of Venus and Earth. Our main research 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 expected increase in data constraining Venus's tectonics from Magellan.

b) Accomplishments of prior "year"

Our major new accomplishment of the past year is the development of an analytic model for crustal deformation of Ishtar Terra. The thickness of the surrounding crust must be < 25 km in order that the low viscosity of the lower crust not permit the mountains to collapse under their own weight. We have also developed the finite element codes that will make possible more realistic models of this process.

c) Proposed work

We will develop numerical models addressing the interaction of mantle convection with crustal deformation and crustal recycling. These models will 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. We will also 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) Publications

Kiefer, W. S., and B. H. Hager, Mantle downwelling and crustal convergence: A model for Ishtar Terra, Venus, *J. Geophys. Res.*, submitted, 1990.

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.

PROPOSAL SUMMARY

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

SCIENTIFIC COLLABORATORS: R. Nelson, W. Smythe, S. Ostro,
D. Paige

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 analyses of images taken by spacecraft and of ground-based observations, with supporting observational, experimental and theoretical research.

(b) Accomplishments of prior year: (1) Continued experimental and theoretical study of light scattering by large, irregular particles. (2) Continued photometric analysis of Voyager and ground-based observations of Europa. (3) Continued theoretical study of effects of thermal emission on reflectance spectra. (4) Identified newly-recognized phenomenon of coherent backscatter as potentially of major importance to the interpretation of both radar and visible wavelength data on outer planet satellites.

(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) Complete photometric analysis of Europa data. (4) Begin experimental investigation of coherent backscatter.

(d) Recent Publications: E. Bowell, B. Hapke, K. Lumme, A. Harris, D. Domingue and J. Peltoniemi (1989) "Application of Photometric Models to Asteroids", in Asteroids II, ed. by T. Gehrels, U. of Ariz. Press, pp. 524-556; D. Domingue & B. Hapke (1989), "Europa's Opposition Effect", BAAS, 21, 984; B. Hapke (1989) "Coherent Backscatter: An Explanation for the Unusual Radar Properties of Outer Planet Satellites", BAAS, 21, 984; A. McGuire and B. Hapke (1990), "Light Scattering by Large Irregular Particles", Lunar & Planetary Science XXI, 767-768.

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: In the last year, most effort has been expended toward publishing observational results from Table Mountain Observatory. 11 full papers and 2 extended abstracts were published in 1989. Principal results include: 1) lightcurve observations from TMO of about 75 asteroids were published. 2) About 100 sets of asteroid phase data have been fit to the H-G magnitude system to derive mean slope parameters for each of the major taxonomic classes of asteroids. 3) The E class asteroids 44 Nysa and 64 Angelina were found to have nearly identical phase relations, exhibiting an "opposition spike" at phase angles under 2° , remarkably similar to that of Saturn's rings, but quite different from that of any other observed asteroid. 4) Several dark asteroids were found to show much less opposition brightening than expected. 5) Several new techniques of data analysis and reporting have been developed and implemented, including modeling of time variable extinction, Fourier analysis of lightcurves to construct composites and phase relations, and archiving of lightcurve data in machine readable form. 6) The theoretical model of collisional evolution of asteroid rotations was extended to non-spherical shapes. 7) The tidal evolution of binary asteroids was investigated to model such objects as 1989 PB.

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 summarizing the results of fitting the H-G magnitude relation to all available phase data in the literature, to define nominal values of the slope parameter for asteroids where it has not been observed, and to explore deviations of the function from observations, with the aim of updating the H-G function, and making physical interpretations of individual objects; 3) Continue a study of debris clouds about asteroids with numerical calculations.

d. Summary bibliography: 11 full papers (5 with Harris as first or sole author) and 2 extended abstracts were published. All are attached.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William K. Hartmann
(Name, Address, Planetary Science Institute
Telephone Number) 2421 E. 6th Street, Tucson AZ 85719
602/881-0332

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Intense Planetary Cratering and Its Effects

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 requests a renewal of a multi-year study of planetary cratering and cratering effects on the evolution of planets. The program concentrates on effects of the early intense cratering of the solar system and heavily cratered surfaces, which are crucial to current interpretations of early Earth history and various satellite and planet surfaces.
 - (b) Progress in the current first year of the study was seriously impacted by a delay in funding. Funding was not received until 3 April, 1990, so that, in principle, no work should have been completed by this date. However, some progress was made on the collaborative study with Dr. David Grinspoon (NASA Ames) on early cratering of Earth, a study which appears very timely in view of recently published papers and the planned 1990 conference on early history of Earth.
 - (c) Proposed tasks are (1) completion of a paper with Dr. Grinspoon on our quantitative modeling of the flux vs time in the early history of Earth, derived from dynamical models of planetesimal scattering calibrated by lunar cratering data, and (2) studies of crater densities in far side heavily cratered lunar areas, to test whether the Strom "lunar highlands" crater diameter distribution, used by the Voyager team as a fundamental calibration, is correct. My earlier studies suggest it is not.
 - (d) Hartmann, W. K. (1989) Phobos: Comparison of Small Craters on Phobos and the Moon. LPSC 20, abstracts; Hartmann, W. K. (1988) Crater Saturation Equilibrium in the Solar System: New Evidence. LPSC 19 abstracts. p. 449.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: B. Ray Hawke
(Name, Address, Planetary Geosciences
Telephone Number) 2525 Correa Road, Honolulu, HI 96822
(808) 948-6488 (after 5/1/90: (808) 956-6488)

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Remote Sensing and Geologic Studies of Lunar and 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, Ganymede, Callisto, Mercury, and the asteroids, 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) our spectral data rule out all hypotheses for the origin of the Reiner Gamma Formation except cometary impact; 5) a remote sensing study of Alphonsus was published; 6) final spectral results were presented for A-type asteroids and 1984 KB; 7) spectral data for lunar impact basins were acquired and analyzed. Pure anorthosite deposits were identified on Orientale and Nectaris basin rings and a summary paper was published; 8) definite or probable rotational spectral variations have been found associated with 16 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-ITR 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 processes 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; 4) continue studies of dark-haloed craters and fresh, bright craters on Ganymede and Callisto; 5) continue studies of lunar resources and outpost sites; 6) conduct a spectral study of Mercury; 7) continue investigations of impact melt deposits associated with craters on the Moon, Mercury, and Earth; 8) conduct geologic and remote sensing studies of lunar rilles to better understand the processes responsible for their formation; 9) continue our efforts to understand the composition and mode of emplacement of lunar pyroclastic deposits; and 10) support the Galileo lunar encounter.
- d) Summary Bibliography: (last year) 10 papers published, 5 papers submitted, 18 extended abstracts (2 or 3 pages), 13 abstracts, 28 oral presentations, 1 Ph.D. Thesis, 2 NASA SPs.

ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head, III

CO-INVESTIGATORS AND SCIENTIFIC COLLABORATORS:
L. Wilson, L. Parfitt, L. Crumpler, S. Murchie, S. Keddie, E. Fischer, J. Aubele, N. Efford

PROPOSAL TITLE: Surface Processes on Mars and its Satellites

ABSTRACT:

a) Objectives: To gain further understanding of the major geological processes on Mars and its satellites through theoretical analysis and observations of volcanism, volcanic deposits and edifices on Mars, and the processes of low velocity cratering and devolatilization on the satellites.

b) New Proposal:

c) Proposed work: 1) Utilize the general theoretical analysis of volcanism in the martian environment to address specific problems associated with plinian, strombolian, hawaiian, vulcanian, and effusive eruptions, specifically the role of volatiles in producing landforms and deposits; 2) examine aspects of effusive eruptions to assess the origin of pyroclastic cones and sinuous rilles; 3) Assessment of the nature and evolution of martian central volcanic edifices, including comparative morphology and structure, associated volcanological processes, processes of caldera formation and evolution, comparisons in style in space, and time, and aspects of composition; 4) Theoretical studies of internal and external processes on Phobos and Deimos with emphasis on the processes of low velocity impact cratering and devolatilization, and comparison to observations.

d) Summary bibliography: (1) Wilson, L. and Head, J. (1990) Ascent and eruption of magma on Mars: Theory and observations: to be submitted to *Jour. Geophys. Res.*; (2) Wilson, L. and Head, J. (1990) Factors controlling the structure of magma chambers in basaltic volcanoes: *LPSC XXI*, 1343-1344; (3) Wilson, L. and Head, J. (1989) Dynamics of groove formation on Phobos by ejecta from Stickney: *LPSC XX*, 1211-1212. (4) Murchie, S., Head, J. and Efford, N. (1989) Morphologic classes of grooves on Phobos: *LPSC XX*, 744-745; (5) Crumpler, L. and Aubele, J. (1989) Influence of volcanic and tectonic stresses on the flank structure of martian volcanoes: MEVTV Conference Abstracts, Richland, Washington, June, 1989; (6) Crumpler, L. et al. (1990) Calderas on Mars: Implications of style and history for subsurface magmatism: *Abstracts for MEVTV Workshop on Magma Bodies on Mars*, LPI, 14-15; (7) Crumpler, L. et al. (1990) Preliminary analysis of Arsia Mons geology as characterized by Phobos 2 Termoskan instrument: *Abstracts for MEVTV Workshop on Magma Bodies on Mars*, LPI, 16-17.

PLANETARY DATA ANALYSIS AND PROCESSES OF CRUSTAL FORMATION AND EVOLUTION

PRINCIPAL INVESTIGATOR: James W. Head, III

CO-INVESTIGATORS AND SCIENTIFIC COLLABORATORS: D. B. Campbell, C. Sotin, P. Hess, E. Parmentier, L. Wilson, D. Senske, S. Frank, L. Crumpler, J. Burt, K. Roberts, S. Keddie, J. Aubele, A. Basilevsky, O. Nikolaeva, M. Ivanov, A. Selivanov, J. Garvin, E. Stofan, J. Harmon.

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 availability 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 the nature of planetary chemical layering.

b) Progress: New Proposal

c) Proposed work: 1) Planetary Data Analysis: a) analysis of time-varying phenomena on Venera lander images and assessment of the regional geology of the Venera sites; b) correlation of Pioneer-Venus imaging data with other data sets; c) complete detailed data reduction and analysis from the Arecibo Venus 1988 opportunity; d) analysis of assemblages of Venera geologic units; e) continuation of analysis of equatorial Arecibo altimetry into eastern Aphrodite and Phoebe Regio; f) mapping of lunar regions using Arecibo data. 2) Processes of Crustal Formation and Evolution: a) assessment of major processes of crustal formation and evolution on Venus; b) assessment of models of spreading centers in the Venus environment; c) study of the formation of plume plateaus; d) analysis of underthrusting and melting relationships at compressional deformation zones; e) analysis of accretion of plume plateaus and protocontinental formation on Venus and Earth; f) documentation of petrological evolution of the crust in different tectonic environments; g) analysis of formation and evolution of primary and secondary crust on one-plate planets.

d) Summary bibliography: (1) Campbell, D.B., Head, J.W., Hine, A.A., Harmon, J.K., Senske, D.A. and Fisher, P.C. (1989) Styles of volcanism on Venus: New Arecibo high resolution radar data: *Science*, 246, 373-377; (2) Head, J.W. (1989a) Basic assemblages of geologic units in the Venus northern hemisphere: *Lunar and Planetary Science XX*, 392-393; (3) Head, J.W. (1990a) Venus crustal formation and evolution: An analysis of topography and crustal thickness variations: *Lunar and Planetary Science XXI*, 477-478; (4) Sotin, C., Senske, D.A., Head, J.W. and Parmentier, E.M. (1989) Terrestrial spreading centers under Venus conditions: Evaluation of a crustal spreading model for western Aphrodite Terra: *Earth and Planetary Science Letters*, 95, 321-333; (5) Head, J. W. and Crumpler L. S. (1987) Evidence for divergent plate-boundary characteristics and crustal spreading on Venus: *Science*, 238, 1380-1385; (6) Vorder Bruegge, R.W. and Head, J.W. (1990) Formation of eastern Ishtar Terra Venus: A comparison of models: *Lunar and Planetary Science XXI*, 1282-1283; (7) Hess, P.C. and Head, J.W. (1989) Derivation of primary magmas and melting of crustal materials on Venus: Some preliminary considerations: *Abstracts of the 28th International Geological Congress*, Washington, DC, July 9-19, 1989, 55; (8) Hess, P.C. and Head, J.W. (1990) Spreading center processes under Venus conditions: Implications for crustal formation, petrology and structure: *Lunar and Planetary Science Conference XXI*, 503-504; (9) Head, J.W. (1981) Lava flooding of ancient planetary crusts: Geometry, thickness, and volumes of flooded lunar impact basins: *Moon and Planets*, 26, 61-88.

ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head, III

CO-INVESTIGATORS AND COLLABORATORS: L. Wilson, E. Parfitt, L. Crumpler, K. Roberts, J. Aubele, E. Slyuta, and A. Basilevsky.

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) Progress: 1) Assessment of the nature of dike systems feeding flank eruptions; 2) Assessment of the nature of shallow magma chambers below cinder cones and domes; 3) Analysis of the factors responsible for the development of pyroclastic eruptions and the characteristics of pyroclastic eruption types (Hawaiian, etc.); 4) Interpretation of the variables in pyroclastic eruptions and how these variations can be interpreted from the resulting facies and deposits; 5) Initial assessment of the role of gravity in planetary eruption characteristics; 6) Preliminary assessment of the characteristics of Venus upland plains and calderas and associated eruption conditions; 7) Initial assessment of Venus cone/dome fields and interpretation of eruption conditions.

c) Proposed work: 1) Completion of a model of the nature of dike systems feeding flank eruptions; 2) Completion of a model for the nature of shallow magma chambers below cinder cones and domes in Hawaii and application to other deposits; 3) Further analysis of the factors responsible for the development of pyroclastic eruptions and the characteristics of pyroclastic eruption types (Hawaiian, etc); application to the eruption sequence of Hawaiian rift eruptions; 4) Further development of a model for the interpretation of variables in pyroclastic eruptions and how these variations can be interpreted from the resulting facies and deposits; application to observations of deposits; 5) Completion of the assessment of the role of gravity in planetary eruption characteristics; preparation of manuscript for publication; 6) Continuation of the assessment of the characteristics of Venus upland plains (Lakshmi Planum) and associated eruption conditions and assessment of the sources of melting and formation of calderas. 7) Completion of the initial assessment of Venus cone/dome fields and interpretation of eruption conditions; mapping of additional areas for continuation of assessment.

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 volcanism: Basal melting of thickened crust? *LPSC XXI*, 1019-1020. (3) L. Wilson and J. Head (1990) Factors controlling the structures of magma chambers in basaltic volcanoes. *LPSC XXI*, 1343-1344. (4) J. Aubele (1990) Two global concentrations of small dome-like hills on Venus. *LPSC XXI*, 32-33.

ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head, III

SCIENTIFIC COLLABORATORS:

L. Crumpler, E. Parmentier, D. Senske, E. Stofan, S. Frank, S. Murchie, S. Keddie, R. Vorder Bruegge, J. Aubele, A. Basilevsky, V. Kryuchkov, C. Sotin, D. Campbell, D. Bindschadler.

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) Progress: 1) Completed initial study of rifting as a geologic process in the Beta Regio area and continued analysis of Beta Regio area; 2) Documented evidence for divergent plate boundary characteristics in the Aphrodite Terra region; 3) Continued documentation of convergence, compressional deformation, and the formation of orogenic belts in the Maxwell and Freyja Montes area of Ishtar Terra, and in ridge belts in the Venus plains; 4) Continued documentation of the characteristics of corona structures and continued development of models for their origin; 5) Continued documentation of the characteristics of tessera terrain, and continued development of models for its origin.

c) Proposed Work: 1) Extend study of rifting in the Beta Regio area east to Asteria, and south to Phoebe Regio; 2) Continue the documentation of evidence for divergent plate boundary characteristics in the Aphrodite Terra region, and assessment of characteristics of other parts of the equatorial highlands; 3) Continue documentation of convergence and compressional deformation and the architecture of orogenic belts, with emphasis on the evolution of orogenic belts in Ishtar Terra and their relationships, and in ridge belts in the Venus plains and their link to compressional and extensional deformation; 4) Continue documentation of the characteristics of corona structures for the area covered by Venera 15/16 and in detail for the region west of Ishtar Terra, and continued development of models for their origin; 5) Continue documentation of the characteristics of tessera terrain with emphasis on distinguishing models for its origin.

d) Summary Bibliography: (1) Senske, D. A., Head, J. W., Stofan, E. R. and Campbell, D. B. (1990) Geology and structure of Beta Regio: Results from new Arecibo data: *Lunar and Planetary Science XXI*, 1128-1129. (2) Head, J. W. and Crumpler, L. S. (1989) Divergent plate boundary characteristics and crustal spreading in Aphrodite Terra, Venus: A test of some predictions: *Earth, Moon, and Planets*, 44, 219-231. (3) Head, J. W. (1990) Formation of mountain belts on Venus: Evidence for large-scale convergence, underthrusting, and crustal imbrication in Freyja Montes, Ishtar Terra: *Geology*, 18, 99-102. (4) Frank, S. L. and Head, J. W. (1990) Styles of compressional deformation on Venus: Examples from ridge belts: *Lunar and Planetary Science XXI*, 387-388. (5) Stofan, E. R. and Head, J. W. (1990) Coronae of Mnemosyne Regio: Morphology and origin: *Icarus*, 83, 216-243. (6) Bindschadler, D. L., Kreslavsky, M. A., Ivanov, M. A., Head, J. W., Basilevsky, A. T. and Shkuratov, Yu. G. (1990) Distribution of tessera terrain on Venus: Prediction for Magellan: *Geophysical Research Letters*, 17, 2, 171-174. (7) deCharon, A. V. and Head, J. W. (1990) Structure of Laima Tessera: Comparison with Earth's oceanic crust: *Lunar and Planetary Science XXI*, 262-263.

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, with emphasis on Ganymede (and comparison of it to Callisto), Enceladus and Ariel. The goal is to complete a detailed investigation of volcanic resurfacing and tectonic modification of Ganymede, to use this as a reference frame for a comparative study of the styles of volcanism and tectonism on other icy satellites with highly evolved surfaces, and to use these results to assess models for the internal dynamical and thermal evolution of these icy satellites.

b) New Proposal.

c) Proposed Work: (a) We will complete a detailed investigation of the tectonic evolution of grooved terrain on Ganymede, 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 undertake an investigation of theoretical aspects of ammonia-water volcanism on large icy satellites, and will assess geologic evidence for the involvement of ammonia in icy-satellite volcanism.

d) Summary bibliography: (a) Murchie, S., J. Head, J., Plescia, and P. Helfenstein, Terrain types and local-scale stratigraphy of grooved terrain on Ganymede, *J. Geophys. Res.*, **91**, E222-E238, 1986; (b) 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.*, in press, 1990; (c) Murchie, S., The volcanic and tectonic history of Ganymede, *Lunar Planet. Sci. XX*, 742-743, 1989; (d) Murchie, S., The tectonics of icy satellites, *Advances in Space Research*, **10**, 173-182, 1990; (e) Sotin, C., and S. Murchie, Internal dynamics of a differentiated Ganymede: Constraints from experimental data, *Lunar Planet. Sci. XIX*, 1107-1108, 1988; (f) 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.

PROPOSAL SUMMARY AND ABSTRACT

PRINCIPAL INVESTIGATOR:

Keith A. Holsapple

Aeronautics and Astronautics, FS-10

University of Washington, Seattle, WA 98195

(206) 543-6198

CO-INVESTIGATORS:

None

TITLE:

FUNDAMENTAL STUDIES OF IMPACT MECHANICS V

ABSTRACT:

a. **Objective:** This research involves theoretical and numerical studies of a variety of impact phenomena, including cratering, surface spall and catastrophic fragmentation. An important facet of the research is to continue to develop and apply scaling laws to bridge the gap between small-scale laboratory experiments and the planetary conditions of interest.

b. **Progress:** It has been determined that the coupling parameter measure arises from and governs the point-source solutions that evolve soon after the initial impact. The existence of that single measure requires many scaling laws to have the observed power-law forms. The **physical** basis for the value of the governing exponents of those power laws was not known. Results during the present funding period have uncovered a number of cases where analytical point source solutions exist, and can be derived, for equations of state which approximate those for geological materials in the range of the problem where the coupling of the source into the problem occurs. Progress also has been made on an important new approach to the numerical solution of impact problems. It is based on a finite element approach with discontinuous basis functions. A discontinuous solution with a shock wave can be captured exactly, and moving shock waves can be explicitly followed without smearing the shock over several zones.

c. **Proposed Work:** Continue theoretical formulation and analyses of point-source solutions for geological materials...Compare real impact problems to those theoretical point-source solutions using existing codes. Continue efforts to develop finite-element code approaches that explicitly capture discontinuous shock wave solutions. Apply results obtained to cases involving impact events in planetology.

d. **Summary Bibliography:**

Holsapple, K.A., "Scaling Issues for Impact Cratering", *Lunar and Planetary Science XXI*, March 1990.

Choe, K.Y. and K.A. Holsapple, "The Discontinuous Finite Element Method with the Taylor-Galerkin Approach for a Nonlinear Hyperbolic Conservation Law", Submitted for Publication, 1990.

Housen, K.R. and K.A. Holsapple, "On the Fragmentation of Asteroids and Planetary Satellites", *ICARUS* 84, 226-253, 1990.

Schmidt, R.M. and K.A. Holsapple, "Planetary Ejection Mechanisms", *American Geophysical Union Fall Meeting*, December, 1989

Holsapple, K.A., "The Scaling of Impact Phenomenon", *Intl. J. Impact Engr.*, 5, 343-355, 1987.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Henry E. Holt
(Name, Address, Telephone Number) Northern Arizona University
Box 4130, Flagstaff, AZ 86011

Co-INVESTIGATORS: Prof. Charles W. Barnes
(Name Only) _____

PROPOSAL TITLE: Alba Patera 1:500,000 Scale Geologic Map

ABSTRACT: (Type single-spaced below line. Lettered paragraphs

a. Objectives: I. Determine the structural and eruptive history of Alba Patera, the largest central vent volcanic structure on Mars. The study will investigate the general evolution of the Alba Patera shield volcano, the nature of the regional structural deformation of the crust and evaluate possible origins of the magma. II. Improve the cratering time scales for Mars and advance our understanding of the present and past flux of solid objects in the inner Solar System. The asteroid and long-period comet flux in the terrestrial planet zone will be reassessed.

b. Progress: Over 600 Viking Orbiter photographs covering Alba Patera has been acquired and organized for geologic mapping. Preliminary mapping of the sequence of flows on the northwest flank of the shield volcano reveal various types and ages of lava flows, implying possible compositional differences between flows or different eruptive styles. Photoclinometric profiles show the lava flows vary from 45 m to over 128 m thick and they increase in thickness downslope. The grabens vary from 260 m to 800 m in depth but the wall slopes (20° to 26°) are less than the angle of repose.

c. Proposed Work: Detailed geologic mapping of the two northwest photomosaic quads MTM 45-117 and 45-112, in the 1:500,000 scale block of Alba Patera will be completed during FY92. Preliminary geologic mapping will be started in the adjacent quads of MTM 40-117 and 40-112. Image processing techniques will be used to enhance albedo differences between flow units and to conduct photoclinometric profiling of discrete lava flows, grabens, scarps, craters and channels. A new estimate of the population of Mars and Earth crossing asteroids will be made by combining discoveries made in the Palomar Asteroid and Comet Survey with earlier surveys.

d. Personnel: One professional (part-time).

PROPOSAL SUMMARY

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

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Lunar Paleomagnetism and 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 published results of a detailed study of the distribution and origin of the lunar swirls, including numerical calculations of the trajectories of simulated solar wind ions in model lunar magnetic anomaly fields to test the solar wind deflection model for the origin of the swirls. In addition, we have investigated theoretically 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., Magnetic field and remanent magnetization effects of basin-forming impacts on the Moon, *Geophys. Res. Lett.*, 14, 844-847, 1987.
Hood, L.L., Magnetic effects of large-scale impacts on airless planetary bodies, in *Lunar Planet. Sci. XVI*, pp. 534-535, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Alan D. Howard
(Name, Address,
Telephone Number) Department of Environmental Sciences, Univ.
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:* 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.

(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. Global groundwater flow models are being developed and tested. A general model for valley network and slope erosion of cratered surfaces by surficial and groundwater processes is under development.

(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. 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:*

Howard, A.D. and C.F. McLane, 1988, Erosion of cohesionless sediment by groundwater seepage: *Water Resources Research*, 24, 1659-74.

Howard, A.D., Kochel, R.C., and H.E. Holt, 1988, Sapping Features of the Colorado Plateau: *NASA SP-491*, 108 p. (includes 3 chapters by the P.I.).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Raymond Jeanloz
301 Earth Sciences
University of California
Berkeley, CA 94720
(415) 642-2639

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; (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 carrying out experiments pertaining to core formation, outgassing and thermal histories of terrestrial planets. Phase equilibria, syntheses of new phases and studies 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. Renewal of NAGW-604.
- c. 1. Characterize the changes in silicate differentiation mechanisms induced by pressure deep inside terrestrial planets: a) X-ray diffraction evidence for structural (coordination) changes in melts; b) Electron microscopic evidence for changes in grain-boundary wetting. 2. Studies of melting at ultrahigh pressures: a) complex core-forming alloys (including meteorite samples); b) Basic theoretical and experimental studies on melting (simple systems). 3. Study volatile- (Ar-, Xe-, H₂O- and C/CO₂-) reactions with silicates iron alloys under P and T to establish planetary volatile budgets (H in Cores? H₂ in Deep Mantles?) and core formation processes. 4. Examine electromagnetic phenomena at planetary mantle-core boundaries.
- d. See Attachment.

Jeanloz, R., 1990, The nature of the Earth's core, *Ann. Rev. Earth Planet. Sci.*, **18**, 357-386.

Jeanloz, R., 1990, Thermodynamics and evolution of the Earth's interior, high-pressure melting of silicate perovskite as an example, in *Proceedings of the Gibbs Symposium* (G. D. Mostow and D. G. Caldi, eds.), Am. Math. Soc., Providence, RI, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: R. E. Johnson
(Name, Address, Department of Nuclear Engineering &
Telephone Number) Engineering Physics 804-924-3244

Co-INVESTIGATORS: _____
(Name Only) Charged Particle Induced Alterations of
Surfaces in the Outer Solar System

PROPOSAL TITLE:

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: Calculations of the effects of charged particle irradiation of the surface of outer solar system objects are performed. This is done in order to describe the state of the surfaces of the satellites, ring particles, and cometary debris and in order to interpret remote sensing and space craft observations of these objects.
 - (b) Progress: We have evaluated the irradiation processes occurring on the surface of Pluto. These were shown to be slow, so that the rates can be used to estimate regolith turnover processes. We have also evaluated the nature of the radiation-induced primordial crust on a comet and showed it can survive entrance into the inner solar system.
 - (c) Proposed work: Because of the proposed lunar orbiter mission we will evaluate the relationship between the sputter-ejected gas and the surface composition. Our recent laboratory reflectance data for ion bombardment of water ice will allow us to re-examine the reflectance on the trailing hemisphere of Europa and the icy Saturnian satellites. We are calculating competition between various surface alteration processes on Io.
 - (d) 4 papers, 2 oral presentations
 - (e) Personnel: 1 faculty (part-time), 1 student (part-time)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Torrence V. Johnson
(Names, Address, Telephone Number) 4800 Oak Grove Drive, MS 183-501, Pasadena, CA 91109
(818) 354-2761

CO-INVESTIGATORS: Robert H. Brown, Dennis L. Matson and Jay Goguen
(Name Only)

TITLE: MULTISPECTRAL ANALYSIS

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: This research involves analysis of multispectral data and images from spacecraft and telescopes. Current thrust is analysis of multispectral global mosaics produced from Voyager observations of the Galilean, Saturnian, Uranian and Neptune Satellites. Included are studies of the distribution of distinct spectral and compositional units on the satellites, and their relationship to: geologic features, ground-based spectral studies and interactions with the Jovian magnetosphere. Integrated studies of Io, including Voyager and groundbased infrared data are arrived at understanding its volcanic nature and the distribution of volatile material on the surface. A search will be made for methane clathrate, ammonium hydroxide ice and carbon monoxide frost on icy satellites using telescopic data obtained under separate funding.

B. PROGRESS: Research highlights of the past year 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, and (5) continued studies of solid state greenhousing, including applications to the driving mechanisms for Triton's active plumes.

C. PROPOSED WORK: During the coming year, we expect to: (1) continue analysis of icy satellite data in conjunction with USGS and UH, (2) analyze Voyager 2 data for Neptune satellites, (3) characterize Io's volcanic distribution and time variability, and (4) analyze spectrophotometry for Europa, Ganymede, Enceladus, Ariel and Titania and (5) update to Voyager camera calibration.

D. SUMMARY BIBLIOGRAPHY: Multiple abstracts, 5 papers published (1988), 1 paper (1989), 4 papers in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William M. Kaula
(Name, Address, University of California, Los Angeles
Telephone Number) Department of Earth & Space Sciences
405 Hilgard Avenue
Los Angeles, CA 90024
213-825-4363

CO-INVESTIGATOR: _____
(Name Only)

PROPOSAL TITLE: Dynamics of the Origin of the Solar System

ABSTRACT:

- a. Objective: to determine the nature of heterogeneities occurring in the collapse of the protosolar cloud, and their effects on protoplanetary nebula formation.
- b. Accomplishments of the prior year: Test runs of the momentum and Poisson equations of the hydrodynamic code using a 31x31x31 grid on the SDSC Cray-YMP, verifying correctness of the code within a fraction of a percent against other codes & analytic models. Development of the radiative transfer equations, and testing thereof at the subroutine level. Set-up of shock treatment and regridding procedures.
- c. Plans for the coming year: Complete development of the hydrodynamic collapse code, apply it initially to clouds of low angular energy, and further develop criteria for problem definition.
- d. Recent relevant publications: Myhill, E. & Kaula, W. A second-order numerical model of protostellar cloud collapse and nebular formation, Astr. Soc. Pac. Cent. Mtg., Berkeley, CA, 1989, and Amer. Astr. Soc. Ann. Mtg., Washington, DC, 1990; Protostellar collapse and nebula formation; a second order model including radiative transfer: "Protostars and Planets III" conf., Tucson, AZ, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Susan W. Kieffer
(Name, Address, Telephone Number) Department of Geology, Arizona State University
Tempe, AZ 85287-1404

Co-INVESTIGATORS: _____
(Name Only) _____
Fluid Dynamics of Multiphase Flow in Volcanic Environ-
ments on the Earth, Io, and Other Planets

PROPOSAL TITLE: _____

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) Objective and justification: The objective of the proposed effort 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 plume are important, and where transitions may occur from incompressible, subsonic to compressible supersonic flow. Particular emphases will be placed on comparing hydrothermal and volcanic processes on the Earth with active processes on Io, but consideration will also be given to eruptions on the Moon, Mars, Venus, and Europa. Particular emphasis has been placed on martian processes during the past year. The propose work differs from past work on planetary volcanism in the nature of the chemistry of materials considered, and in its focus on equations-of-state appropriate to the very low pressure and temperature conditions which erupting materials reach as they enter the low-pressure planetary atmospheres. In response to, and agreement with, reviewers comments that the proposed work was too ambitious, modifications to the level of detail previously proposed are discussed in this renewal. The justification for the work is that it extends volcanic eruption models to pressures, temperatures, and chemistries not yet quantitatively examined, and that it could provide suggestions for specific observations that can be made both by Galileo spacecraft and by ground-based observers.

(b) Progress: Progress has been frustratingly slow because year 2 funds have not arrived from NASA as of 4/10/90. This resulted in a freezing of my spending of year 1 funds (because notification of continuing funding or a no-cost extension is required from NASA before ASU allows expenditure of funds), and the year 1 funds had arrived after the year 2 proposal was due (May, 1989), and were then frozen when the 10/31/90 deadline passed, i.e., I have had--to date--almost no funding from NASA and this has not allowed me to hire a student systematically (the main expense in this proposal) to help get the major project (formulation of and graphic display of a thermodynamic data base) underway. Nevertheless, the data base is being worked on, and a major paper on geothermal, hydrothermal, and phreatic eruption processes on Mars is in preparation, and it is expected that a similar approach to Io will be fruitful.

(c) Work Plan, year 3: As soon as funds become available and a search can be made, I plan to hire a computer specialist to assist in transfer and organization of the computer programs relevant to the thermodynamic data base. I will then proceed with addition of more data (low temperature, high pressure) for the H₂O-CO₂ system, add the calcium and silica solubilities as planned, and add the S and SO₂ systems. I plan to finish the calculations of plausible geothermal, hydrothermal, and phreatic eruption models for Mars. I will import or create best combination of thermodynamic databases and fluid-flow models onto Sun work stations.

(d) Relevant bibliography: None because of the problems described in (b)

PROPOSAL SUMMARY

(Names, Address,
Telephone Number) Trude V.V. King
USGS, MS 964, Box 25046 DFC, Denver, CO 80225
(303) 236-1373; FTS 776-1373

CO-INVESTIGATORS:
(Name Only) R.N. Clark, D. Sherman

TITLE: Compositional Analysis of the Martian Surface

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. Fine-grained materials cover a significant portion of the surface of Mars, however their compositions are not well-defined. Theoretical applications, direct sampling by the Viking landers and remote observations argue for the presence of high-Fe basalts and associated altered materials as the predominant mineral assemblages on the surface of Mars. Although, recent interpretations of remote sensing data suggest that sulphate and carbonate-bearing materials may also be present. The proposed work will more accurately determine the surface composition of Mars by using spectroscopy of mineral mixtures, based on laboratory experiments and theoretical considerations in the wavelength region from 0.2 to 200 μ m as comparisons to remotely sensed data. Using these measurements it should be possible to distinguish the primary rock-forming silicates and their weathering products.

b. Renewal proposal

c. The proposed work will incorporate the spectra (0.2-200 μ m) of standard laboratory mineral and rock samples in conjunction with theoretical mineral mixing models to more accurately determine the composition of the Martian surface. The laboratory data will be compared and contrasted to the reflectance spectra (0.35 to 2.5 μ m) of Mars obtained by Earth-based telescopic methods, the Mariner 6 and 7 IRS instrument (2.0-14.0 μ m) and the Mariner 9 Infrared Interferometer Spectrometer (IRIS) data (~6.0-50 μ m). The spectra will be collected using a modified Beckman 5270 Spectrophotometer, a Nicolet 740 FTIR Spectrometer and a modified Mossbauer Spectrometer.

d. King, T.V.V. and R.N. Clark, 1989, Spectral Characteristics of serpentines and chlorites using high resolution reflectance spectroscopy. *J. Geophys. Res.* 94, 13997-14008.

Calvin, W.M., and T.V.V. King, 1990, Analysis of Mariner 6 and 7 Spectra for Weak Absorption Features From 2-6 μ m. *Lunar and Planetary Science XXI*, 153-154.

Calvin, W.M., 1990, Additions and Corrections to the Absorption Coefficients of CO₂ Ice: Applications to the Martian South Polar Cap. *J. Geophys. Res.*, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Randolph L. Kirk
(Name, Address, U.S. Geological Survey, Flagstaff, AZ 86001
Telephone Number) (602) 527-7020; FTS 959-7020

Co-INVESTIGATORS: Henry J. Moore
(Name Only)

PROPOSAL TITLE: Mars Surface Roughness From Two-Dimensional Photoclinometry

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 apply recently developed techniques for two-dimensional photoclinometry (PC) to Viking Orbiter image data to calculate digital topographic models for selected Martian sites to determine from these models the surface-roughness characteristics of these sites. These surface-roughness data will be used to (1) provide independent confirmation of the radar slope estimates, if possible, and estimate slopes in areas not probed by radar (with application to landing-site selection for future Mars missions); (2) investigate the variation of rms slope over well-defined horizontal scales in an attempt to explain the lack of wavelength dependence in the radar results; (3) quantify more subtle aspects of the surface roughness such as the shapes of slope probability distributions and the isotropy of slopes, and (4) relate the roughness properties to the geologic features in the images. Estimates of the surface roughness of Mars based on radar scattering properties (which are sensitive to the distribution of slopes \gtrsim a wavelength in extent, averaged over large and frequently geologically inhomogeneous areas of the planet) have proven difficult to relate to other properties. In contrast with the Martian data, the lunar radar-derived roughness estimates correlate strongly with roughness estimates from images, with geologic units, and with a wide variety of properties including thermal inertia, albedo, and age (Moore *et al.* 1980). Particularly perplexing is the lack of evidence for dependence of the radar-derived roughness on wavelength for most Martian areas studied. Such dependence (clearly seen for the Moon) would be expected on the basis of the simple arguments that slopes measured over shorter baselines normally exceed those on longer baselines and that different wavelengths are sensitive to slopes at different scales. On the basis of lunar experience, the range of baselines that best correlate with 13 to 70-cm radar data is readily resolvable in Viking images, giving hope that PC results may allow us to solve this problem.

b. Progress: (1) Development of statistical techniques to test the hypotheses of the original physical-optics interpretation of Hagfors scattering law and the geometric-optics interpretation. (2) Selection and initial processing of images near the 1986 Goldstone radar tracks. Results favor the geometric-optics interpretation: surfaces do not show increasing roughness with decreasing baseline at the image resolution but are smooth, and the slope distributions are similar to those that would result in Hagfors's law. Measured rms slopes are similar to those obtained by radar.

c. Work Plan FY91: (1) Complete PC roughness analysis of areas covered by radar. (2) Select and analyze additional images that extend the method to regions for which radar data are not available. (3) Correlate the derived roughness properties with local geology and compare radar-scattering behavior predicted from the topography with that observed (where available).

d. Relevant Bibliography: KIRK, R. L. (1984) A Finite Element Approach to Two-Dimensional Photoclinometry (abs.). *Bull. Amer. Astron. Soc.*, 16, 709. KIRK, R. L. (1987) *A Fast Finite Element Algorithm for Two-Dimensional Photoclinometry*. Part III, Ph.D. Thesis (unpubl.), Caltech, 165-258. MOORE, H. J. *et al.* (1980) Lunar Remote Sensing and Measurements. U.S. Geol. Surv. Prof. Paper 1046-B, 78 p.

PROPOSAL SUMMARY

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

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Practical Two-Dimensional Radarclinometry and
Photoclinometry.

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: Photoclinometry (PC) and especially radarclinometry (RC) are potentially valuable tools for deriving topographic information that is unavailable by other methods and is useful in a wide variety of geologic studies of planetary surfaces. Preliminary testing of a rapid finite element PC/RC algorithm indicated that a simultaneous solution for the topography can be obtained at an equivalent serial rate of 10 pixels per second. Work conducted as part of this project has substantially increased the speed, stability, generality (notably application to surfaces with non-uniform albedo using two images), and ease of use of the clinometry algorithm. Further development will permit incorporation of various types of *a priori* information about the topography, and of surface-atmospheric interaction of scattered light as part of the model. Scientific topics selected for study in this project include the nature of cryovolcanism and origin of grooved terrains on icy satellites, the geology of Valles Marineris interior deposits, and the stratigraphy and origin of the Martian polar layered terrains.

b. Progress: (1) Advances in the clinometry algorithm leading to increases in speed, stability, applicability to small bodies for which the full disk is visible, and introduction of point constraints on topography (benchmarks). Implementation of ultra-fast approximate PC/RC algorithm that does not require entire image in computer memory at once, allowing processing of extremely large datasets. (2) Study of Triton cryovolcanism using photoclinometry. Preservation of topography limits global CH₄/N₂ layers to less than 100 m and eliminates these substances as mare fill. Based on height/width measurements, linear eruptions were formed by material up to 10⁴ times less viscous than those on Ariel; CH₄ or N₂ cannot be ruled out on purely rheologic grounds. (3) Topographic models of Triton, Miranda, Ariel, Enceladus, and portions of Ganymede constructed. Comparative study of morphology and origin of grooved terrains on icy satellites begun using these models.

c. Work Plan FY91: (1) Continue development of *a priori* constrained photoclinometry to incorporate estimation of atmospheric scattering. (2) Use bispocopic and constrained photoclinometry to study the stratigraphy of Valles Marineris and of polar deposits on Mars.

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. (1990) Diffusion Kinetics of Solid Methane and Nitrogen: Application to Triton (abstract). *Lunar Planet. Sci.*, XXI, 633-634.

Progress Report

**INVESTIGATIONS OF TECHNIQUES APPLIED TO
HYDRODYNAMIC INTERPRETATIONS OF FLOODS**

Paul D. Komar
*College of Oceanography
Oregon State University
Corvallis, Oregon 97331*

Introduction

We are limited in our ability to quantitatively assess the hydraulic parameters of paleofloods, whether those floods occurred on Earth or Mars. The desire is to be able to examine the products of floods, whether erosional or depositional, and to use that evidence to evaluate flow velocities, bed stresses, depths and discharges. Such techniques have been applied mainly to prehistoric floods of still-active river systems, to evaluate unusual flow events that left a significant record in the form of eroded landforms and deposited sediments. Such hydraulic reconstructions also have been attempted for cataclysmic floods such as those which carved the Channeled Scabland in eastern Washington (Baker, 1973;) and glacial-lake spillways in North Dakota and southern Canada (Lord and Kehew, 1987; Komar, 1988, 1989). The overall objective of my NASA research has been to improve our techniques for evaluating the hydraulic parameters of major flood events so as to enhance reconstructions of the flows that eroded the outflow channels on Mars. This on-going research is focusing on three techniques:

- (1) flow-competence evaluations
- (2) scour around flow obstacles
- (3) channel sinuosity

Most of my progress to date, reported in a series of journal publications, has centered on improved flow-competence assessments of flood hydraulics. That work is nearing completion, so my research efforts are increasingly directed toward the remaining two techniques.

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 the 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 data analysis from spacecraft encounters with asteroids and other small bodies by missions such as Phobos, Galileo, Cassini, and CRAF.

b) During this period, we have obtained visual and infrared spectra of a suite of meteorites and low-albedo materials and have begun comparisons with telescopic observations. We have also made some preliminary attempts at obtaining spectra of cooled samples. We are now collaborating with Dan Britt at Brown University and so have access to their meteorite spectra. c) During the next year, we propose to continue our laboratory studies. We are close to purchasing an environmental chamber for cooling our samples, in order to observe the effects on water in asteroidal clay minerals. 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 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) continue efforts to obtain spectra under low-temperature conditions with the system we are procuring under previous year funding, 4) 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, 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).

PROPOSAL SUMMARY

Principal Investigator:

Steven W. Lee
Laboratory for Atmospheric and Space Physics
Campus Box 392
University of Colorado
Boulder, Colorado 80309
Telephone: (303) 492-5348

Co-Investigator:

R. Todd Clancy

Proposal Title:

Viking Photometric, Albedo, and Thermal Studies of Mars

ABSTRACT

- a) The goals of this project are to determine the physical properties of dust in the martian atmosphere, to develop corrections for the effects of dust loading on observations of the martian surface, and to examine the photometric behavior of the surface and atmosphere.
- b) During the previous year, a radiative transfer model of the Mars atmosphere and surface has been developed. This has been utilized to examine atmospheric dust properties and to examine the temporal behavior of surface albedo (corrected for the effects of dust loading) in the Cerberus region.
- c) During the coming year, we will expand upon our earlier photometric analyses of IRTM emission-phase-function observations, incorporating the radiative transfer modelling developed during 1989 and 1990.
- d) Clancy, R.T. and Lee, S.W. (1990). Derivation of Mars atmospheric dust opacities from radiative transfer analysis of Viking IRTM emission phase function sequences (abstract), *Lunar Planet. Sci. Conf. XXI*, 194-195. Lee, S.W. and Clancy, R.T. (1990). The effects of atmospheric dust on observations of the surface albedo of Mars (abstract), *Lunar Planet. Sci. Conf. XXI*, 688-689.

PROPOSAL SUMMARY – ABSTRACT

PRINCIPAL INVESTIGATOR:

Eugene H. Levy, Professor of Planetary Sciences
Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85721
(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; developed theory of nebular disk magnetic flares and explored the possible connection to the formation of meteoritic chondrules and the consequences for our understanding of the protoplanetary nebula; investigated 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.
- (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) 1988, *Generation of dynamo magnetic fields in protoplanetary and other astrophysical accretion disks* (T. Stepinski and E.H. Levy) *Astrophysical Journal*, 331, 416.

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.

PROPOSAL SUMMARY

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

Co-INVESTIGATORS: None
(Name Only)

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) Analyzed spiral waves in Saturn's rings as seen by the Voyager radio occultation. 2) Continued analysis of Voyager PPS uranian ring occultation data. 3) Continued investigating three-body planetary accretion rates in planetesimal disks with low random velocities. Submitted first paper on this topic for publication. 4) Began work on review of planetesimal dynamics for *Protostars and Planets III* book.
- (c) Proposed Work: 1) Finish analysis of wave features observed in the Voyager radio occultation of Saturn's rings. 2) Derive 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) Compute protoplanet accretion rates in a gas-rich solar nebula. 4) Incorporate the effects of three-body scattering of planetesimals by protoplanets into a planetary accretion code. 5) Finish review chapter for *Protostars and Planets III* book. 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*, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Baerbel K. Lucchitta
(Name, Address, Telephone Number) U.S.G.S., 2255 N. Gemini Dr., Flagstaff, AZ 86001

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: A fundamental study concerning the origin of the troughs has been addressed - are the troughs predominantly of tectonic or of erosional origin? A morphometric study of chain craters and troughs showed that they do not form a morphologic continuum. This result suggests that different processes made these depressions: whereas the chain craters probably formed by surficial collapse of materials into subsurface voids, the troughs apparently formed by tectonic failure of more coherent blocks.

Anticipated work: All structures (faults, ridges, lineations, grabens, tilted beds) inside the Valles Marineris will be identified, mapped, and classified, and fault-plane attitudes will be determined. We will calculate the volumes of units and voids and publish the results.

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., Young volcanic deposits in the Valles Marineris, Mars: *Icarus*, in press.
Lucchitta, B.K., Clow, G.D., Geissler, P.E., McEwen, A.S., Schultz, R.A., and Squyres, S.W., The canyon system on Mars: Submitted to the "The Mars Book," University of Arizona Press.

PROPOSAL SUMMARY

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

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Mars Geologic Mapping: Eastern Candor and Central
Melas Chasmata.

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: To prepare geologic maps of eastern Candor (MTM -05067) and central Melas (MTM -10072) Chasmata. The maps adjoin a map prepared under a previous project. Specific objectives are (1) to identify, map, and establish relations among three major units that border or cover the floors of troughs: wall rock, layered deposits, and irregular floor deposits; (2) to establish a relative time sequence for the units; (3) to shed light on the origin of the units; and (4) to contribute to an understanding of the relative roles that tectonism or erosion played in the origin of the troughs and in the formation of "moats" between layered deposits and trough walls.

Progress: Base materials and images have been assembled, preliminary units identified, and preliminary contacts located for map MTM -05067 (eastern Candor Chasma). Critical relations among units were investigated, leading to the recognition that eastern Candor Chasma is composed of two structural troughs that probably developed sequentially.

Work Plan: FY90 and FY91 -- Finalize map MTM -05067 and produce map MTM -10072.

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., Young volcanic deposits in the Valles Marineris, Mars: Icarus, in press.
- Lucchitta, B.K., Clow, G.D., Geissler, P.E., McEwen, A.S., Schultz, R.A., and Squyres, S.W., The canyon system on Mars: Submitted to "The Mars Book," University of Arizona Press.

PROPOSAL SUMMARY

TITLE: Theoretical Studies of Volatile Processes in the Atmospheres and Surfaces of Outer Solar System Bodies

PERFORMING ORGANIZATION: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

INVESTIGATOR'S NAME: Jonathan I. Lunine, Asst. Professor of Planetary Sciences, 602-621-2789.

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 include published ground-based studies, and Voyager results.

(b) (1) A preliminary model of the Triton surface-atmosphere interactions in the polar cap regions has been constructed based on the initial analysis of Voyager data; (2) A model of the production of photochemical hazes on Pluto was constructed and used to show that such a haze is likely not responsible for certain feature of the stellar occultation light curve of Pluto; (3) A review of available data sets of Io was conducted to reassess the model that sulfur compounds are present on the surface of Io; (4) A model of the thermodynamics of clathrate formation was applied to compute the amount of noble gases which could be trapped in permanent ice deposits on Mars; (5) The drag heating of infalling solids has been quantified in detail to assess the amount of ammonia and other volatiles which remained sequestered in grains in the outer solar nebula during planet formation; (6) The experimental investigation of the rheology of the ammonia-water system has been completed and compared with simple theoretical models to derive the identity of molecular clusters in the liquid.

(c) (1) More sophisticated models of surface-atmosphere interactions on Triton and Pluto will be constructed, utilizing to the fullest extent the available ground-and space-based data sets; (2) A volatile inventory of Triton and Pluto will be constructed and used to constrain models for the origin of these materials in the solar nebula and precursor giant molecular cloud; (3) Work will begin on models of the earliest evolution of Titan's atmosphere and surface; (4) Preliminary examination of the IRIS data on Loki will be undertaken to compare against current hot spot models and to prepare for the 1991 mutual events data.

(d) Lunine, J.I., 1989. Volatile processes in the outer solar system, *Icarus* **81**, 1-13; Hubbard, W.B., R.V. Yelle and J.I. Lunine. 1990. Non-isothermal Pluto atmosphere models. *Icarus* **84**, 1-11.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Paul G. Lucey
(Name, Address, Planetary Geosciences
Telephone Number) 2525 Correa Road, Honolulu, HI 96822
(808) 948-6488 (after 5/1/90: (808) 956-6488)

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: MINERALOGIC MAPPING OF THE LUNAR SURFACE

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 project is intended to map the mineralogy of the lunar surface through the application of two "new" remote sensing techniques: imaging spectroscopy in the visible and near-IR and mid-IR spectroscopy. These techniques offer unique opportunities to better understand the mineralogical variation of the lunar surface through contiguous spectral coverage of large portions of the surface and through detection of minerals to which the near-IR is relatively insensitive.

b) Two major areas of progress were completed. An imaging spectroscopic data set for the Humorum multiringed impact basin was fully calibrated and a preliminary analysis was completed. It was found that there were two distinct spectral units in the highlands exterior to the basin mare fill which were interpreted to be due to extensive buried mare basalts. It was also shown that two craters in the mare penetrated the mare fill and excavated highland material from beneath the basalt. It was also shown that these craters show asymmetric distribution of composition within their rims, exposing mare material on their western portions but highland material on their east walls. Direct comparison of new and historic mid-IR measurements of the Moon was carried out to determine the cause of the apparent inconsistency between interpretations of these data sets. It was determined that the inconsistency was due to the widely varying wavelength range measured and precision of the data sets and that direct comparison shows that they all demonstrate substantial and interpretable variation in spectral properties from site to site on the lunar surface.

c) In the coming year detailed analysis will proceed on the Humorum data set including comparison of the lunar sample spectral data set of Adams and the continuation of the multiring basin study series of Spudis, Hawke and myself, this time concentrating on Humorum. Analysis of new data will proceed as it becomes available.

d) Publications resulting: Lucey, P.G., B.R. Hawke, and B.C. Bruno, Preliminary results of imaging spectroscopy of the Moon, LPSC XXI, pp726-727, 1990; Lucey, P.G., Comparison of thermal emission spectroscopic measurements of the lunar surface, LPSC XXI, pp 724-725, 1990; Lucey, P.G., Telescopic mid-infrared measurements of the lunar surface; Bull Am Astron. Soc. 21, 3, 970, 1989. Two papers on these topics are in prep for submission to Proceedings of Lunar and Planetary Science 21.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael C. Malin
(Name, Address, Department of Geology, Arizona State University
Telephone Number) Tempe, AZ 85287-1404 (602) 965-4335, -5081

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.)

-
- 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, to use quantitative analyses of steep martian hillslopes to examine the physical properties of martian bedrock, and to examine mechanisms that create and transport coarse sediments on Mars.
 - b. Progress: 1) completed and submitted for publication a study of heavily cratered terrain in northeastern Arabia, which indicated substantial deposits of semi-indurated, plains-forming material draped over pre-existing topography that have experienced a diverse and extensive erosional history; 2) sublimation experiments of bare and dust-covered ice under simulated martian conditions showed that theoretical models overestimate sublimation; and 3) preliminary stability analyses of steep martian cliffs suggest physical properties similar to glacial till (i.e., unsorted debris).
 - c. This Year: 1) continue laboratory study of ice/silicate mixtures under martian conditions, and initiate study of multi-component, non-volatile mixtures (dust, sand, crust, and rock); 2) develop laboratory and numerical basis for examining martian bedrock properties using slope failure criteria, and apply to Olympus Mons caldera and walls of Valles Marineris; 3) continue analysis of boulder populations as indicators of geologic process; and 4) initiate study of martian valley network longitudinal profiles.
 - d. Summary Bibliography:
McEwen, A. S. and Malin, M. C., 1989, Dynamics of sediment gravity flows: Lahars, avalanche, pyroclastic flows, and blast surge of Mount St. Helens, *J. Volcan. Geotherm. Res.* 37, 205-231.
Malin, M. C., 1989, Rock populations as indicators of geologic processes, in *Reports of the Planetary Geology and Geophysics Program-1988, NASA Tech. Mem.* 4130, 363-365
Moore, J. M., 1990, Nature of the mantling deposit in the heavily cratered terrain of northeastern Arabia, Mars, *J. Geophys. Res.* (in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ho-kwang Mao
(Name, Address, Telephone Number) Geophysical Laboratory
2801 Upton Street, N. W.
Washington, D. C. 20008

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

PROPOSAL TITLE: High-Pressure Studies of Planetary Gases & Ices (Third Year)

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 a systematic study of the high-pressure properties of planetary gases and ices to 300 GPa and 77-500 K using recently developed synchrotron x-ray and spectroscopic techniques and theoretical calculations. The results will be used to constrain models of outer planets.

b. Progress: We reached the pressure range for metallization of hydrogen (above 150 GPa) and observed large change in optical properties at visible wavelengths above 200 GPa. By use of vibrational Raman spectroscopy, we discovered major structural phase transitions in hydrogen and deuterium beginning at 150 GPa. Low-frequency rotational (librational) and phonon spectra of solid normal H₂ and D₂ are consistent with the assignment of the 150 GPa transition being a transition to metallization by closure of an indirect gap. The dielectric function for hydrogen, calculated from measurements of the index of refraction and the dispersion to 160 GPa predicts the onset of visible absorption above 200 GPa and closure of the direct gap above 250 GPa. Pressure-volume equations of state (EOS) of planetary gases, ices and minerals, which include H₂, D₂, He, H₂O, Ne, Xe, (Mg,Fe)₂SiO₄, CaSiO₃ and SiO₂, were measured at high pressures with synchrotron x-ray diffraction techniques and calculated from phenomenological models and lattice dynamics.

c. Proposed work for this year: (1) Crystal structure of H₂, D₂, and He to an extended range of pressures up to 100 GPa and temperatures down to 10 K. (2) Phase transitions and EOS of planetary gas or ice up to 300 GPa, 77-500 K with synchrotron x-ray techniques and Raman, fluorescence, absorption, and reflectance spectroscopies. (3) Theoretical calculations to be tested against the experimental results. (4) Working models of the interiors of Jovian planets based on the new results. (5). Extending high-pressure experimental capabilities.

d. Recent publications: R. J. Hemley and H. K. Mao, Isotope effects in dense solid hydrogen: Phase transition in deuterium at 190(±20) GPa, Phys. Rev. Lett., 63, 1393-1395, 1989; H. K. Mao and R. J. Hemley, Optical studies of hydrogen above 200 gigapascals: Evidence for metallization by band overlap, Science, 244, 1462-1465, 1989.

PROPOSAL SUMMARY

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

CO-INVESTIGATORS:

Dr. Ted L. Roush
Dr. James B. Pollack

TITLE: MINERALOGY OF THE MARTIAN SURFACE FROM MARINER 6/7
INFRARED SPECTROMETER DATA

ABSTRACT:

- a. Recent work to restore the Mariner 6/7 IR Spectrometer data set has created an opportunity to expand knowledge of the state of the Mars surface. It is proposed that these data be analyzed to extract information about the presence and nature of mineral species, focussing on their hydration state and the presence of various salts.
- b. Progress: during FY 90, the wavelength calibration of the IRS data was completely redone, using information from inflight spectra of Mars taken through a polystyrene film and from the locations of Martian CO₂ bands. The response functions of the various wavelength channels of the two instruments were then rederived, using laboratory blackbody spectra.
- c. Specific IRS spectra corresponding to regions of both low and high albedo will be treated to produce radiance and brightness temperature spectra, for comparison with lab data and KAO airborne spectra.
- d. Summary bibliography: no activity in FY90 to date.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ted A. Maxwell
(Name, Address, Telephone Number) NASM 3784, Smithsonian Institution
Washington, D.C. 20560, (202) 357-1424

CO-INVESTIGATORS: Thomas R. Watters
(Name Only)

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. "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, and developing models for the origin of surface features.

(b) During the past year, a paper dealing with the extent and causes for modification of the highland terrain on Mars was published. Further work detailing the ages of discrete erosional surfaces in the highlands was initiated.

(c) Continued funding will enable studies of the structural geology along the Mars cratered terrain boundary by analyzing the age sequence and distribution of specific landforms, and the comparison of mapped structures along the boundary with the tectonic sequence based on models for the formation and evolution of the boundary. Single and multiple impact hypotheses will be tested, and relative ages of ridges and faults will be determined via superposition of datable surface units. The style of scarp retreat will be studied using erosion models.

(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).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Thomas B. McCord
(Name, Address, Telephone Number) Planetary Geosciences
2525 Correa Road, Honolulu, HI 96822
(808) 948-6488 (after 5/1/90: (808) 956-6488)

Co-INVESTIGATORS:
(Name Only) _____

PROPOSAL TITLE: Remote Compositional Analysis of Lunar and Planetary 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.)

- 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 is essential to support the existing and planned planetary missions such as Galileo, Mars Observer, Mars '94 OMEGA-VIMS and HRSC, CRAF/Cassini, Lunar Observer.
- b. During the past year we have analyzed telescopic reflectance data we acquired for Mars. The major results include the discovery of an absorption band at 4.5 μm which we interpret to indicate SO_4 in the Mars surface. Also, we increased our understanding of the nature of the crystalline iron oxide on Mars. Laboratory data has been greatly increased to support data interpretation. Major input has been made to the design of the OMEGA-VIMS instrument for Mars study.
- c. The main tasks for the coming year are: 1) interpret the past and the upcoming 1990 Mars opposition telescopic data we are acquiring 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 data from the Earth-Moon I encounter in December 1990.
- d. J.F. Bell III, T.M. McCord, and P.D. Owensby, Observational evidence of crystalline iron oxides on Mars. *JGR* in press. 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 Planet. Sci. Conf.*, p479-486, Lunar and Planetary Institute, Houston, 1990. 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 . submitted June, 1989 to *J. Geophys. Res.* Blaney, D.B. and T.B. McCord, Spectroscopy of Mars between 4.5 μm and 5.1 μm and indications of sulfate minerals. in prep.

PROPOSAL SUMMARY

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

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

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: Improvements to camera pointing angles for the complete set of Voyager 1 high-resolution (4 km/pixel or better) images of Io have been completed. Improved pointing solutions have been applied to 32 IRIS observations (FDSC 16377.46-16382.38); these spectra are being used to produce synthesized spectra consisting of imaging colors (UV, VI, BL, OR) and IRIS radiometer and interferometer observations. A note to Icarus and an encyclopedia article are in press.

c. Work Plan FY91: (1) Continue to improve solutions for IRIS pointing, concentrating on high-resolution observations (FDSC 16388.48-16393.36). (2) Produce a high-resolution (~1 km/pixel) digital controlled mosaic of the hemisphere of Io centered on longitude 310° (~80 images). (3) Analyze synthesized spectra from Voyager images and the IRIS interferometer and radiometer for compositional implications. (4) Use the IRIS radiometer and interferometer observations for new background and hotspot thermophysical models. (5) Publish results in one or more papers.

d. Bibliography: (1) McEwen, A., Lunine, J., and Carr. M., 1989, Dynamic geophysics of Io, NASA SP-494, 11-46. (2) McEwen, A., Lunine, J., 1990, Comment on "The surface of Io: A new model" by Bruce Hapke, Icarus 84, 268-274. (3) McEwen, A., 1990, Io: Volcanism and geophysics, in Reference Encyclopedia of Astronomy and Astrophysics, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Lucy-Ann McFadden
(Name, Address, California Space Institute A-016
Telephone Number) University of California, San Diego, La Jolla, CA 92093

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Asteroid Surface Processes: Experimental Studies of
the Solar Wind on Spectral Reflectance and Optical 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) 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. Similarly, we will use carbonaceous chondrites to see if simulated solar wind bombardment produces the spectral features of C and F-type meteorites. 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 exist and can be built on and expanded. Problems of laboratory simulation of the solar wind are better known and can be overcome. New analytical techniques are available for determining the physical and chemical changes due to solar wind, enabling us to understand the processes producing observed optical changes. 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) Renewal proposal for work that was awarded funding that was not available.
- c) Apply sputtering model to asteroids. Measure the optical properties of 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, particularly the S-type asteroids located at the predicted location of ordinary chondrite parent bodies 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.) McFadden, Tholen and Veeder, 1989, *The Physical Properties of Aten, Apollo, Amor Asteroids*, Asteroids II, U. of Arizona Press. McFadden L.A. and Vilas, F., (1987). *The 3:1 Kirkwood Gap as Sources of Ordinary Chondrites: Perspectives from Spectral Reflectance*, Lunar and Planetary XVIII, 614-615, 1987.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: George E. McGill
(Name, Address, Telephone Number) 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 history

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: Constrained impact model for origin of martian crustal dichotomy, and reviewed all hypothesis for the dichotomy; continued study of fracture history along martian dichotomy boundary; improved image-processing capability.
- C. Anticipated Effort: Revise Jg2 and Jg5; continue studies of martian northern lowlands and crustal dichotomy boundary; continue development of PC-based image-processing system.
- D. Summary Bibliography: 3 abstracts, 5 presentations
Dimitriou, A.M., Minimum estimates for volume removal from the martian fretted terrain between 270°W and 360°W, Lunar Planet. Sci. XXI, 291-292, 1990.
Dimitriou, A.M., Stratigraphy of the Ismenius Lacus SE subquadrangle: clues to an upland/lowland boundary forming event?, Lunar Planet. Sci. XXI, 293-294, 1990.
McGill, G.E., Polygonal terrane of Mars: stresses from drape folding, Lunar Planet. Sci. XXI, 763-764, 1990.

1 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
Yuri Mekler, Tel Aviv University
Morris Podolak, Tel Aviv University
Dina Prialnik, Tel Aviv University

Abstract: a. Objectives: The objectives of this 1-Year proposal are to begin a joint NASA Ames/Tel Aviv University study on the thermal processes within comets. During this initial investigation we propose 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. We feel that we can make significant advances in these areas using our current numerical comet models as a starting point.

b. Accomplishments: New proposal.

c. First-Year Plans: The numerical model that will be the basis for our work will be that of Prialnik and Bar-Nun (1987). We will couple the vapor transport equations 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 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, 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.*, in press.

Podolak, M. and G. Herman (1985). Numerical simulations of comet nuclei II. The effect of the dust mantle. *Icarus* **61**, 267-277.

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.

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.)

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 targets (morphology, phase changes, jetting, spallation, etc.).

b) Accomplishments: modeled Neptune's possible gas drag capture of Triton, including solar perturbations which greatly extend Triton's orbital lifetime against gas drag; modeled the coupled tidal heating and orbital evolution of an initially eccentric Triton (as in a capture scenario), showing that a largely molten Triton evolves relatively slowly and may stay hot (molten) beyond the end of heavy bombardment; successfully predicted Triton's density, assuming a capture origin and an analogy with Pluto/Charon; examined the angular momentum budget for Pluto/Charon, finding that a large collision is required and that an upper limit to Charon's density can be set; calculated the conditions necessary for jetting to occur during the impact of water-ice bodies, and applied these to Pluto's formation; synthesized aspects of crater formation on the Uranian satellites; synthesized models for the albedo evolution of icy satellites, and applied these to dark-ray craters on Ganymede.

c) To be done this year: further explore consequences of capture and alternative origins for Triton; constrain the relative roles of asynchronous rotation and polar wander in producing Europa's tectonics; calculate the tectonic responses of non-uniform shells (as may apply to Europa); 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, Tethys; constrain Ganymede, Callisto and Tethys heat flow; complete study of Mercurian crater terrace widths, Mercurian and lunar ejecta blankets, and simple-to-complex crater model; revise Ganymede map.

d) Publications: Schenk, P.M. and W.B. McKinnon, 1989. Fault offsets and lateral crustal movement on Europa: Evidence for a mobile ice shell. *Icarus* **79**, 75-100; McKinnon, W.B., and S. Mueller, 1989. The density of Triton: A prediction. *Geophys. Res. Lett.* **16**, 591-594; McKinnon, W.B., 1989. On the origin of the Pluto-Charon binary. *Astrophys. J. (Lett.)* **344**, L41-L44; McKinnon, W.B., 1989. Impact jetting of water ice, with application to the accretion of icy planetesimals and Pluto. *Geophys. Res. Lett.* **16**, 1237-1240; McKinnon, W.B., C.R. Chapman, and K.R. Housen, 1990. Cratering of the Uranian satellites. In *Uranus*, J. Bergstrahl, 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, 1990. Geologic map of the Hathor Quadrangle of Ganymede. USGS Misc. Inv. Map., in revision; McKinnon, W.B., and A.C. Leith, 1990. Gas drag and the evolution of a captured Triton. *Icarus*, in revision; Schenk, P.M., and W.B. McKinnon, 1990. Dark ray and dark floor craters on Ganymede, and the provenance of large impactors in the Jovian system. *Icarus*, revised.

PROPOSAL SUMMARY

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

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

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 addressed the implications of a giant impact for the thermal state of the early earth. An analytic model for atmospheric erosion was constructed that indicates that a substantial fraction of Mars' primitive atmosphere could have been ejected by impacts during late heavy bombardment, in agreement with the geologic evidence for an early wet era. The atmospheric erosion studies were applied to the Cretaceous/Tertiary impact on Earth, and a new theory that explains the global ignition of forest fires was published. A fragmentation algorithm for simulating the breakup of asteroids by impact was successfully tested against data from laboratory-scale impacts. A finite element model of the viscous relaxation of craters on Ganymede was constructed and showed that, contrary to analyses based on purely viscous models, the measured rheology of cold ice is in good agreement with the observations of craters. Tectonic models of the effects of loads on one-plate planets showed that there are two basic tectonic responses to loads, a small-planet (shell) response and a large-planet (plate) response. The implications of these models for the Tharsis rise on Mars were deduced. Graben mechanics was elucidated with an energy-based failure criterion. Finite element models for corona formation on Venus showed that the coronae may be simply isostatically relaxed former volcanic centers. Our models successfully reproduce the detailed topographic forms observed on Venus.

(c) Next year's work will be principally concerned with analysis of the 3-D numerical models we have (and will) run at Sandia. Other tasks include further numerical study of the impact evolution of planetary atmospheres, testing of the 2-D fragmentation algorithm by comparison with the existing suite of laboratory data, and a computer study of the morphology of craters formed in a Bingham medium.

(d) H. J. Melosh and D. M. Janes, *Science* 245, 195-196 (1989), H. J. Melosh, in *Origin of the Earth*, Oxford, in press, V. J. Hillgren and H. J. Melosh, *GRL* 16, 1339-1342 (1989), H. J. Melosh and A. M. Vickery, *Nature* 338, 487-489 (1989), H. J. Melosh and C. A. Williams, *JGR* 94, 13,961-13,973 (1989), H. J. Melosh, N. M. Schneider, K. J. Zahnle, and D. Latham, *Nature* 343 251-254 (1990).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Albert E. Metzger
(Name, Address, Jet Propulsion Laboratory
Telephone Number) 4800 Oak Grove Drive, Pasadena, CA 91109
(818) 354-4017 (FTS) 792-4017

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

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, planned for CRAF, and under consideration for Lunar Observer and subsequent missions. Science studies are required to optimize instrument design 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 ability of the GRS neutron and gamma-ray modes to detect the possible presence of frozen H₂O at the lunar poles, and the ability to uniquely identify lunar rock types, 4) the first quantitative analysis of neutron-gamma-ray mode coupling, and 5) an analysis of laboratory data on the response of passive and active neutron modes.
- C. In the coming year we plan to 1) model the potential GRS capability for measuring polar cap composition and seasonal cycling at Mars, 2) analyze the ability of the GRS to derive stratigraphic information, 3) document the analysis of thick target data, and 4) resume development of the deconvolution technique for increasing GRS spatial resolution from orbit
- D. Recent publications: 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," to appear in special *JGR* Fourth Internationl. Conf. on Mars issue.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Henry J. Moore MS-946, U.S. Geological Survey
(Name, Address, Telephone Number) 345 Middlefield Road, Menlo Park, CA 94025

(415) 329-5175 FTS 459-5175

CO-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: GOLDSTONE 1986-88 RADAR OF MARS

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: To continue to examine the 1986-1988 Goldstone (CW dual-polarization) radar observations of Mars at 3.5- and 12.6-cm wavelengths. There are six objectives: (1) to correlate the radar data with the geology interpreted by using high-resolution Viking orbiter images, (2) to interpret the diffuse echoes in terms of geologic conditions, (3) to provide information on potential landing sites, (4) to compare reflectivities and surface roughnesses at two wavelengths, (5) to confirm results from previous radar experiments, (6) to obtain probability density distributions of quasi-specular and diffuse echo reflectivities and quasi-specular echo surface-roughness estimates. The results will be published on a timely basis.

B. PROGRESS: We have developed a model for 12.6-cm radar echoes from Mars that accounts for polarized and depolarized total cross sections (and their ratios) as a function of longitude along 7°S and 22°N and that broadly matches the observed echo spectra (and their ratios).

C. WORK PLAN FY 91: We plan to continue to examine the 1986 Goldstone radar observations and model the 1988 observations. Of particular importance is our plan to reexamine the procedures used to separate the quasi-specular and polarized-diffuse echoes and the Hagfors scattering law.

D. PUBLICATIONS.

Moore, H. J. and Jakosky, B. M., 1989, Icarus, v. 81, p. 164-184.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Peter J. Mouginis-Mark
(Name, Address, Planetary Geosciences
Telephone Number) 2525 Correa Road, Honolulu, HI 96822
(808) 948-6490 (after 5/1/90: (808) 956-3147)

Co-INVESTIGATORS: NONE
(Name Only) "GEOMORPHIC ANALYSIS OF HIGH RESOLUTION
IMAGES OF MARS, VENUS & THE MOON"

PROPOSAL TITLE: IMAGES OF MARS, VENUS & 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) **Objectives:** To further investigate the small-scale (sub-kilometer) geomorphology of the surface of Mars, Venus and the Moon in order to constrain the geologic processes responsible for the emplacement of ejecta around impact craters on Mars and the Moon, the possible geomorphic influence of martian ground-ice, and the morphologic characteristics of flows around volcanoes on Venus. Data sets to be used in these analyses include digital and high-resolution Viking Orbiter images for the analysis of the martian landforms, the new high-resolution lunar radar data of Zisk (3.0 cm wavelength; 15-30 m resolution) for the study of lunar craters, and the 1988 dual-polarization Arecibo radar images for the analysis of volcanic landforms on Venus.

B) **Progress:** 1) An analysis of high resolution Viking images for the Tharsis area revealed numerous very young small water channels that post-date the most recent lava flows in this area. A paper describing these results is currently in press in Icarus. 2) Lunar dual-polarization radar data for ray systems around Bessel and Copernicus Craters have been studied in collaboration with Dr. Stan Zisk (Univ. Hawaii) and presented as a poster at LPSC XXI. 3) Depth/diameter measurements for 62 fresh impact craters in Hesperia Planum, Mars have been made using PICS software, and a poster describing these results was presented at Fall AGU 1989. 4) New polarimetric radar data for the Eisila Regio region of Venus have been reduced in collaboration with Don Campbell (Cornell), and preliminary results of a geologic analysis of flows around the two large volcanoes, Sif and Gula Montes, have been presented at LPSC XXI.

C) **Work Plan (Year 3):** Task #1: Continue the analysis of impact crater morphometry in Hesperia Planum, Mars, using digital Viking images and PICS software. Enlarge the existing data base of 62 craters to investigate local variations in crater depth/diameter ratio and the possible effects of sub-surface volatiles on crater geometry. Task #2: Lunar radar images will be used to map the distribution of secondary craters and possible primary material as a function of distance from parent crater. Stokes vector information will also be used to analyze the polarization behavior of the target surfaces at very high spatial resolution. Task #3: The 1988 Arecibo dual-polarization radar images will be used to map the distribution, morphology and dielectric properties of volcanic deposits in western Eisila Regio, Venus. These results will also be compared with topographic and gravity data for the area derived from the Pioneer Venus measurements.

D) **References:** 1) Mouginis-Mark, P.J. (1990). Recent water release in the Tharsis region of Mars. Icarus, in press. 2) Campbell, B.A., Hawke, B.R., Bell, J.F., and Zisk, S.H. (1989). The Bessel ray region: Preliminary analysis of remote sensing data. LPSC XX, 139 - 140. 3) Campbell, B.A. and Campbell, D.B. (1990). Volcanic deposits in western Eisila Regio: Preliminary results of radar polarization studies. LPSC XXI, 157 - 158. 4) Hayashi-Smith, J. and Mouginis-Mark, P.J. (1990). Morphometry of fresh impact craters in Hesperia Planum, Mars, Lunar Planetary Science Conference XXI, 475 - 476.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bruce Murray
(Name, Address, Caltech, Mail Stop 170-25
Telephone Number) Pasadena, CA 91125 (818) 356-6780

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Specification of the Current Water Cycle
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.)

We propose to conduct a study of the small-scale surface processes controlling the current water cycle on Mars. Our focus is on water sources and sinks and an experimental verification of proposed hypotheses by the 1990s missions to Mars. This includes water frost occurrence, morphology, and timing. The following specific tasks are described in this proposal:

The surface frost sublimation in a radiation dominated environment, such as Martian polar frost, inherently tends to develop substantial surface relief. This is crucial for our attempts to understand the remote sensing observation of Martian polar caps. During the two past years we have conducted an investigation of this phenomenon including the exploratory field work in Antarctica. We propose to create a comprehensive model of evolution of surface frost in Mars-like conditions, particularly stressing the experimental validation.

The exchange of water vapor between atmosphere and surface is controlled by the permeability of regolith which depends on grain size distribution. We have developed a technique of constraining this distribution using observations of a Phobos shadow cast on surface of Mars. These data were taken by the Termoskan instrument during the Phobos '88 mission. We plan to use the complete Phobos data set for this analysis and to propose further tests by upcoming missions.

A useful tool for understanding the water sources and sinks is a comparison of observations taken by the Viking MAWD, IRTM, and imaging experiments. Our preliminary investigation concentrated on two particular areas of interest: an edge of retreating seasonal frost at the North, and the Memnonia region where early morning fogs were observed. We propose to continue this work with the complete available data set. (Only a small fraction of relevant Viking observations has been analyzed so far).

Finally, we are convinced that the field investigation of solid/vapor water exchange in Antarctica must be a part of any future Mars surface exploration of the water cycle. We have performed the preliminary field testing in Antarctica of the Vaissala humidity sensor being proposed for the Mars '94 mission. A comprehensive set of Antarctic experiments simulating proposed Mars surface instrumentation is very desirable. We plan to outline the requirements for such testing within the research effort proposed here.

ABSTRACT

PRINCIPAL INVESTIGATOR: Douglas B. Nash
San Juan Capistrano Research Institute
31878 Camino Capistrano, Suite 278
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 irradiation effects, and electrodynamic surface properties of planetary satellites and especially Io and the Moon. Conduct key experiments and use lab and thermodynamic data to interpret spacecraft and groundbased observational data, and derive improved composition and surface process models for these satellites and other planetary bodies.

PROGRESS: Carried out infrared reflectance study (with J. Salisbury) of plagioclase feldspars and glass equivalents; found that vitrification does not effect diagnostic value of Christiansen Frequency band for powdered feldspar and thus, in emission spectra of particulate materials, it is an important indicator of silicate composition for impact regoliths such as on the Moon. Continued experimental study of vacuum-weathered sulfur (with J. Gooding); found more calorimetric evidence that vacuum-weathered sulfur contains polymeric sulfur. Completed lab study (with J. Moses) of time-dependent spectral properties of frozen sulfur; deduced physics of spectral aging process associated with solid-state phase changes; results indicate that metastable sulfur phases on Io's surface may be short- or long-lived depending on their thermal history. Wrote review paper on spectral properties of planetary ices for book chapter (with S. Gaffey and L. McFadden). Continued work on detailed quantitative theoretical model on vacuum weathering (with S. Baloga)

PROPOSED WORK (for FY 91): (1) Continue lab work on infrared spectra (2.2-22 μm) of silicate minerals and rocks with applications to Moon, Mars, and asteroids (with J. Salisbury). (2) Continue lab study of vacuum weathering effects on physical properties and spectra of sulfur with applications to Io (with J. Moses). (3) Continue study of thermodynamic properties of vacuum-mature sulfur phases (with J. Gooding). (4) Resume work on lab spectra of $\text{H}_2\text{S}/\text{SO}_2$ mixtures, and experimental modeling of H_2S physics on Io's surface.

BIBLIOGRAPHY: Nash and Salisbury (1990), Infrared reflectance spectra of plagioclase feldspars, LUN. PLAN. SCI. 21, 845-846. Moses and Nash (1990), Phase transformations and the spectral reflectance of solid sulfur: can metastable sulfur allotropes exist on Io?, ICARUS (submitted). Gooding and Nash (1990), Sulfur on Io: Calorimetric analyses of laboratory analogs, in Reports of the Planetary Geology and Geophysics Program-1989.

PROPOSAL SUMMARY

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

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

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 H₂ and "synthetic Uranus."

(b) Progress: New Proposal. In FY90 Double-shock EOS data points of synthetic Uranus were measured in the range 0.98 - 2.2 Mbar. The maximum density achieved is 3g/cm³, which corresponds to a depth of about one-half the radius of Uranus. A double-shock temperature point was also measured for synthetic Uranus. The first measurement of the electrical conductivity of shocked liquid hydrogen was performed.

(c) Work Statement: We will complete measurements of the electrical conductivity and shock temperature of liquid hydrogen. The purpose is to obtain a scaling relation for the conductivity of molecular hydrogen for modeling the magnetic fields of the giant planets.

(d) Publications: W. J. Nellis and A. C. Mitchell, "Equation-of-State Data of "Synthetic Uranus," 1989 (to be published in proceedings of Twelfth AIRAPT International High Pressure Conference, Paderborn, West Germany, July, 1989).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip D. Nicholson
(Name, Address, Telephone Number) 418 Space Sci. Bldg., Cornell University
Ithaca, NY 14853-6801 (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.)

(a) Objectives: To characterize the dynamical processes which control the structure and evolution of planetary ring systems, and the physical properties of the particles which comprise them.

(b) Progress: (1) Successfully observed the occultation of 28 Sgr by Saturn's rings on 3 July 1989; data reduction in progress. (2) Completed a re-analysis of the radio and stellar occultation data for Saturn's rings, to re-determine the planet's pole direction and thus the absolute radius scale of the rings; results checked against theoretical density wave locations to ± 2 km. (3) Combined earth-based occultation observations of Neptune's ring arcs with Voyager imaging and occultation observations; at least 3 observations of 1989N1R identified, and used to refine the orbital mean motion and semi-major axis of the arcs. (4) Observing time allocated at Palomar for near-IR imaging studies of the inner satellites of Saturn, Uranus and Neptune in July 1990. (5) Completed a theoretical study of probable scenarios for Triton's tidal evolution history. (6) Extended Showalter and Nicholson model for occultation statistics to include effects of diffracted light; revised paper on Saturn PPS data submitted. (7) Completed analysis of Voyager images of the Keeler Gap in Saturn's A Ring, in a study of its width variations.

(c) Proposed work: (1) Complete reduction of 28 Sgr data; refine kinematical models of variable features and model centimeter size particle distribution. (2) Re-examine all our earth-based Neptune occultation data, using the Voyager pole, to set limits on non-arc regions of the rings. (3) Reduce near-IR imaging data for small satellites, and refine the dynamical model of the Saturn coorbital satellites.

(d) Bibliography: Chyba, Jankowski and Nicholson (1989), *Astron. & Astrophys.* **219**, L23-26; Lissauer and Nicholson (1990), *Adv. Sp. Res.* **10** (1) 231-237; Nicholson, Cooke, Matthews, Elias and Gilmore (1990), *Icarus* (in press). 4 additional papers published, plus 4 conference abstracts.

PROPOSAL SUMMARY AND ABSTRACT

PRINCIPAL INVESTIGATOR: Peter L. Olson
(Name, Address, The Johns Hopkins University
Telephone Number) Baltimore, MD 21218
(301) 338-7707

Co-INVESTIGATORS: none
(Name Only)

PROPOSAL TITLE: Mantle Plume Dynamics in 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. Objectives: This proposal is a request for continued support for an ongoing investigation into the mechanics of transsolidus plumes in the mantles of Earth and Venus. Thermal plumes are considered to be the cause of volcanic hotspots on Earth and have been proposed as the cause of volcanic highlands on Venus. Since all of the evidence for mantle plumes is indirect, dynamically-based fluid mechanical models are required to interpret this evidence. The objective of this research is to construct fluid mechanical models of thermal plumes with partial melting, and apply these models to hotspot style volcanism on Earth and Venus.
- b. Accomplishments: In the past year we have constructed three different models of thermal plume interaction with lithosphere. In order of increasing complexity, these are: (1) A one-dimensional steady-state analytical model of basaltic crust formation above a partially molten thermal plume. The model has been applied to the problem of heat loss and highland formation on Venus. (2) A two-dimensional (vertically-integrated) model of plume refraction beneath a moving lithospheric plate. This model will be used to understand the dynamics of hotspot tracks on Earth. (3) A two-dimensional (axisymmetric) model of diapir intrusion into the lithosphere, with decompression partial melting. This will be applied to the Venusian highlands and to the problem of flood basalt eruptions on Earth.
- c. Proposed Research: In the coming year we propose to apply the second and third of these models to hotspot uplift and volcanism on Venus and on Earth. Specifically, we intend to: (1) model the topography, and gravity (geoid) and magma production due to intrusion of a transsolidus diapir intruding stationary lithosphere in order to constrain the origin of Venusian volcanic highlands and continental flood basalt provinces on Earth, and (2) model the topography and stress field along hotspot tracks produced by relative motion between a stationary mantle plume and moving lithosphere.
- Relevant Publications: (1) Olson, P., Hotspots, swells and mantle plumes, *in Magma Storage and Transport*, M. Ryan, ed., John Wiley and Sons, NY, 1990 (in press). (2) Olson, P., P. G. Silver, and R. W. Carlson, The large-scale structure of convection in the Earth's mantle, *Nature*, 344, 209-215, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Orenberg (415) 338-1292
(Name, Address, San Francisco State University
Telephone Number) Dept. of Chemistry & Biochemistry
1600 Holloway Avenue, San Francisco, CA 94132

Co-INVESTIGATORS: Ted L. Roush
(Name Only) Determination of the Optical Constants of Hydrates,
Carbonates, Sulfates, and Nitrates for the Interpretation
PROPOSAL TITLE: of Thermal Infrared Spectra of Martian Surface

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 relative abundances, chemical compositions, and mineralogies of volatile-bearing compounds (*e.g.* carbonates, sulfates, hydrates, and nitrates) provide important information regarding the evolutionary history of the martian surface and atmosphere. Until samples are returned from well characterized sites on Mars, remote sensing observations will provide the only means of obtaining information regarding the surface and atmospheric constituents of Mars. Several absorption features present in recent thermal infrared observations of Mars indicate the presence of hydrates present on the martian surface, and CO_3^- and SO_4^- -bearing materials within the dust suspended in the martian atmosphere. The position of these features indicate that the CO_3 and SO_4 is located in distorted crystallographic sites. Quantitative modelling of these data currently rely upon optical constants of calcite and anhydrite, neither of which exemplify minerals with distorted sites. The goal of the proposed research is to derive the infrared (2.5-25 μm) optical constants for more pertinent volatile-bearing materials. These materials include : 1)hydrous and anhydrous carbonates; 2)hydrous and anhydrous sulfates; 3)hydrated and/or hydroxylated silicates; and 4)hydrous and anhydrous nitrates.

b. New Proposal

c. During the first year carbonates and sulfates, whose infrared transmission spectra are consistent with recent thermal infrared measurements of Mars, will be acquired, chemically and structurally characterized, their near-normal reflectivity measured, and their optical constants derived.

d. Roush, T.L., J.B. Pollack, C. Stoker, F. Witteborn, J. Bregman, D. Wooden, and D. Rank CO_3^{2-} - and SO_4^{2-} -Bearing anionic complexes detected in martian atmospheric particulates, presented at the 4th International Conference on Mars, Tucson, AZ, January 1989.

Roush, T.L. J. B. Pollack, C. Stoker, F. Witteborn, J. Bregman, D. Wooden, and D. Rank CO_3^{2-} - and SO_4^{2-} -Bearing anionic complexes detected in martian atmospheric dust, Lunar and Planetary Science Conference XX, Lunar and Planetary Institute, Houston, TX, 928-929.

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) *The Shape of Eros.* The convex hull of 433 Eros' pole-on silhouette, estimated from radar echo spectra obtained in 1975, is found to be shaped like a rounded trapezoid whose long and short bases faced Earth during epochs of primary and secondary maxima, respectively, in January 1975 optical lightcurves. The hull's non-axisymmetric shape helps to explain odd harmonics in Eros' echo spectral signature as a function of rotational phase. Convex-profile inversion of a 1975 optical lightcurve yields an estimate of Eros' mean cross section, whose elongation resembles that of Eros' hull.

(2) *Doppler-Radar Imaging of Spheres.* A new approach to making radar reflectivity maps of spherical planetary objects uses echo spectra acquired as a function of rotation phase and at arbitrary subradar latitudes. The target's reflectivity distribution is expanded in a spherical harmonic series and the distribution of echo power in phase and frequency is obtained as a linear, analytic function of the series coefficients. To estimate the coefficients from an observed phase-doppler distribution, the inversion is cast as a least-squares problem and solved using singular value decomposition. The result is a linear imaging system whose fidelity can easily be explored with simulations.

C. Proposed Work: (1) Use convex-profile inversion to estimate the mean cross sections of selected mainbelt and near-Earth asteroids, including the "double" object 1989 PB. (2) Develop procedures for inverting delay-doppler radar images of small bodies to estimate their three-dimensional shapes; if successful, apply the procedures to images available for 1989 PB. (3) Apply the recently developed doppler-imaging methodology to existing radar datasets to make radar maps of Mars, Callisto, and Ganymede.

D. Recent Publications: (1) Ostro, S. J., K. D. Rosema, R. F. Jurgens 1990. The shape of Eros. *Icarus*, in press. (2) Hudson, R. S., and S. J. Ostro 1990. Doppler-Radar Imaging of Spherical Planetary Surfaces. *J. Geophys. Res.*, in press.

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) The question of whether or not subsurface ice deposits are widespread on Mars is fundamental to our understanding of the planet, and of potential importance for human exploration. Unfortunately, much of the present evidence for subsurface ice on Mars is inferential and not uncontroversial.
- Our study will take a new approach to the Mars permafrost problem. Its initial goal will be to map the surface and subsurface thermal properties of Mars at high latitudes using Viking Infrared Thermal Mapper (IRTM) data in conjunction with diurnal and seasonal thermal models. A preliminary analysis indicates that subsurface ice may be present at +75° latitude. A more global study may provide a quantitative picture of the present distribution of permafrost in both hemispheres. The results of this work will have important implications for understanding the initial volatile inventory, atmospheric evolution, geology and climate of Mars.
- (b) Although we have not yet received any new funding since our original proposal was written last year, we have nonetheless made progress towards our objectives. First, we have used IRTM north polar observations obtained during the summer season to create a series of broad-band albedo maps of the north polar region of Mars. Second, we have used a series of thermal model calculations to predict the present distribution of permafrost with latitude and depth, and investigate its sensitivity to geographic variations in the thermophysical properties of the Martian soil.
- (c) This year, we plan to complete our north polar thermal mapping and permafrost modeling studies, and publish the results. Our examination of the available IRTM observations indicates that it will be possible for us to produce a thermal inertia map and surface albedo map of the north polar region of Mars with a spatial resolution of 1/2 degree of latitude. These maps should be valuable for a wide range of Mars geology and Mars volatile studies.
- (d) Paige, D. A., Herkenhoff, K. E. and Murray, B. C., "Mariner 9 Observations of the South Polar Cap of Mars: Evidence for Residual CO₂ Frost" *J. Geophys. Res.* 95, 1319 (1990).

PROPOSAL SUMMARY

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

Co-INVESTIGATORS: None
(Name Only)

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.)

Abstract

Research funded by grant NAGW-1928 (formerly NSG-7605), completed during the funding period 10/1/89-9/30/90 has focussed in the following three areas. (a) We have completed a paper that predicts a relationship between the wavelength, which could be expressed as either the width or spacing of tectonic features, and surface elevation (1). This is a consequence of the dependence of both the density and strength stratification, which control the isostatic elevation and dominant wavelengths, respectively, on temperature distribution and crustal thickness. There is a preliminary suggestion that the type of correlation that we predicted can be observed on Venus. (b) We have also completed a paper that formulates a finite amplitude necking model for the evolution of a rift zone that forms by faulting (2). This model illustrates two important aspects of rift evolution that previous models do not explain: the narrowing of a rift and the finite strain that accumulates as extension proceeds. This explains important aspects of terrestrial rift zones and the Beta Regio rift on Venus. (c) We have also completed a paper that examines surface topography and deformation due to convection beneath a ductile crust and consider the implications for the origin of Venusian highlands. The basic point of the analysis is to argue that, in the terrestrial continents with a thick granitic crust and on Venus where the surface temperature is high, the lower-crust can flow in response to forces exerted on it from a convecting mantle beneath.

As proposed last year (4/1/90), we are undertaking three new studies. (a) To understand the formation of rifts, it is necessary to consider how a rift develops along strike. This along strike development can be envisioned as the propagation of a crack into an elastic plate. We propose to continue our studies of rift propagation by treating the rift (crack) as a region of finite amplitude necking. We will also study the role of buoyancy forces in driving rift propagation. (b) We also propose to study the role of compositional buoyancy due to partial melting and melt extraction in the structure and evolution of mantle plumes. Dynamical behavior resulting from the combined effects of thermal and compositional buoyancy (3) could have important implications for the formation and evolution of swells on Venus, Mars, and the Earth. (c) Finally we have made substantial progress on studying the initiation of subduction which is necessary for plate tectonics.

References: (1) Zuber and Parmentier, On the relationship between isostatic elevation and the wavelengths of tectonic surface features on Venus, Icarus, in press 1990. (2) Lin and Parmentier, A finite amplitude necking model for the formation and evolution of rift zones in a brittle lithosphere, J. Geophys. Res., in press, 1990 (3) Sotin and Parmentier, Dynamical consequences of thermal and compositional density stratification beneath spreading centers, Geophys. Res. Lett. 16, 835-838, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: S. J. PEALE
(Name, Address, DEPARTMENT OF PHYSICS, UNIVERSITY OF CALIFORNIA
Telephone Number) SANTA BARBARA, CA Telephone: (805)961-2977

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 resonance configurations, constrain properties of planetary interiors and develop techniques in dynamics which aid in this understanding. Constraints on the structure and evolution of the preplanetary nebula and the formation of planets are also sought.

b. Progress: The papers "On the density of Halley's comet" and "Some unsolved problems in evolutionary dynamics in the solar system" have been published in *Icarus* and *Celestial Mechanics* respectively. A model of confinement of arc rings has been developed based on the ring particles being in a corotational, eccentricity-type orbital resonance with a small satellite. The libration zones of such resonances are characterized by distinct regions of quasiperiodic and chaotic motion, which constrain the amplitude of libration and hence the angular size of the confined arc on one hand and allow leakage from the confined longitudes on the other. Alas, Neptune's arcs are apparently not in any orbital resonance. A chapter "Rotation properties of planetary satellites" has been submitted to *The Reference Encyclopedia of Astronomy and Astrophysics* to be published in 1990. A revised and probably final form of the manuscript "Accretion rates of protoplanets" has been submitted to *Icarus*. A normal distribution of orbital parameters of planetesimals in the primordial nebula has been shown to lead to higher accretion rates for protoplanets than obtained in the submitted paper. In addition, it appears possible to constrain the rotational properties of the protoplanets from the statistics of accretion. Work has begun on the history of the Titan-Hyperion orbital resonance, but progress is so far limited to the development of numerical algorithms for following the evolution and calculating surfaces of section using a Hamiltonian expanded to second order in the eccentricities of both orbits. A preliminary result is the limitation of quasiperiodic libration to amplitudes less than that allowed in the first order model of the resonance because of chaotic motion.

c. Proposed work: (For more than one year) We are waiting for the release of the precise orbital characteristics of the newly discovered Neptune satellites to investigate the detailed resonance structure near the orbit of the arc rings. Some modification of the gravitational confinement mechanism developed last summer may still be viable. Remaining works described in the original proposal include the possibility of disrupting a primordial 2/1 Ariel/Umbriel orbital resonance, effects of gas drag on planetary accretion, inconsistencies between theory and observation for the Galilean satellite system, evolution of the Titan-Hyperion orbital resonance, effect of nebular dissipation on the amplitude of libration of the Trojan asteroids. An additional work to be completed by my student, Yuval Greenzweig, concerns the dependence of the accretion rate of protoplanets on the distribution of orbital elements of the planetesimals and the resulting rotation states.

d. Recent publications: Peale, S. J., and J. J. Lissauer (1989) The rotation of Halley's comet, *Icarus* 79, 396-430. Peale, S. J. (1989) On the density of Halley's comet, *Icarus* 82, 36-49. Peale, S. J. (1989) An analysis of Arc Ring Dynamics (Abst), *Bull. Amer. Astron. Soc.* 21. Peale, S. J. (1989) Some unsolved problems..., *Celest. Mech.* 46, 253-275.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Roger J. Phillips
Southern Methodist University
Department of Geological Sciences
Dallas, TX 75275
(214) 692-3196

CO-INVESTIGATORS: Robert E. Grimm, Southern Methodist University

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 of Ishtar Terra, (ii) origin of horizontal forces in the Venusian lithosphere, and (iii) generation of basaltic crust on Venus.

b. *Progress:* 1) Completed work on the initiation of subduction. 2) Completed work on modeling and interpretation of Bell Regio, Leda Planitia, and Tellus Regio gravity anomalies. 3) Completed work on end-member models of Ishtar Terra. 4) Completed preliminary global analysis of geoid-to-topography ratios of specific topographic features. 5) Completed preliminary analysis of the separation of crustal and mantle sources of Venusian gravity anomalies. 6) Completed preliminary work on the generation of basaltic crust on Venus.

c. *Proposed Work:* 1) Test Ishtar Terra hypotheses with finite element thin viscous sheet model. 2) Complete analysis of basaltic crust generation on Venus. 3) Develop a formalism to invert crater size-frequency distributions for the "obliteration histories" of planetary surfaces. 4) Test models for the origin of horizontal forces in the Venusian lithosphere.

d. *Summary bibliography:* (3/89 - 3/90) 2 papers published, 1 paper in press, 3 papers submitted, 8 abstracts published, 5 seminars given, 8 papers presented at meetings; e.g.,

Phillips, R.J., Convection-driven tectonics on Venus, *J. Geophys. Res.*, **95**, 1301-1316, 1990.

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**, in press, 1990.

Mueller, S., and R.J. Phillips, On the initiation of subduction, submitted to *J. Geophys. Res.*, 1990.

Grimm, R.E. and R.J. Phillips, Gravity anomalies, compensation mechanisms, and the geodynamics of Lakshmi Planum, Venus, submitted to *J. Geophys. Res.*, 1990.

Phillips, R.J., and R.E. Grimm, Generation of basaltic crust on Venus, *LPSC XXI*, 958-959, Lunar and Planetary Institute, Houston, 1990.

PROPOSAL SUMMARY

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

TITLE: Remote Sensing Information Applied to Geological
Studies of Planets (NAGW-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. This program concentrates largely on analysis of remotely acquired information derived from the optical properties of planetary surfaces. Our research in geological sciences relies on integration of observational, laboratory, and theoretical investigations. Diverse research topics concerning exploration of the Moon, asteroids, and Mars are all included in this single proposal.

b) Progress examples: Analytical approaches to extracting compositional information from reflectance spectra have been developed and are being tested to determine mineral abundance and mineral composition for geologic materials using remotely acquired reflectance spectra. A version of the Hapke model was applied to remote observations of the Moon (requiring derivation and removal of an ALT component). Mineral abundances of deep-seated materials excavated by Copernicus were evaluated and provided evidence for a layered pluton (with a large range of Ol/Plag abundances in the peaks). Results from systematic mathematical deconvolution of absorption characteristics (MGM) have been documented and are close to yielding the ability to determine composition of olivine from reflectance spectra. Statistical comparisons of the spectral properties of meteorites and asteroids continue to provide evidence that optical alteration occurs on asteroidal surfaces. Frequency statistics of the shock darkened meteorites are near completion (~14% of ordinary chondrites) and the cause of the optical alteration narrowed to the physical form of finely dispersed metallic particles (trilite and FeNi). Drawing on our successful experience with imaging spectrometer data, preliminary analyses of ISM data for Syrtis Major and Olympus Mons regions have been performed. The surface of Mars is shown to be quite heterogeneous at high resolution with some areas exhibiting clear diagnostic mafic mineral absorptions and other areas exhibiting subtle variations of alteration products and dust. Progress has been made on the book *Remote Geochemical Analysis* and it is expected to be available in about a year.

c) Continuing tasks: Completion of MGM analysis of olivine spectra should result in a useful analytical tool with broad applications for the Moon, Mars, and asteroids. An initial application goal is to determine the composition of the olivine at Copernicus. We will explore and test additional analytical approaches to mineral mixtures, including an independent (probability) method. We intend to obtain sufficient data on black chondrites to quantify the character and nature of the finely dispersed opaques and their relation to observed properties. Frequency statistics on optically altered meteorites will be completed for publication. Cooperative analyses on the composition and high precision spectral reflectance properties for separates of Murchison and Migei (CM) meteorites will be underway with Soviet colleagues. At a lower level of effort, polarization and opposition effects will be evaluated using measurements from controlled surfaces. ISM analyses of Syrtis Major geology should be ready for publication. Experiments with prepared Mars analogue materials over the spectral range from 0.45 to 20 μm should commence using the new Keck facility. RGA should be available to the community.

d) Bibliography: Direct results from this grant during the last year include two JGR manuscripts, a book chapter, 6 diverse LPSC21 abstracts of work in progress, plus a variety of shorter science abstracts.

PROPOSAL SUMMARY

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

CO-INVESTIGATORS:

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 of this work is an assessment of the net extension and compression associated with grabens and wrinkle ridges in Tharsis and Elysium. Topographic data derived from photogrammetry and shadow measurements combined with planimetric data will be used with kinematic models to assess the strain associated with each feature; these data in turn will be used to assess the isotropy of regional strains and assessed in terms of tectonic models. *Martian Volcanism:* This task focuses on a study of the most recent volcanism of the large Tharsis and Elysium volcanoes and a study of the geologic and volcanic history of the small, older, "enigmatic" Tharsis volcanoes (e.g., Tharsis Tholus). The morphology and volcanic aspects of small scale volcanism (e.g., low shields, fissure eruptions) will also be investigated. These two tasks (I and II) will provide important information about the tectonic and volcanic history of Mars. Quantification of the net strain is an important component of the tectonic history. An understanding of the styles of volcanism that characterize the large volcanoes and a study of the older central volcanoes provides important constraints on the evolution of volcanism. *Ganymede-Callisto Surface Age Relations:* The objective is to develop a global stratigraphy for the most widespread geologic units on Ganymede. Understanding the age of major terrane units will provide a context for evaluating the geologic history. 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:* The focus is on the reduction and modelling of gravity data already acquired at three large Australian impact craters (Connolly Basin, Mt. Toondina, and Kelly West).

b. "New Proposal" Much of the proposed work is the outgrowth of activities conducted under previous proposals. Work on wrinkle ridges in Lunae Planum indicates that individual ridges accommodate 130 m of compression and that the regional compressive strain across Lunae Planum is 0.2-0.5% (1600 m). Preliminary work on the graben south of Alba Patera in Tharsis indicates that these features are 8-670 m deep and <1 - 8 km wide. Assuming 60° bounding faults, the typical extension would be 160 m. Preliminary analysis of the gravity data for the Connolly Basin impact structure indicates the central peak is composed of a relatively high density material drawn up from a deeper stratigraphic level and that the crater is now filled with relatively high density clastics shed off the central peak. Both the crater interior and central peak exhibit a gravity high relative to the area outside the crater.

c. FY 91 Work Plan: Task I: Collection and reduction of data for graben in the area of northern Tharsis, used in connection with geologic data, to assess the time-strain history; collection and reduction of data for wrinkle ridges in Arcadia Planitia. Task II: Study the morphology and volcanology of the low shields and fissure flows of Elysium, and map several of the small, old central-vent volcanoes of Tharsis.. Task III: Compile a global stratigraphy for areas on Ganymede for which crater count data has already been compiled; collect additional crater count data for critical areas. Task IV: Reduce and model gravity data for Australian craters.

d. Publications: Golombek, M., Plescia, J., and Franklin, B., (1990), Faulting and folding in the formation of planetary wrinkle ridges, *Proceedings 21st Lunar Planetary Science Conference* (to be submitted). Golombek, M. P., Suppe, J., Narr, W., Plescia, J., and Banerdt, B., (1990) Does wrinkle ridge formation on Mars involve most of the lithosphere? *Abstracts, 21st Lunar Planetary Science Conference*, 421-422. Murchie, S. L., Head, J. W., and Plescia, J. B., (1989) Crater densities and crater ages of different terrain types on Ganymede. *Icarus*, **81**, 271-297. Plescia, J. B., (1990), Recent flood lavas in the Elysium region of Mars. *Icarus* (submitted). Plescia, J. B., (1990), Recent flood lavas in the Elysium region, Mars, *Abstracts, 21st Lunar Planetary Science Conference*, 969-970. Plescia, J. B., (1990), Photoclinometric analysis of wrinkle ridges on Lunae Planum, Mars, *Abstracts, 21st Lunar Planetary Science Conference*, 967-968. Shoemaker, E. M., Shoemaker, C. S., and Plescia, J. B. (1989) Gravity investigation of the Connolly Basin impact structure, Western Australia, *Reports Planetary Geology and Geophysics Program, NASA TM 4130*, 588-589.

PROPOSAL SUMMARY

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

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) Obtaining thermal emission spectra of Mars in the 5.4 to 10.5 micron spectral region and tentatively identifying features due to sulfates, carbonates, and hydrates. 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) Characterizing the particle size distribution and spatial distribution of Saturn's F ring.
- c) During the next year, the following research is proposed: 1) Obtaining new high resolution spectra of Mars in the thermal and near IR and analyzing the results to further constrain the surface mineralogy. 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.*, in press;
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*, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Pollack
(Name, Address, Telephone Number) NASA/Ames Research Center, MS 245-3
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 initial numerical simulations of turbulence 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) conducting initial simulations of the evolution of a nebular disk that is gravitationally unstable; 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 with emphasis on the effects of rotational shear and density stratification; 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 and develop parameterizations of the gravitational torques and asymptotic behavior; 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.*, in press; 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.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Katherine H. Price
(Name, Address, 206 Julian Center, DePauw University
Telephone Number) 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, and -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) New proposal.

(c) During the first year I will map MGM -40267 following standard planetary geologic mapping principles specified by Wilhelms (1972). I will begin 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: Dr. Carolyn C. Porco
(Name, Address, Telephone Number) Lunar and Planetary Laboratory, University of Arizona
Tucson, AZ 85721 (602) 621-2390

Co-INVESTIGATORS: None
(Name Only) _____

PROPOSAL TITLE: Studies 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. Objective : i) Investigate the role played by spiral density wakes in the origin of the azimuthal brightness asymmetry in Saturn's A ring and the lack of it elsewhere in the rings. Results from this research may provide a valuable probe of dynamical and collisional processes within the rings; ii) Examine the behavior and evolution of spokes (contrasts, orbital velocities, etc.) as they pass through Saturn's shadow on the rings for the purpose of elucidating the mechanisms of spoke creation/enhancement in the shadow region and their relationships to meteoroid impact, the magnetic field, the SED's, etc.

b. Progress : i) Preliminary modelling results showing that the asymmetry can be explained by density wakes of the type found by Julian and Toomre (1966) in explaining galactic structure were presented at DPS meeting (Providence, R. I. 1989). Began modification of the original computer code used in generating wakes (obtained from A. Toomre) to match dynamical conditions within Saturn's rings; ii) Completed second major step in the reduction of Voyager 1 images showing passage of spokes through Saturn's shadow on rings. Preliminary findings indicate that some spokes entering shadow emerge significantly enhanced in size and brightness, especially those within SKR-active sector of magnetic field. It may be that the imprinting of a new, radial spoke occurs in shadow.

c. Proposed work : i) Investigate further the nature and origin of the azimuthal asymmetry by using particle size and location (spiral wake) distributions appropriate to Saturn's rings and geometric ray tracing code to model this photometric effect as it is observed in Voyager imaging data. (In collaboration with Dr. Luke Dones of the Canadian Institute of Theoretical Astrophysics.) ii) Complete observational work on Voyager images of spokes to arrive at a data set which will provide unique input to models for spoke creation/rejuvenation.

d. Publications : Porco, C.C. (1988). *Eos, Trans. Am. Geophys. Union* 69,391.; Porco, C.C. (1990). *Advances in Space Research*. 10, 221-229.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Names, Address,
Telephone Number)

Frank M. Richter
Dept. of the Geophysical Sciences
Univ. of Chicago, Chicago, IL (312)702-8102

CO-INVESTIGATORS:
(Name Only)

TITLE:

Studies for Lunar Magma-oceanography: Cumulate Dynamics

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. The long range goal of the proposed research is to develop governing equations and parameterizations for the chemical and dynamical processes that control crystal fractionation from a cooling magma system in order to address the formation and layering of the lunar crust. Topics to be studied both separately and combined include: (i) crystal settling (or floating) and post-cumulate compaction, (ii) convection in magma layers and within porous cumulates, (iii) assimilation and replenishment, and (iv) representations of phase equilibria and material properties of both crystals and melts as crystallization proceeds.

B. We have used compaction theory to successfully model melt profiles for melt redistribution in a basalt-olivine aggregate driven by surface forces.

C. We will continue to concentrate on modelling crystal settling (or floating) in an otherwise quiescent fluid (melt) over the entire range of crystal content from dilute, through hindered settling, to the final expulsion of interstitial melt by matrix deformation. Also in the first year we will develop the necessary representations of the phase equilibria and material properties of crystallizing basaltic melts.

D. Daines and Richter (1988) An experimental method for directly determining the interconnectivity in a partially molten system, Geophys. Res. Lett., V. 15, p. 1459-1462. Richter and Daly (1989) Dynamical and chemical effects of melting a heterogeneous source, J. Geophys. Research, v. 94, p. 12, 499-510.

PROPOSAL SUMMARY

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

Co-INVESTIGATORS: B. N. Khare
(Name Only) 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. Laboratory simulation of CH₄/H₂O (and other) ice irradiation chemistry in comets and outer solar system satellites; comparison with spacecraft observation. Cometary delivery and erosion of volatiles and organics on the early terrestrial planets. Triton and Titan surface ices and chemistry; Triton windblown dust and tidal evolution; Titan radar properties. Oxidants on Mars. Optical constants of minerals and ices.
- b. First smoothed particle hydrodynamic calculation of temperature fields in large cometary impacts (Chyba *et al.*, 1990); cometary contribution to oceans of early Earth (Chyba, 1987, 1990); saltation and plume transport explains windstreaks on Triton (Chyba and Sagan, 1990); modelling radar studies of Titan and other icy Saturnian satellites (Thompson and Squyres, 1990); solid organic residues from irradiation of hydrocarbon/H₂O ices; comparison with vis/ir properties in outer solar system (Khare *et al.*, 1989a, 1989b); and successful modelling of 3.4 μm cometary comae emission from organic grains (Chyba and Sagan, 1987, 1988, 1989; Chyba *et al.*, 1989); optical constants of basalt, CH₄ ice, kerogens, meteorite organics (Khare *et al.*, 1990; Arakawa *et al.*, 1990).
- c. Extension, including 2D → 3D of SPH models of volatile and organic delivery to terrestrial planets; new project on geomorphology and volume of Martian valley networks; depth of oxidant diffusion zone for Mars rover drilling; production and fate of organic sediments on Titan, Triton, Pluto; dielectric properties Titan surface; optical constants of ices, minerals and meteorite residues; reflectance spectroscopy of irradiated ices in new composition and dose regimes; Triton color/albedo classification and spectral properties; test, predicted heliocentric evolution, cometary emission spectra.
- d. Chyba *et al.* (1990), Cometary delivery of organic molecules to the early Earth, *Science*, in press; Khare *et al.*, Solid organic residues produced by irradiation of hydrocarbon-containing H₂O: IR spectroscopy and astronomical implications, *Icarus* 79, 350 (1989); Thompson and Squyres (1990), Titan and other icy satellites: Dielectric properties, *Icarus*, in press; Chyba, Sagan, Mumma, Heliocentric evolution of IR cometary spectra, *Icarus* 79, 362 (1989).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John W. Salisbury
(Name, Address, Dept. of Earth & Planetary Sciences
Telephone Number) Johns Hopkins University
Baltimore, MD 21218 Tel:301-338-7048

Co-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Mid-Infrared Spectroscopic Investigation

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. Growing interest in the thermal infrared has led to an 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 thermal infrared measurements are underway of Mercury, the Moon and asteroids. These developments show the need for both a library of thermal 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 provide this needed capability.

b. This is a renewal proposal for research that during the past year has resulted in expansion of the mineral spectral library in preparation for a second edition; expansion of the rock library to include metamorphic and sedimentary rocks, for which initial measurements have been made; enlargement of the meteorite library to include more than 60 samples; establishment of a soils library; and two interpretative papers of the igneous rock library data published in JGR. Initial testing of a new portable infrared field spectrometer is complete and we have demonstrated the ability to extract absolute emissivity from emittance data. Finally, cooperative research with other NASA investigators has resulted in significant new findings about mixing models and the spectral signatures of lunar soils and shocked minerals and rocks.

c. During the coming year we will publish the libraries of mineral, meteorite and soil spectra, and complete characterization and spectral measurements of metamorphic and sedimentary rocks. We will also use the new field spectrometer to measure environmental effects on spectral emittance.

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., Walter, L. S. and Vergo, Norma, 1989, Availability of a library of infrared (2.1-25.0 μm) mineral spectra: *American Mineralogist*, v. 74, p. 938-939.

Gardiner, J. L. and Salisbury, J. W., 1989, Spectral reflectance of mineral mixtures in the mid-infrared (7-25 μm): Abstracts of the ERIM 7th Thematic Conference on Remote Sensing and Exploration Geology, Calgary, Canada, October 2-6, 1989, p. 2.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gerald G. Schaber
(Name, Address, Telephone Number) USGS, 2255 N. Gemini Dr., Flagstaff, AZ 86001
(602) 527-7485, FTS 959-6640

Co-INVESTIGATORS: Richard Kozak
(Name Only)

PROPOSAL TITLE: Geology and Tectonics 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 research on the geology, tectonics, and cratering history of Venus using all available databases; to publish these results and integrate them into pre-Magellan and Magellan operational and data-analysis activities; and to provide geologic mapping training to the planetary geoscience community, by making available geologic, geomorphic, and structural database products. Major products anticipated include published 15:000,000-scale geologic/geomorphic and structure maps of the northern quarter of Venus based on synthetic stereoimage analysis of Venera 15/16 data, as well as relevant journal articles describing aspects of regional and global volcanism, tectonism, and surface chronology.
- b. Accomplishments (Major): Completion of 1:15,000,000-scale geologic/geomorphic and structural maps of the northern quarter of Venus based on Venera 15/16 data was given top priority during the past year. These maps, on two sheets with accompanying text and unit descriptions and interpretations, were released in March, 1990 as USGS Open-File Report 90-24.
- c. Work Plan (April 15, 1990 - Sept 30, 1991): (1) Prepare USGS Open-File Report (Schaber and Kozak, 1990) for formal publication in USGS Misc. Investigation Series; (2) complete and submit for publication a paper describing digital analysis of the distribution, characteristics, and relations of 34 geologic/geomorphic units recognized in Venus' northern quarter; (3) complete and submit for publication papers on the styles of Venusian tectonics, large shields, and "domical hills" (domes); and (4) provide training tutorials and geologic/tectonic databases for Magellan mission operations and later geologic mapping activities.
- d. Recent Publications (major): Schaber, G.G. and Kozak, R.C., 1990, Geologic/geomorphic and structure maps of the northern quarter of Venus: U.S. Geological Survey Open-File Report 90-24, 27 p., 2 plates

Proposal Summary

Principal Investigator: Robert M. Schmidt
Boeing Aerospace Company Mail Stop 3H-29
P.O. Box 3999, Seattle, WA 98124-2499
(206) 657-3485

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. Initially we believed that large-scale (i.e. gravity dominated) impacts in rock would produce larger craters than in porous targets (e.g. megaregolith), because energy and momentum coupling would be more efficient in nonporous rock. However, recent results (Schmidt, 1990) from experiments performed in rock targets and rock simulants suggest that craters in jointed rock may be considerably smaller than those 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. 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. The advantage of water is that we can photograph complex shock wave interactions for simulated layered targets with different layer conditions. We now think that we can extend this technique to impact plexiglas targets. In addition to shock wave photography, miniature carbon foil stress gauges have been used successfully to measure waveforms in water and between layers in rigid targets. Ultimately, we hope to provide information on the propagation of stress waves in the region near the impact point. Here results will help constrain theories on the ejection of high-speed debris, with particular implications for the origin of SNC meteorites.

c. 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. We also want to decrease the plate thickness relative to the impactor size. This will be done by varying both the projectile size and the plate thickness. To do this we have a larger two stage light gas gun, used previously in our 1G experiments, which will now be mounted on the centrifuge. This gun is capable of launching 1/4" projectiles, as compared to the smaller light gas gun, which was limited to 1/16" impactors. To investigate atmospheric effects we have mounted a vacuum/pressure chamber on the centrifuge which will allow us to isolate pressure effects from drag effects.

d. Schmidt R. M. and K.R.Housen (1987) Some recent advances in the scaling of impact and explosion craters, *Int. J. of Impact Engineering* 5, 543-560.

Holsapple K. A. and Schmidt R. M. (1987) Point-source solutions and coupling parameters in cratering mechanics, *J. Geophys. Res.*, 92(B7), 6350-6376.

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

Schmidt R. M., Voss M. E. and Watson H. E. (1990) 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. 1083-1034, Lunar and Planetary Institute, Houston, TX.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gerald Schubert

(Name, Address,
Telephone Number)

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.)

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- (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: 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. Developed a thermal history model of the Earth that includes degassing/regassing and the dependence of mantle viscosity on volatile content. Demonstrated that tidal heating in Enceladus could be a factor of 2000 greater than previous estimates. Showed that tidal heating in Io's mantle and asthenosphere leads to the alternating basin and swell topography observed on Io's equator. Determined that solid friction in the Earth has been the main energy sink in the Earth-Moon tidal evolution with tidal dissipation in the oceans having a relatively small effect over geologic time (though it is important at present).
- (c) Proposed Work: Investigate the effects of inhomogeneous heating by large impacts on the thermal histories of terrestrial planets. Study the coupled orbital and thermal evolution of Triton to determine the role of tidal heating. 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: (01/89-04/90): 5 papers published, 3 papers in press, 5 abstracts published, 5 oral presentations.
- (e) Personnel: 1 faculty (part time), 1 graduate research assistant.

PROPOSAL SUMMARY/ABSTRACT

Principal Investigator: Peter H. Schultz
(Name, Address, Brown University
Telephone Number) 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. 5.) New estimates on the rate and style of erosion around the low-gradient continuous ejecta of Meteor Crater 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 ejecta properties on emplacement styles on Mars, in laboratory experiments, and eventually Venus; (2.) field studies of contrasting ejecta emplacement styles recognized at Meteor Crater; and (3) Investigation of the styles of crater erosion on Mars and Earth as a means to recognize atmospheric effects on ejecta emplacement as well as changing climates.

d.) Summary Bibliography:

- Schultz, P.H. and Gault, D.E. (1989). In *Proc. Global Catastrophes* (in press).
- Schultz, P.H. (1990a). Atmospheric Effects on Cratering Efficiency, *J. Geophys. Res.* (in revision).
- Schultz, P.H. (1990b). Atmospheric Effects on Crater Shape, (to be submitted to *J. Geophys. Res.*, May).
- Schultz, P.H. (1990c). Atmospheric Effects on Ejecta Emplacement, (to be submitted to *Icarus*, May).
- Grant, J. and Schultz, P.H. (1990a), *Icarus* 84, 166-195.
- Grant, J. and Schultz, P.H. (1990b), Erosional history of Ejecta at Meteor Crater, Arizona (submitted to *Geol. Soc. Am. Bull.*).
- Crawford, D. and Schultz, P.H. (1990), Laboratory investigations of impact-generated plasma (to be submitted to *J. Geophys. Res.*, May).
- Wichman, R.W. and Schultz, P.H. (1989), *J. Geophys. Res.*, 94, 17,333-17,357.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: *Richard A. Schultz*
Mackay School of Mines
University of Nevada, Reno
Reno, Nevada 89557

PROPOSAL TITLE: Geologic mapping of the Ophir Planum region of Mars

ABSTRACT:

- (a) **Objective:** 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 nearly completed. New crater counts define an Early Hesperian age for both Ophir Planum plateau and 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.
 - (c) **Current Work:** Refine stratigraphy in key areas (e.g., at junction of Coprates and Melas Chasmata). Verify compatibility of map units with those on adjacent map sheets and prepare map and text for submittal to USGS. Prepare journal paper on structural relations in the map area.
 - (d) **Relevant Papers:**
Aydin, A. and R.A. Schultz, Effect of mechanical interaction on the development of strike-slip faults with echelon patterns, *J. Struct. Geol.*, 12, 123-129, 1990.
Schultz, R.A., Strike-slip faulting of ridged plains near Valles Marineris, Mars, *Nature*, 341, 424-426, 1989.
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PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David H. Scott
(Name, Address, Telephone Number) U.S.G.S., 2255 No. Gemini Dr., Flagstaff, AZ 86001
(602) 527-7188; FTS 765-7188

Co-INVESTIGATORS: James Dohm
(Name Only) Mary Chapman

PROPOSAL TITLE: Mars Elysium Basin: Water Volumetric Analysis and Water Sources.

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: (1) To map circumbasin materials and their transecting channels and drainage areas that were water sources for the Elysium basin, and to estimate the amount of water supplied to the basin for comparison with data obtained from the first objective. (2) To calculate the volume of water that filled the Elysium basin, one of the largest and most recent depositional basins on Mars. This basin is especially important for quantitative determinations of water volume, because it is the only known basin where direct evidence of a former high-water level can presently be established.
- b. Work Progress and Accomplishments: Preliminary geologic and physiographic-topographic maps have been compiled at 1:5,000,000 scale of the Elysium basin region. The positions of paleolake shorelines and outlet waterways from the basin are approximated on the maps. Our studies indicate that the highest shoreline of the Elysium basin lies between 1000 and 500 m below the Martian datum and that the deepest part of the basin is below -2,000 m; water depths may have been as great as 2500 m. The paleolake(s) at greatest extent probably covered about 1,000,000 km² and had a volume of 5x10¹² km³. Two spillways from the Elysium basin appear to lead into Amazonis Planitia, which may also have been a lacustrine basin. Inflow channels of three different ages suggest that lakes were recurrent in the Elysium basin throughout the geologic record.
- c. Work Plan FY91: Complete geologic and physiographic-topographic maps for publication as U.S. Geological Survey Misc. Inv. Series I-Maps (scale 1:5,000,000). Refine and complete water-volume computations; calculate inflow-channel drainage areas and estimate their runoff capacity. Also, estimate the amount of heat that may have been generated by postulated ash flows of the Medusae Fossae Formation and their potential for melting ground ice in the regolith. Prepare reports for publication in appropriate journals.
- d. Summary Bibliography: 2 papers published, 2 maps in press, 4 abstracts published.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Virgil L. Sharpton
(Name, Address, Telephone Number) LPI - 3303 NASA Road One, Houston, TX 77058
713-486-2111

Co-INVESTIGATORS: Dr. Richard W. Shorthill
(Name Only) _____

PROPOSAL TITLE: ALSE Data Reduction: Constraints on Lunar Substructure
and Regolith Thicknesses

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 Apollo Lunar Sounder Experiment (ALSE) was an orbiting multispectral radar operating during orbits 16 - 18 of the Apollo 17 mission and was capable of mapping substructure to a depth of a few kilometers. By employing a variety of data processing techniques, Peeples et al., (1978) found evidence in the HF-1 band ALSE returns for subsurface layering in Maria Serenitatis and Crisium. These data remain our only clues to the regional configuration of the Moon's near-surface substructure. ALSE data for other mare regions such as Oceanus Procellarum were collected but remain unprocessed. The objectives of the proposed research are to (1) Repeat and verify some of Peeples et al., (1978) results on Maria Serenitatis and Crisium; (2) Process all unprocessed HF-1 data and interpret (where possible); (3) Assess the feasibility of determining regolith thickness estimates from the VHF band ALSE data.

(b) New Proposal

(c) (1) Adjust and test the optical processor at University of Utah; upgrade optics as necessary; (2) Reprocess selected portions of HF-1 data to insure correct processor alignment and to verify and enhance the results of Peeples et al., (1978) over Mare Serenitatis and Mare Crisium;

(d) (1) Sharpton, V.L., and J.W. Head, Stratigraphy and structural evolution of Southern Mare Serenitatis: A reinterpretation based on Apollo Lunar Sounder Experiment data, J. Geophys. Res., 87, 10,983-10,998, 1981. (2) Sharpton, V.L., Analysis of Topography and Implications for the Tectonic Evolution of Mare Basins, Part I: Lunar Substructure, Mare Ridges and the Tectonic Evolution of Mare Basins, Part II: A Comparison of the Regional Slope Characteristics of Venus and Earth, Ph.D. thesis, Brown University, 171 pp., 1984. (3) Sharpton, V.L., and J.W. Head, Lunar mare ridges: Analysis of ridge/crater intersections and implications for the tectonic origin of mare ridges, Proc. 18th Lunar Planet. Sci. Conf., 307-317, 1988.

PROPOSAL SUMMARY

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

Co-INVESTIGATORS: Carolyn S. Shoemaker
(Name Only) _____

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: Field work in 1989 led to the completion of mapping of all craters in the Henbury crater field, N.T., a detailed geologic and gravity survey of the Mt. Toondina structure, S.A., and a geologic and gravity survey of the Kelly West structure, N.T.

c. Proposed work: A major effort will be to complete a monograph on the Australian impact structures. This book will contain an up-to-date account of all 22 impact sites now recognized. It will be based chiefly on the results of our five field seasons of previous work, but it will also include chapters by other authors. Field work will be carried out to search for new impact structures in Queensland, to study the Fiery Creek Dome, Queensland, to investigate the Strangways impact structure, N.T., and to acquire further samples for studies of the erosion history of five meteorite craters.

d. Bibliography:
Shoemaker, E.M., 1983, Asteroid and comet bombardment of the Earth: Ann. Rev. Earth Planet. Sci., v. 11, p. 461-494.
Shoemaker, E.M., and Wolfe, R.F., 1986, Mass extinctions, crater ages, and comet showers, in Smuluchowski, R., Bahcall, J.M., and Matthews, M., eds., The Galaxy and the Solar System: Tucson, Univ. of Arizona Press, p. 338-386.
Shoemaker, E.M., and Shoemaker, C.S., 1988, Impact structures of Australia (1987) [extended abs.]: Lunar and Planetary Science XIX, p. 1079-1080.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Eugene M. Shoemaker
(Name, Address, Telephone Number) USGS, 2255 No. Gemini Dr., Flagstaff, AZ 86001

Co-INVESTIGATORS: Carolyn S. Shoemaker
(Name Only) Ruth F. Wolfe

PROPOSAL TITLE: Chronology of Bombardment 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. Objective: The broad objective of this investigation is to improve the cratering time scales for the terrestrial planets and to advance our understanding of the present and past flux of solid objects in the Outer Solar System. Some specific goals are to 1) reassess the asteroid and long-period comet flux in the terrestrial planet zone, 2) derive a more precise cratering time scale for Venus, 3) reassess the population of Jupiter-family comets, and 4) continue our assessment of the populations and dynamical structure of the L4 and L5 Trojan swarms.
- b. Progress: A reevaluation of the population, size distribution, and collision rate with Earth was completed for Earth-crossing asteroids. A family of Mars crossers was identified that provides direct evidence that Mars-grazing asteroids in relatively stable orbits remote from resonances are an important source of Earth crossers. Cratering rates by comet impact were derived for the Neptune satellite system. New precise orbits of Trojans were obtained, proper elements were calculated, and the L5 Trojan swarm was shown to be collisionally evolved.
- c. Proposed Work: On the basis of our present estimate of the population and size distribution of Earth-crossing asteroids and new calculations of the collision probability with Venus of the subset of Venus crossers, we will derive a refined cratering time scale for Venus. Analysis of observations of long-period comets discovered in the Palomar Asteroid and Comet Survey (PACS) will be undertaken in order to prepare a new estimate of the long-period comet flux out to the orbit of Jupiter. In addition, we will reduce available positional observations of Trojan asteroids discovered by the PACS in order to derive more secure orbits and expand knowledge of the dynamical structure of the L4 and L5 swarms.
- d. Bibliography: Shoemaker, E.M., Shoemaker, C.S., and Wolfe, R.F., in press, Asteroid and comet flux in the neighborhood of the Earth, *in* (Sharpton, V.L., ed.), Global Catastrophes in Earth History: Geol. Soc. Am. Spec. Paper. Shoemaker, E.M., Shoemaker, C.S., and Wolfe, R.F., 1989, Trojan asteroids: Populations, dynamical structure, and origin of the L4 and L5 swarms, *in* Binzel, R.P. and Matthews, M.S., eds., Asteroids II, p. 487-523. The University of Arizona Press.

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 second-year renewal of a three-year program for research 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 to conduct the proposed science. We will continue to play a major role in closing the gap between image data and spectroscopic data.
- B. Progress** The past year has seen good progress and publications related to all tasks. Please see the attached Progress Report for more details. 1) The spectrophotometric study of the Coprates/Valles Marineris region has progressed well, concentrating initially on the nature and origin of low-albedo materials, found on canyon floors and in layers in the canyon walls. 1 journal paper, 2 abstracts, and contributions to a book chapter have resulted. 2) We participated in field work and remote-sensing data acquisition for the Geologic Remote Sensing Field Experiment (GRSFE), and have recently begun to analyze the first of that data. In parallel there has been major progress investigating Mars-analog basaltic pyroclastic and hydroclastic deposits: field geology, sample collection, and laboratory analysis. 1 journal paper and 3 abstracts have resulted. 3) Work has continued to confirm the discovery of the mineral scapolite on Mars, and to refine estimates of composition and regional abundance. We have successfully and thoroughly answered objections raised concerning spectral interference by Mars atmospheric CO. 1 journal article and 1 abstract have resulted.
- C. Proposed Work** 1) Continue 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) Analyze remote-sensing, field geology, and laboratory data collected during first year for investigation of basaltic pyroclastic and hydroclastic volcanism on Earth, for application to Mars remote-sensing and exploration. We will continue to participate in the GRSFE effort. 3) Continue geologic investigation of scapolite on Mars, based on existing 1988 telescopic data and new higher-resolution spectral observations to be made during 1990 (under separate funding). Refine our understanding of the regional occurrence, abundance, and possible modes of origin of scapolite on Mars.
- D. Recent Publications:**
- Dark Materials in Valles Marineris: Indications of the Style of Volcanism and Magmatism on Mars. J. Geophys. Res., in press (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., in press (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., in press (1990) (R.N. Clark, G.A. Swayze, R.B. Singer, J. Pollack).
- Analysis of Poorly Crystalline Clay Mineralogy: Near Infrared Spectrometry Versus X-Ray Diffraction. Lunar and Planet. Sci., **XXI**, 347-348 (1990) (W.H. Farrand and R.B. Singer).
- Visual and Near Infrared Reflectance of Tuff Rings and Tuff Cones. Submitted to the International Volcanological Congress (1990) (W.H. Farrand and R.B. Singer).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Laurence A. Soderblom
(Name, Address, U.S.G.S., 2255 N. Gemini Dr., Flagstaff, AZ 86001
Telephone Number) 602-527-7018; FTS 765-7018

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: The goals of this project are to generate a refined global-scale digital two-color map of Mars' normal albedo and to use this database to help elucidate the surficial geology of the planet. The new map will have about 100 times the information content of the Viking 2 approach mosaic of Soderblom et al. (1978). The images to be used were acquired during ideal seasonal and photometric conditions. The new database, to be distributed widely, will have scientific applications far beyond those described here.
- b. Progress: Generation of eight of the basic regional color mosaics from about 600 images is complete. Four of these cover more than 90% of the equatorial belt, (40°N to 50°S). The other mosaics cover higher latitude regions. The base mosaics are in radiometric units (I/F) and in orthographic and sinusoidal projections at about 1 km/pixel. We developed photometric modeling software to generate numerical models of the anisotropic, multiply scattered irradiance fields that will be used to empirically fit a simple set of functions used to extract maps of normal geometric albedo. By the end of the current fiscal year, we will have completed this photometric modeling procedure and merged the eight existing mosaics into global maps of normal albedo at two wavelengths (0.45 μm and 0.59 μm).
- c. FY91 Work Plan: The database completed in FY90 will be augmented with at least four additional mosaics. Two or more of these are oblique mosaics of the northern latitudes that were acquired during the same Martian summer as the global base and will be merged directly with it. Two others are equatorial mosaics acquired one Martian year earlier than the global base; these will merged as a separate base to be used to study temporal phenomena. Most of FY91 will be spent in analyzing the two final databases to prepare maps and scientific publications. The entire collection of digital products will be prepared for conversion to CDRom for distribution to the science community.
- d. Relevant Bibliography: 1) McEwen, A.S. and Soderblom, L.A., 1989, Mars color/albedo and bedrock geology (abs.): Fourth International Conference on Mars, Tucson, Arizona, p. 138; 2) Soderblom, L.A., in press, Visible and near-infrared reflectance of the Martian surface, in Mars, eds. H. Kieffer, M. Mathews, B. Jakowsky, and C. Snyder, University of Arizona Press, Tucson.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address,
Telephone Number)

Sean C. Solomon
54-522, M.I.T.
Cambridge, MA 02139 617/253-3786

CO-INVESTIGATORS:
(Name Only)

Tectonic History of the Terrestrial Planets

PROPOSAL TITLE:

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 carried out tests of models of crustal divergence in the Venus equatorial highlands, estimated the lithospheric thermal gradient and heat flux on Venus and Mars from the elastic lithosphere thickness, developed new models for the early thermal evolution of the terrestrial planets and meteorite parent bodies, including in particular the role of interior volatiles, developed finite-element models of stress within and near large volcanoes to study the relation between stress and volcano evolution, and initiated finite-difference models of the thermal evolution of zones of lithospheric underthrusting and orogeny on Venus.
- (c) In the coming year our proposed work includes further development of mechanical and thermal models for the formation and evolution of Venus mountain belts; the application of viscous relaxation calculations to limit the mode of origin, age, and dynamics of highlands and coronae on Venus; the quantification of global patterns of tectonic deformation on Venus; the further investigation of lateral heterogeneity in lithospheric thermal gradients on the terrestrial planets from elastic flexure models; the continued development of finite element models of stress within and around large volcanic constructs to study the relation between volcanic processes and stress; and the systematic investigation of global thermal history models for the Moon and Venus.
- (d) Grimm, R.E., and S.C. Solomon, Tests of crustal divergence models for Aphrodite Terra, Venus, *J. Geophys. Res.*, 94, 12103-12131, 1989.

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.*, in press, 1990.

Solomon, S.C., and J.W. Head, Lithospheric flexure beneath the Freyja Montes foredeep, Venus: Constraints on lithospheric thermal gradient and heat flow, *Geophys. Res. Lett.*, submitted, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Steven W. Squyres
(Name, Address, Center for Radiophysics & Space Research
Telephone Number) Cornell University, Ithaca, NY 14850 (607) 255-3508

Co-INVESTIGATORS: Daniel M. Janes
(Name Only)

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 volcanic eruptions on icy 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 funding period, we have (a) Determined likely despinning times for Mercury and examined the consequences for Mercury's geological evolution; (b) Constructed numerical simulations of mantle plume-lithosphere interactions on Venus; (c) Investigated formation of coronae on Miranda by sinker tectonism; (d) Investigated delivery of organics to Earth by comets using detailed simulations of aerobraking and impact physics for comets; (e) Constructed models of stresses and faulting on the flanks of martian volcanoes; (f) Performed mapping and sedimentological study of ancient sedimentation basins on Mars and modeled ice thickness on ice-covered martian lakes; (g) Developed and tested a new photoclinometric code for Mars, and performed a detailed study of error sources in planetary photoclinometry; (h) Modeled viscous relaxation of crater topography on Mars; (i) Developed a new model for palimpsest formation on Ganymede; (j) Demonstrated that long-wavelength radar sounding through a deep CH₄-C₂H₆-N₂ ocean on Titan may be possible; (k) Modeled relaxation of large impact basins on icy satellites; and (l) Investigated thermal stress tectonics on icy satellites.
- (c) Proposed work: In the coming funding period, we propose to (1) Construct 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, better constrain the topography associated with them, and model the physical and chemical characteristics of their environments of deposition; (3) Model the effects of mixing of dissimilar planetary surface materials in varying geometries on the spectra of emitted gamma radiation; (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) Develop a detailed model of the response of a planetary lithosphere to mantle convection and loading, and apply it 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, 4 papers in press, 4 papers submitted, numerous abstracts published (see appendices). *e.g.*, Thomas, P.J., and Squyres, S.W., *JGR* 93, 14919; Squyres, S.W., *Icarus* 79, 229.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David J. Stevenson
(Name, Address, 170-25, Caltech, Pasadena, CA 91125
Telephone Number) 818/356-6108

Co-INVESTIGATORS:
(Name Only)

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 work directed toward understanding the origin, evolution, and structure of planets and satellites.
 - b. (i) Models of Uranus and Neptune directed toward reconciling the similarities of these planets with the gross differences in their heatflows. (ii) Quantitative understanding of accretion shocks and drag heating of dust grains during the formation of the primitive solar nebula. (iii) Preliminary estimation of the role of hydromagnetic torques in the despinning of proto-giant planets. (iv) Demonstration that the hydrocarbon "ocean" on Titan can be stored in the regolith. (v) Estimation of rheological laws for nitrogen and methane ices on Triton; implications of these laws for the interpretation of Voyager results. (vi) Evaluation of volcanic fluxes tied to a generalization of parameterized convection schemes that include the density effects of partial melting. An initial effort has been made to apply this to Mars. (vii) A demonstration that dry carbonate production is probably limited by diffusion through existing carbonate rinds. This leads to the prediction that the Martian atmosphere is undergoing a gradual exponential decline.
 - c. (i) Models for the tidal Q of Jupiter and Saturn based on the resonant excitation of gravity waves in deep, stably stratified regions. (ii) Quantitative assessment of the role of hydromagnetic torques in determining the current spin states of giant planets. (iii) Detailed models of the Neptune interior, especially directed toward understanding the differences and similarities of Uranus. (iv) A major effort to understand the evolution and present internal structure of Triton. (v) Tidal heating in small icy satellites: A novel model based on heating concentrated at faults in a "blocky ice" model. (vi) Simulation of mantle convection in the presence of volcanism, with a focus on understanding the volcanic history of Mars. (vii) Mars climate history based in part on an understanding of dry carbonate production. (viii) Formation of the moon from moonlets.
 - d. 8 papers published, 4 in press, 2 submitted, in past year.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address,
Telephone Number)

Robert G. Strom
Dept. of Planetary Sciences
University of Arizona
Tucson, Arizona 85721
(602) 621-2720

CO-INVESTIGATORS:
(Name Only)

Steven K. Croft

TITLE:

PLANETARY GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS

ABSTRACT:

a. This proposal consists of three main tasks, two of which are continuations of previous research. Task 1 is a continuation of the study on the Solar System cratering record involving the incorporation of the Triton cratering record and a re-evaluation of the cratering records on Ganymede and Callisto. Task 2 is the continuation of the study of icy satellite geology and geophysics, including cryovolcanism and thermal histories. Task 3 is the development and evaluation of a martian climatological and hydrological model involving an ancient ocean(s) in the northern hemisphere and an concomitant ice sheet(s) in the southern hemisphere.

b. Progress Report. Task 1, completed simulations of orbital dynamics model of impacting objects; completed review chapter of martian cratering morphology and statistics; continued crater counts on Callisto. Task 2, revised map of Tiamat Sulcus Quadrangle, Ganymede; completed study of geology of uranian satellites; continued equation of state analysis of molecular ices; initiated study of Maxwell material models of molecular ices; initiated construction of thermal models; completed rheological measurements of $\text{NH}_3\text{-H}_2\text{O}$ -other liquids. Task 3, continued study of Mars geology: layered terrains and canyon formation; initiated study of glacial-like features.

c. Work Statement (First Year). Task 1, complete crater counts on Callisto and leading/trailing asymmetry analysis to distinguish crater populations internal and external to jovian system; modify scaling laws to ice impacts. Task 2, complete tectonic mapping of saturnian satellites and detailed geologic map of Ariel; continue development of material property and thermal history programs for icy satellites; complete survey of physical volcanic structures on icy satellites and begin modeling of cryovolcanic processes. Task 3, complete global mapping of glacial-like features; establish relative dating of glacial events, and initiate martian ice sheet models.

d. Summary Bibliography. 14 Abstracts, 2 papers, 2 book chapters, 1 revised map.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Kenneth L. Tanaka
(Name, Address, 2255 N. Gemini Drive, Flagstaff, AZ 86001
Telephone Number) 602-527-7208

Co-INVESTIGATORS: David MacKinnon
(Name Only)

PROPOSAL TITLE: Intrusion and 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) Our physical model for the ancient impacted Martian crust (composed of a 1-2-km zone of ejecta overlying fractured basement rock; MacKinnon and Tanaka, 1989) provides some of the constraints needed for investigations of intrusive and tectonic processes and history. The form and size of intrusions are important factors controlling hydrothermal processes that may lead to ground-ice melting and discharge of groundwater. Such activity may result in channels, degraded terrain, and volcanoclastic deposits. Intrusions may also uplift strata. Also, narrow (1- to 3-km-wide) grabens are the most prevalent structure on Mars, indicating that shallow mechanical discontinuities hinder continuity between surface and basement structure. Possible basement structures are seen at the Thaumasia plateau (a part of Tharsis); this area also documents early Tharsis regional stresses. To improve our understanding of intrusion and tectonism in the Martian crust, we propose (1) to analyze the mechanics of intrusion in the Martian crustal setting to evaluate plausible form and size of Martian intrusions and to see if consistent landforms exist; (2) to determine the structural history of Thaumasia, where possible intrusion and extensional and compressional basement deformation may be evidenced by structure, topography, and secondary landforms; and (3) to document the early stress history of Tharsis and to understand why the Tharsis volcanotectonic record is so varied.
- (b) New proposal; supersedes the expiring project, "Mars: Hydrologic Anomalies Caused by Volcanism and Tectonism", of the PGG/MDAP/MEVTV program.
- (c) Analyze scenarios for intrusion into an impacted Martian crust under various host-rock, magmatic, and stress conditions. Begin geologic mapping of Thaumasia plateau, emphasizing structural landforms.
- (d) MacKinnon, D.J., and Tanaka, K.L., 1989, The impacted Martian crust: Structure, hydrology, and some geologic implications: *J. Geophys. Res.*, 94, 17,359-17,370. Tanaka, K.L., and Davis, P.A., 1988, Tectonic history of the Syria Planum province of Mars: *J. Geophys. Res.*, 93, 14,893-14,917.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Kenneth L. Tanaka
(Name, Address, Telephone Number) 2255 N. Gemini Dr., Flagstaff, AZ 86001
(602) 527-7208; FTS 765-7208

Co-INVESTIGATORS: Mary Chapman
(Name Only)

PROPOSAL TITLE: Geologic Maps of Parts of Kasei and Mangala Valles, 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 and Justification: The objective of this proposal is to produce interpretive and detailed (1:500,000-scale) geologic maps of central Kasei Valles (MTM bases 25062, 25067) and north-central Mangala Valles (MTM bases -05152, -10152). Images of the map areas have good to excellent quality and resolution, and the map areas include channel and degradational features and relations illustrative of hydrologic conditions. The investigators will apply image-processing and photoclinometry techniques to supplement standard photogeologic mapping.
- b. Accomplishments: We have completed preliminary geologic mapping of the central Mangala Valles area (MTM -05152 and -10152) and submitted the combined photomosaics as a single map for MGM review for publication as a USGS Miscellaneous Investigations Series I-Map. The preliminary map product was presented as a poster at the GSA National Meeting (Chapman and Tanaka, 1989) and at the 21st Lunar and Planetary Science Conference (Chapman and Tanaka, 1990a). Two papers were prepared summarizing the results of the Mangala Valles mapping. In the first paper (Chapman and Tanaka, 1990b) we discussed origins of small valleys exposed mostly in adjacent areas of Mangala; the interpretations pertain to our map area as well. In the second paper (Tanaka and Chapman, in press), we showed the relations among flooding (partly catastrophic), faulting, and volcanism in the region. In the central Kasei Valles area, preliminary mapping of MTM 25062 has been completed.
- c. Work Plan for FY 91. During the coming year (late FY90 to early FY91), we will complete the geologic map of central Kasei Valles (MTM 25062 and 25067) and submit it for review. The bases will be combined into one sheet. Scientific results will be presented in articles and abstracts.
- d. Summary Bibliography. MacKinnon, D.J., and Tanaka, K.L. (1989) *J. Geophys. Res.*, 94, 17,359-17,370; Chapman, M.G., and Tanaka, K.L. (1989) *Geol. Soc. Am. Abs.*, 21, A108; Chapman, M.G., and Tanaka, K.L. (1990a) *Lunar Planet. Sci. Conf. XXI*, 179; Chapman, M.G., and Tanaka, K.L. (1990b) *Proc. Lunar Planet. Sci. Conf. XX*, 531-539; Tanaka, K.L., and Chapman, M.G. (in press) *J. Geophys. Res.*

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Peter C. Thomas
(Name, Address, 322 Space Sciences Building, Cornell U., Ithaca, NY
Telephone Number) 607-255-9581

Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: "Studies of Morphologic and Surface Properties 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. **Objectives.** 1. Study the properties and movement of eolian sediments on Mars with Viking Orbiter imaging and IRTM data, and relationship of dunes to areas of active sand movement. 2. Develop and apply techniques for disk-resolved photometry of irregular objects. 3. Study the geology and surface processes of irregular objects in part using the cartographic and stereogrammetric capabilities developed in Part 2. 4. Study the significance of roughnesses and shapes of ellipsoidal and irregular satellites.
- b. **Progress.** 1. Begun interpretation of finding that early frost on dunes is CO₂ and not H₂O ice. 2. Developed grid and stereo software for irregular object photometry and mapping. Started the application to martian and saturnian satellites. 3. Finished the refinement of software for measurement of ellipsoidal satellites and obtained better measures of Mimas and Enceladus.
- c. **Work this year.** 1. Finish the study of dune sediment characteristics based on the frost study, on correlation of dune field morphologies and other wind markers, and on dune photometric characteristics. 2. Complete shape and photometry studies of Phobos, Deimos, Hyperion, Amalthea, Epimetheus, and Janus. Generate new maps of all these objects. 3. Complete the analysis of satellite shapes and limb roughnesses, to include work on cratering characteristics on small icy objects and on asteroids.
- d. **Publications:** Dermott and Thomas (1990). "Shapes, Masses and Interiors of Satellites." *Adv. Space Res.* 10, 165-172.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William C. Tittlemore, Assistant Professor
(Name, Address, Dept of Planetary Sciences/LPL
Telephone Number) Univ. of Arizona, Tucson, AZ 85721

CO-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Dynamical Evolution in the Solar System

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). I propose to investigate dynamical evolution in the solar system. The goal of these studies is to increase our understanding of the origin and evolution of the solar system and the objects within it. I will make use of the methods of modern nonlinear dynamics to address these complex dynamical problems.
- (b). I began an investigation of the possible dynamics of the Galilean satellites prior to the establishment of the Laplace resonance. If Europa and Ganymede evolved through the 3:1 resonance, their orbital eccentricities would have reached large values during a phase of chaotic motion. The icy mantles of both satellites may have been extensively melted and fractured due to tidal effects, explaining their relatively young surfaces. Passage through this resonance provides an unambiguous explanation of the Ganymede-Callisto dichotomy. I have continued to study chaotic resonances in the Uranian satellite system, with particular attention to the tidal heating of Ariel. During temporary capture in the 4:1 resonance with Titania, the interior of Ariel may have been tidally warmed by up to 20 K, perhaps triggering the geological activity that led to its resurfacing.
- (c). I will continue the investigation of mean-motion resonances in the satellite systems of Saturn and Jupiter. I will continue to carry out numerical and analytical studies of mean-motion commensurabilities among planetary satellites, in order to determine the effects of passage through resonances on satellite orbits and thermal histories. The stability of the solar system will be investigated, by studying the dynamics of few-planet solar systems. I will carry out an investigation of the dynamics of the Lagrangian satellites of Saturn, in order to determine the origin and explain the stability of these satellites.
- (d). Tittlemore, W. C. 1990. Tidal Heating of Ariel. *Icarus*, in press.
Tittlemore, W. C. 1990. Past Chaotic Motion of the Galilean Satellites: An Explanation of the Resurfacing of Europa and Ganymede and the Ganymede-Callisto Dichotomy. Submitted for publication.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald L. Turcotte
(Name, Address, Telephone Number) Department of Geological Sciences
4122 Snee Hall, Cornell University
Ithaca, NY 14853-1504

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 objective of the proposed research is to study the thermal evolution of the moon, Mars and Venus, to determine the implications of this evolution with respect to tectonics and volcanism, and to integrate the results with available observations on the earth. The focus of our work will be on crustal fractionation, crustal recycling, and the impact of these on thermal convection.

b. During the past year we completed our parameterized calculations using a very approximate model. Our results indicate that crustal fractionation has a profound influence on planetary evolution.

c. (1) We propose to improve our planetary fractionation models in a variety of ways.
(2) We propose to consider early planetary differentiation.
(3) We propose to study the effects of crustal recycling by delamination.

(4) We propose to compare our results with a variety of observations.

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 from parameterized convection calculations, Lunar Planet. Sci. XXI, 1266-1267 (1990)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

G. Leonard Tyler (415-723-3535)
Center for Radar Astronomy (Durand Bldg - Room 232)
Stanford Electronics Laboratories
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 on the near 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. An early objective 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: 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; presently up to 300 wires and/or patches may be analyzed. Tests on canonical objects (cubes, cylinders, and spheres) show good agreement with theory. We have begun calculations on pairs of spheres. For spheres which are almost in physical contact with diameters on the order of $\lambda/3$ we find that body-body coupling changes backscattered field strength by up to 40%; the effect decreases with increasing center-center spacing. This implies that for an important class of objects -- centimeter-size rocks on Venus being probed by the Magellan radar, for example -- rock-rock interactions are important but do not dominate the total scattered field.

(c) Task Summary for Next Year: We propose to continue testing and using NEC for scattering studies. This will include completion of the two-sphere study and initiation of a comparable "two mesh" problem, to simulate behavior of small surface fragments. Generalization of the program to remove the 300 element limit is also planned.

(d) Summary Bibliography: One abstract published in NASA TM

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James R. Underwood, Jr.
(Name, Address, Department of Geology, Kansas State University
Telephone Number) Manhattan, Kansas 66506-3201
(913) 532-6724

Co-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Photogeologic Study 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 ridge.
 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. Evaluate the possibility of a site in, or near, Claritas Fossae having the appropriate characteristics for a Mars landing site.
 5. Coordinate the response to the reviews of the Galileo Regio (Jg-3) quadrangle, Ganymede (Underwood, Casacchia, Woronow, Teeling) to suggestions of three reviewers.
- B. Progress
- Served as Discipline Scientist, PG&G Program, 6/1/87-8/1/89.
Research Assistant (employed 11/16/87-resigned 9/30/88 to accept position with city of Buffalo; not replaced) and PI worked on revision of map and text for Galileo Regio (Jg-3) quadrangle, Ganymede.
Acquiring data bases and making literature search, Claritas Fossae project. Participated in MEVTV workshop on the Tharsis province of Mars, October 4-6, 1989. Two base maps, 1:500,000 scale, of part of Claritas Fossae now in press.
- C. Work Plan
- 1990: Acquire data base for 1:500,000-scale geologic mapping; prepare 1:2,000,000-scale geologic map of Claritas Fossae.
- Complete revision of map and text of geology of Galileo Regio (Jg-3) quadrangle, Ganymede.

C. (continued)

1991: Map geology on two 1:500,000-scale base maps of Claritas Fossae; compare Claritas Fossae structural block with the two other major linear mountain blocks on Mars; prepare final maps, sections, and reports.

D. Summary Bibliography: NASA - Related Publications

MS Thesis:

Teeling, Michael J., 1987, Geology of Galileo Regio quadrangle, Ganymede, Kansas State University MS thesis, 66 p.

Other:

- Underwood, James R., Jr., 1987-1989, Dear Colleague (series of six letter-reports to Planetary Geology and Geophysics community), in Impact, R. Greeley, ed., 8, no. 2; 9, no. 1, 2, 3; 10, no. 1, 2.
- _____, 1989a, The far encounter: Neptune at last (abstract), Kansas Geol. Soc. Bull., 65, no. 3, 5.
- _____, 1989b, Planetary geology and geophysics program: A summary, FY '88, in Reports of Planetary Geology and Geophysics Program - 1988, NASA Tech. Memo. 4130, 618-621.
- _____, 1990a, Planetary geology has come of age: Geol. Soc. America Abstracts with Programs, 22, no. 1, 34.
- _____, 1990b, Planetary geology and geophysics program: A summary, FY '89, in Reports of Planetary Geology and Geophysics Program - 1989 (in press).
- Scott, D. H. and James R. Underwood, Jr., 1990, Mottled terrain: A continuing martian enigma, Lunar and Planetary Science XXI, 1117-1118.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Joseph Veverka
(Name, Address, Telephone Number) 310 Space Sciences Bldg.
Cornell U
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 several comprehensive investigations of the color and photometry of icy satellites of Saturn (Rhea) and Uranus (Miranda, Umbriel, and Oberon).
- 2) Initiated detailed photometric study of Triton using Voyager 2 images.
- 3) Obtained improved phase curves for Callisto and Ganymede.
- 4) Initiated studies of Neptune's small satellites using Voyager 2 data.
- 5) Published and/or completed several comprehensive review papers.

Proposed Work for Coming Year:

- 1) Extend Hapke's theory to anisotropic multiple scattering and apply technique to Enceladus and Triton surface photometry.
- 2) Complete color/photometry investigation of terrains on Ariel.
- 3) Continue detailed photometry of Triton, leading up to production of detailed color, albedo, and photometric parameter maps.
- 4) Continue investigations of frosts on Callisto and Ganymede to determine scattering properties and frost/dark component mixing ratios.
- 5) Continue investigations of small satellites concentrating on the Nereid and the newly discovered small satellites of Neptune.
- 6) Continue photometric and radiometric investigations of individual areas on Io using Voyager data.

Summary Bibliography

Verbiscer and Veverka (1989) (*Icarus* 82, 336-353);
Hillier et al. (1989) (*Icarus* 83, 314-335); and 9 other papers listed in recent bibliography (p. 15).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Prof. Joseph Veverka
(Name, Address, Telephone Number) 310 Space Sciences Building
Cornell University
Ithaca, NY 14853

Co-INVESTIGATORS: Dr. Paul Helfenstein
(Name Only)

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 REPORT

- 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) Further developed two-component regolith mixing model and applied it successfully to interpretation of Oberon color photometry.
- 3) 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 $\bar{\theta}$.
- 4) Continued development of analytical framework for improving Hapke's macroscopic roughness correction so that it can be applied to bright surfaces for which scattering between topographic elements is important.

c) PROPOSED WORK FOR COMING YEAR

- 1) Complete ray-tracing model of multiply scattered light between topographic facets and obtain a more generally valid representation of Hapke's $\bar{\theta}$ correction.
- 2) Complete laboratory measurements of regolith particle phase functions out to 170° . Use lunar data (including from Galileo) to constrain actual phase function of lunar regolith particles.
- 3) 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.

d) SUMMARY BIBLIOGRAPHY

Helfenstein and Veverka (1989) in *Asteroids II* (pp. 524-593).
Helfenstein et al. (1990), *Icarus*, in press; Appendix 1). See 4 other publications in Summary Bibliography.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. William R. Ward
(Name, Address, Jet Propulsion Laboratory MS 183-501
Telephone Number) (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 planet-nebula 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: Stephen G. Warren
(Name, Address, Telephone Number) Atmospheric Sciences, AK-40, University of Washington
Seattle, WA 98195 (206) 543-7230

Co-INVESTIGATORS: Conway B. Leovy
(Name Only) _____

PROPOSAL TITLE: "Optical Properties of CO₂-ice and CO₂-snow in the 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 CO₂ ice will be measured in the weakly absorbing regions of the near ultraviolet, visible and infrared, 0.15-50 μ m wavelength. The planned advance over previous work is to discover a method of growing thick, clear samples (>100 μ m). The spectral absorption coefficient is needed for understanding the reflection, absorption, transmission and emission of radiation by particulate media containing CO₂ ice. We will use it to model the spectral albedo and emissivity of clouds and surface frosts in the polar regions of Mars. This in turn we will use to determine a strategy for remote sensing of grain size, water ice content and dust content.

b) (1st year of funding) We have succeeded in growing clear samples of ~18cm³ volume (~4cm thickness) in a thermally isolated chamber which can be cooled to any desired temperature. We can grow samples at any temperature below about 170K and of thickness 1.6-107.5mm. Most of the necessary optics for transmission spectroscopy have been designed and fabricated.

c) (2nd and 3rd year of funding) Samples of 5 different thicknesses and two different temperatures will be grown and their transmission compared to a standard will be measured. This will be done using a grating monochromator for 0.15-5.5 μ m and a Fourier transform interferometer for 2.5-50 μ m. The measurements can be reduced to absorption coefficient and index of refraction by linear regression. The radiative transfer modelling can be performed with the revised optical constants (functions of wavelength and temperature) in the third year.

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 CO₂ snow in Martian polar caps: Model results, *J. Geophys. Res.*, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Thomas R. Watters
(Name, Address, Telephone Number) National Air and Space Museum
Smithsonian Institution
Washington, DC 20560 (202) 357-1424

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE:

Analysis of Tectonic Features on
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.)

ABSTRACT:

- (a) This proposal is for a 1-year continuation of NASA Grant NAGW-940 to investigate tectonic features on the terrestrial planets. The objectives of the proposed research are to formulate models for the origin of certain tectonic features based on detailed morphologic and structural analysis. Essential to the proposed research are field investigations of potential terrestrial analogs.
- (b) During the past year we completed an analysis of domains of pure shear on the Earth, Mars and Venus and expanded our mapping of strike-slip faults in the deformed basalts of the Columbia River flood basalt province. An analysis of the distribution of strain in the floor of the Olympus Mons caldera is nearly complete and the symmetry of inferred stress fields in the Tharsis region of Mars was investigated.
- (c) In the third year of the grant the following will be accomplished: 1) the study of wrinkle ridge-fault scarp associations on the Moon and Mars, initiated in the second year, will be completed and kinematic and mechanical models for their origin finalized; 2) a study of the nature and origin of second-order ridges in the wrinkle ridge assemblage will be initiated; 3) a two week field study of structures on the Columbia Plateau that may serve as terrestrial analogs to second-order ridges and wrinkle ridge-fault scarp associations on the Moon and Mars.
- (d) Watters, T.R., Periodically spaced anticlines of the Columbia Plateau, in GSA Sp. Paper No. 239: Volcanism and Tectonism in the Columbia River Flood-Basalt Province, S.P. Reidel and P.R. Hooper eds., 283-292, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Thomas R. Watters
(Name, Address, Telephone Number) National Air and Space Museum
Smithsonian Institution
Washington, DC 20560 (202) 357-1424
Ted A. Maxwell

Co-INVESTIGATORS:
(Name Only) Geologic and Tectonic Evolution of
Southwest Lunae Planum

PROPOSAL TITLE:

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 has been completed and work has been initiated on MTM 05072 and will be completed at the end of the second year. The curvilinear graben mapped in these two quadrangles have been analyzed and a model for their origin formulated. An apparent wrinkle ridge-fault scarp association that occurs in MTM 05072 is being investigated.
- c) In the third year of this study: 1) a geologic map of MTM 00072 will be completed; and 2) wrinkle ridge crosscutting relationships will be analyzed.
- d) Watters, T.R. and M.J. Tuttle, Origin of curvilinear graben in southwest Lunae Planum, Mars, LPSC XXI, 1308-1309, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Stuart J. Weidenschilling
(Name, Address, Telephone Number) Planetary Science Institute
2421 E. 6th St., Tucson AZ 85719
602/881-0332
Co-INVESTIGATORS: Donald R. Davis
(Name Only) _____

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 improved our numerical code and tested it against an analytic coagulation problem to demonstrate its validity and to optimize the choice of parameters. We find excellent agreement with the analytic result. We have also computed the accretional evolution of a planetesimal swarm for cases corresponding to those of Wetherill and Stewart (1989), and show good agreement with their results.

c) Proposed Research: During the second year of our three-year program to model numerically the accretion of planetesimals in the inner and outer parts of the solar system, we will use our spatially resolved multi-zone code to investigate phenomena of runaway growth of planetary embryos, dynamical isolation of feeding zones, radial transport by drag-induced orbital decay, long-range perturbations, resonances, and related phenomena. This work will be applied to accretion in the terrestrial planet zone in the presence of nebular gas and resonant phenomena.

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, and D. R. Davis (Appendix A).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address,
Telephone Number)

Stuart J. Weidenschilling
Planetary Science Institute
2421 E. 6th St., Tucson AZ 85719
602/881-0332

Co-INVESTIGATORS:
(Name Only)

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.
- (b) New proposal. 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 develop a self-consistent model of dust aggregate structure, with density dependent on collision velocities, and carry out simulations of coagulation including fragmentation. We will also investigate orbital evolution with resonances and drag, for both PR drag and gas drag to evaluate mechanisms for Trojan capture (for IDP's and asteroids). In following years, we will evaluate the scenario for rapid formation of Jupiter-zone planetesimals by H₂O 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) Orbital resonance and Poynting-Robertson drag, S. J. Weidenschilling and A. Jackson, in preparation (Appendix A). 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).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Paul R. Weissman
(Name, Address, Jet Propulsion Laboratory, Mail stop 183-601
Telephone Number) 4800 Oak Grove Drive, Pasadena, CA 91109
(818) 354-2636 FTS 792-2636

Co-INVESTIGATORS: None
(Name Only)

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 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. It was shown (with A. Dobrovolskis and A. Stern) that the low eccentricity of the tidally damped orbit of Pluto's satellite Charon can be used to set an upper limit on the total mass of comets in the Kuiper Belt. Estimates of cratering rates in the Pluto-Charon system showed that impacts are dominated by Kuiper belt comets. The resulting upper limit of ~ 10 Earth masses in the Kuiper belt is not as tight as that found from studies of perturbations on Comet Halley. A survey of physical processes which may modify cometary nuclei over their histories (with H. McSween) showed that many of the effects are similar to, though more subtle than, those seen in recovered meteorites. Such effects must be taken into account in analyzing compositional studies on CRAF and returned samples from Rosetta. Work was begun on a thermal model of Chiron, in order to assess possible causes for its recent cometary-type activity. Two reviews on the Oort cloud were completed, one for Nature, and the other for the Conference on *Comets in the Post-Halley Era* held in Bamberg, FRG.

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. A new study of the Sun's varying galactic motion and its effect on the dynamical history of the Oort cloud will be begun (with K. Innanen). Thermal modeling of Chiron and other outer solar system bodies will continue. In addition, thermal modeling of comets Kopff and Wild 2 in support of the CRAF mission will be undertaken.

d. Weissman, P. R., Dobrovolskis, A. R., & Stern, S. A., Constraints on impact rates in the Pluto-Charon system and the population of the Kuiper comet belt. *Geophys. Res. Lett.* **16**, 1241-1244, 1989. McSween, H. Y., & Weissman, P. R., Cosmochemical implications of the physical processing of cometary nuclei. *Geochim. Cosmochim. Acta* **53**, 3263-3271, 1989. Weissman, P. R., The Oort cloud, *Nature*, in press, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: George W. Wetherill
(Name, Address, Telephone Number) Department of Terrestrial Magnetism
Carnegie Institution of Washington
5241 Broad Branch Road, N.W., Washington, DC 20015

Co-INVESTIGATORS: None
(Name Only) _____

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. Numerical and theoretical problems of planetary system formation are being investigated. 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. During the proposed grant period, particular emphasis will be placed on studying the extent to which present models of Earth formation are consistent with lunar cratering; investigating the relationships between asteroidal origin, asteroidal flux during the formation of the planets, and the present state of the asteroid belt; and understanding the sensitivity of planetary formation models to the time of nebular gas removal.

b. (1) Completed a comparison between our numerical physical modelling of planetesimal growth and analytic solutions of the coagulation equation.

(2) Major rewriting of the computer code used for study of growth of planetesimals into planetary embryos, including more complete treatment of planetesimal fragmentation.

(3) Completed Monte Carlo calculations for the complete evolution of trans-Neptunian comets into objects of asteroidal appearance.

(4) Prepared a comprehensive review article concerning the formation of the Earth and its relationship to the origin of the Solar System and the initial state of the Earth.

d. Wetherill, G. W. The final stage of cometary evolution: Cometary bodies of asteroidal appearance. In press, Comets in the post-Halley era, R. Newburn, ed. Kluwer, Amsterdam, 1990.

Wetherill, G. W. Formation of the Earth. In press, Ann. Rev. Earth Planet. Sci., 18, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Fred L. Whipple
(Name, Address, Smithsonian Institution Astrophysical Observatory
Telephone Number) 60 Garden Street, Cambridge, MA 02138

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.)

a) This study of comets concerns their nature, origin, aging and differences, if any, in the basic character 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) The author's research has helped to demonstrate the "battered" character of the nucleus of Halley's comet, highly relevant to comet formation. He has also demonstrated differences among LP comet groups, depending upon the direction of their orbital major axes with respect to the Galaxy and the Ecliptic, and has studied various types of aging and environmental effects particularly among LP comets.

c) The current intent is to continue the present studies and to concentrate on seeking criteria that measures ages and aging among the SP comets.

d) A presentation at the Bamberg FRD Colloquium in April 1989 entitled "The Forest and the Trees" is attached. It presents both a requested short summary of the meeting and also a presentation of most of the results mentioned or implied in paragraphs a) and b) above.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James G. Williams
JPL, 238-332
Pasadena, CA 91109
(818) 354-6466, FTS 792-6466

CO-INVESTIGATOR: James Gibson

TITLE: Solar System Dynamics -- Asteroids, Comets, and the Moon

- 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 differentiation 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. 3) CCD images and Palomar Schmidt photographs provide positions of comets and minor planets which need further positions for the determination of accurate orbits. The observation program is separately funded. 4) The analysis of lunar laser ranges gives information on the lunar harmonics, moments of inertia, Love number, and dissipation.
- b. Progress: 1) A study and paper on the Alexandra family is nearly complete. 2) A program for the computation of short-period perturbations has been made operational and used in a 300 asteroid run. 3) Astrometric positions were published for 12 comets, 11 planet crossers, a 2:1 librator, and a high inclination object. 4) New programs for numerically integrated lunar physical librations are complete and their results have been used in fits to lunar range data.
- c. Proposed Work: 1) A paper on the Alexandra family will soon be submitted for publication. 2) A paper on the discovery of asteroid families will be prepared and submitted for publication if the review panel wishes it. 3) The classification of families by morphological type will be started again. Physical properties data will be associated with the individual families. 4) The taxonomy work will be extended to additional data sets. 5) Theoretical work will be done as needed. 6) The astrometry program will continue to measure positions of comets and unusual asteroids, e.g. planet crossers, Trojans, Hildas, members of rare families, and high inclination objects. 7) Lunar laser data will be processed to determine lunar gravity field, Love number, and dissipation.
- d. Summary Bibliography: 1) 4 papers published. 2) 2 abstracts published. 2) Astrometric positions are published in the Minor Planet Circulars.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Steven H. Williams Lunar and Planetary Institute
(Name, Address, 3303 NASA Road 1, Houston, TX 77058
Telephone Number) (713) 486-2113

Co-INVESTIGATORS: James R. Zimbelman
(Name Only)

PROPOSAL TITLE: 1:500,000 Scale Geologic Mapping in Western Utopia
Planitia, 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 initial objectives of this mapping project was to place constraints on the interpretation of geologic events affecting the lowland side of the martian crustal dichotomy near the Nilosyrtris Mensae and to examine the morphology and distribution of concentric-fill craters. The objective and background sections of the original proposal are included as Appendix 1 and provide more information.
- (b) Mapping is almost complete; submission of map and text for both quads should occur prior to the June/July Flagstaff meeting. The 1990 PGPI abstract cited below in (d) is included as Appendix 2 and provides a more detailed scientific progress report.
- (c) This year will see the submission and revision of both maps.
- (d) 1. Williams, Steven H. and James R. Zimbelman, Preliminary Geologic Mapping of MTM Quads 40292 and 40297, North of Nilosyrtris Mensae, Mars (abs.), submitted as a PGPI 1990 abstract/progress report. (Appendix 1)
2. Williams, Steven H. and James R. Zimbelman, 1990, Preliminary geologic mapping near the Nilosyrtris Mensae, Mars (abs.), Lunar and Planetary Science Conference, 21st, 1341-1342.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Jack Wisdom
Department of Earth, Atmospheric,
and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, Massachusetts
(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 shown that the large amplitude oscillations in the shape of Neptune's Great Dark Spot (GDS) are well reproduced by simple dynamical models of an isolated vortex embedded in a background shear flow. From the time series of non-dimensional aspect ratio and orientation of the Great Dark Spot we estimate values for the background shear and the mean vorticity of the GDS, and place a lower bound on the Rossby deformation radius. Our models imply the existence of a planetary-scale zone of deterministic chaotic behavior in the atmosphere of Neptune.

(c) We shall continue our investigations of the dynamics of the solar system, using the same pioneering techniques we have used in our earlier studies. We intend to extend the range of applicability of our work on the rotational dynamics of irregularly shaped satellites to the rest of the satellites in the solar system. Numerical investigation of the long-term evolution of the solar system and of small bodies in the solar system will be continued. Qualitative investigation of the stability of small solar systems will be continued, with emphasis on gaining a qualitative understanding of the Sun-Jupiter-Saturn phase space. We shall carry out further studies of tidal evolution of natural satellite systems through resonance.

(d) Polvani, L.M., and Wisdom, J. with DeJong, E. and Ingersoll, A.P. (1990) "Simple Dynamical Models of Neptune's Great Dark Spot," submitted to *Science*.

Polvani, L.M., and Wisdom, J. "On Chaotic Flow around the Kida Vortex," to appear in *Topological Aspects of Fluid Mechanics*, H.K. Moffat, Ed. (Cambridge).

Tittemore, W., and Wisdom, J. "Tidal Evolution of the Uranian Satellites. Part III, Evolution through the Miranda-Umbriel 3:1, Miranda-Ariel 5:3 and Ariel-Umbriel 2:1 Mean Motion Commensurabilities." *Icarus*, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Charles F. Yoder
INSTITUTION: Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91009
PHONE: (818) 354-2444 FTS 792-2444
TITLE: Dynamical Studies of Planets, Planetary Satellites
and Asteroids

ABSTRACT

(a) overall objectives and justification of the work; (b) 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; (d) bibliography

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 increased funding level.

B. A libration theory for Phobos was completed and is in press. 1) Dynamical model which connects horseshoes orbits with the synchronously locked epicyclic orbits has been derived and applied to Soviet Phobos spacecraft. 2) Martian structural model has been constructed in order to estimate k_2 and infer Q from Phobos' secular acceleration. Influence of Mars fluid core on nutations have been estimated. The paper on Phobos gravity field was completed.

C. Dynamical mechanisms related to the formation and dynamical stability of the coorbital pair, Janus and Epimetheus shall be examined. Several studies related to Phobos orbital dynamics, librations, gravity field and their relationship to Phobos origin shall be continued. The constraint imposed by Mars' precession constant on its internal structure shall be explored. The martian Q shall be inferred from the observed Phobos tidal acceleration and a modeled k_2 factor. The study of tidal history of the lunar orbit which includes significant lunar dissipation shall be completed.

D. Salo, H. and C. F. Yoder (1988). The Dynamics of coorbital Satellite systems, Astron. Astrophys., 202, 309-327; Yoder, C. F., S. P. Synnott and H. Salo (1989), Orbits and Masses of Saturn's co-orbiting satellites, Janus and Epimetheus, Astron. J., 98, 1875-1889. Yoder, C. F. and J. P. Berthias (1989), Stability and Dynamics of Synchronously locked, Epicyclic orbits, BAAS (abstract), 21. 1-11.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James R. Zimbelman, CEPS/NASM, Smithsonian
(Name, Address, Institution, Washington, D.C. 20560
Telephone Number) (202) 736-2547

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: As of April 5, 1990, neither base map materials nor FY 90 funding were forwarded to NASM. Information provided to the Principal Investigator indicates the FY 90 proposal was recommended favorably and that the base maps are now completed.
- c) Proposed Work: 1) Complete geologic mapping of MTM sheets -10117 and -10122 (7.5°S to 12.5°S, 115°W to 125°W), covering the majority of the Arsia Mons volcanic shield and a portion of the debris lobe west of the volcano. 2) Transfer the map information to a stable base and submit the maps and text to the U.S.G.S. for technical review. 3) Start preliminary geologic mapping of MTM sheets 10102 and 10107 (7.5°N to 12.5°N, 100°W to 110°W) covering the majority of the Ascraeus Mons volcanic shield and its associated debris lobe. 4) Evaluate the physical properties of the mapped geologic units using remote sensing data at visual, thermal, and radar wavelengths with emphasis on the emplacement and modification history of the surface materials.
- d) Bibliography: 1) Zimbelman, J.R., Geologic interpretation of remote sensing data for the martian volcano Ascraeus Mons, in Advances in Planetary Geology, NASA TM-88784, 271-572, 1986. 2) Mouginis-Mark, P.J., L. Wilson, and J.R. Zimbelman, Polygenic eruptions on Alba Patera, Mars, Bull. Volc. 50, 361-379, 1988.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)

Dr. Stanley H. Zisk
Planetary Geosciences Division, Hawaii Institute of Geophysics
2525 Correa Rd. Honolulu, HI 96822
(808) 948-6488

CO-INVESTIGATORS: none

(Name Only) _____

PROPOSAL TITLE: Lunar Geologic History from High-resolution Earth-based Radar Images

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 to investigate crater impact-melt sheets or other unusual small-scale surface morphologies by their effects on radar echo polarization, and possibly to develop an age-dating technique for impact craters; to investigate the effects of blocks vs. regolith micro-morphology on radar brightness and de-polarization in crater ejecta blankets and rays; to investigate the volcanian history of Alphonsus crater; to analyze hi-res radar images for other geological information. b. Additional data has been analyzed (see figs.); evidence for some age dependence of anomalous cross-polarization; evidence for blocks (not micro-craters) as cross-polarizing mechanism; discovery of additional rilles in Alphonsus c. This Year: Analyze existing additional images of impact craters and rays for ongoing research (Alphonsus, cross-pol); characterize location, age, strength, etc of anomalous cross-pol crater echoes. d. Pubs: Coombs, Hawke, Peterson, Zisk, LPSC XXI, "Regional Pyroclastic Deposits..."; Campbell, Zisk, Bell, Hawke, LPSC XXI, "...Crater Ray Materials in Mare Serenitatis; Campbell, Zisk, Mougins-Mark, "...Lava Surface Textures From Radar Data...", Rem Sens Envir (in press)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: M.T. Zuber
(Name, Address, Geodynamics Branch, Code 621
Telephone Number) NASA/GSFC, Greenbelt, MD 20771 (301) 286-2129

Co-INVESTIGATORS: _____
(Name Only) _____

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 depth of the magma chamber of the martian volcano, Olympus Mons; (2) investigated models for the isostatic compensation of Aphrodite Terra, Venus; (3) developed models that relate the regular spacings of Tharsis-related plains ridges to the shallow mechanical structure of the martian lithosphere; and (4) established a relationship between isostatic elevation and the wavelengths of tectonic features on Venus.
- (c) During the next year we will: (1) measure tectonic deformational wavelengths for a variety of terrain types on Venus and interpret the results in the context of lateral variations in lithospheric structure; (2) analyze the nature of deformational instabilities in a horizontally stressed, strength-stratified lithosphere that contains a detachment surface, with the goal of better understanding the mechanics and style of tectonics on Venus, and (3) investigate the relationship between the state of stress of volcanic edifices and magma chamber mechanics through 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.*, in press, 1990.
Zuber, M.T., and E.M. Parmentier, On the relationship between isostatic elevation and the wavelengths of tectonic surface features on Venus, *Icarus*, in press, 1990.
Zuber, M.T., and P.J. Mougini-Mark, Constraints on the depth and geometry of the magma chamber of the Olympus Mons volcano, Mars, *Lunar Planet. Sci. Conf. XXI*, 1387-1388, 1990.



Report Documentation Page

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