NASA Technical Memorandum 4484

Directory of Research Projects

Planetary Materials and Geochemistry

Edited by
Tamara Dickinson
NASA Office of Space Science
Washington, D.C.

National Aeronautics and Space Administration

Office of Management

Scientific and Technical Information Program

1993

INTRODUCTION

This Directory of Research Projects provides information about the scientific investigations funded by the NASA Planetary Materials and Geochemistry (PMG) Program in fiscal year (FY) 1993. The Directory consists of summary sheets from the proposals indicating the title, principal investigator, institution of investigator, and information related to the objectives, past accomplishments, and the research activities proposed for FY 1993.

The Directory is intended to provide the science community with an overview of the types of research proposals that have been successful in obtaining support under the NASA PMG Program. The PMG Program supports scientific investigations that involve laboratory studies of a variety of extraterrestrial materials (lunar samples, meteorites, and cosmic dust); or that are aimed at understanding the geochemical nature of the Moon, the planets, other satellites, and small bodies in the solar system. The goals of this program are to support research projects that increase the understanding of the origin of the solar system and the processes by which its planets and small bodies have evolved to their present state; and/or yield direct information on the formation of the solar system, the exact time scales for planetary formation and history, the nature and development of planetary surfaces, and past activity of the Sun and cosmic rays. Individual investigations may involve direct measurements of physical and chemical properties, and/or research efforts that contribute new data, which analyze and synthesis existing data, or which combine both kinds of activities. The PMG PRogram also supports lunar, meteorite and cosmic dust curation activities at the NASA Johnson Space Center.

Research projects identified in this Directory were selected for funding in FY 1993 on the basis of scientific peer review conducted by the Lunar and Planetary Geoscience Review Panel. Statiscal information about the FY 1993 program is enclosed. A total of 4 new research projects were selected for funding in FY 1993.

For additional information about the PMG Program contact one of the following:

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Planetary Materials and Geochemistry
Code SLC
NASA Headquarters
Washington DC 20546
202-358-0292

PLANETARY MATERIALS & GEOCHEMISTRY PROGRAM, FY 93

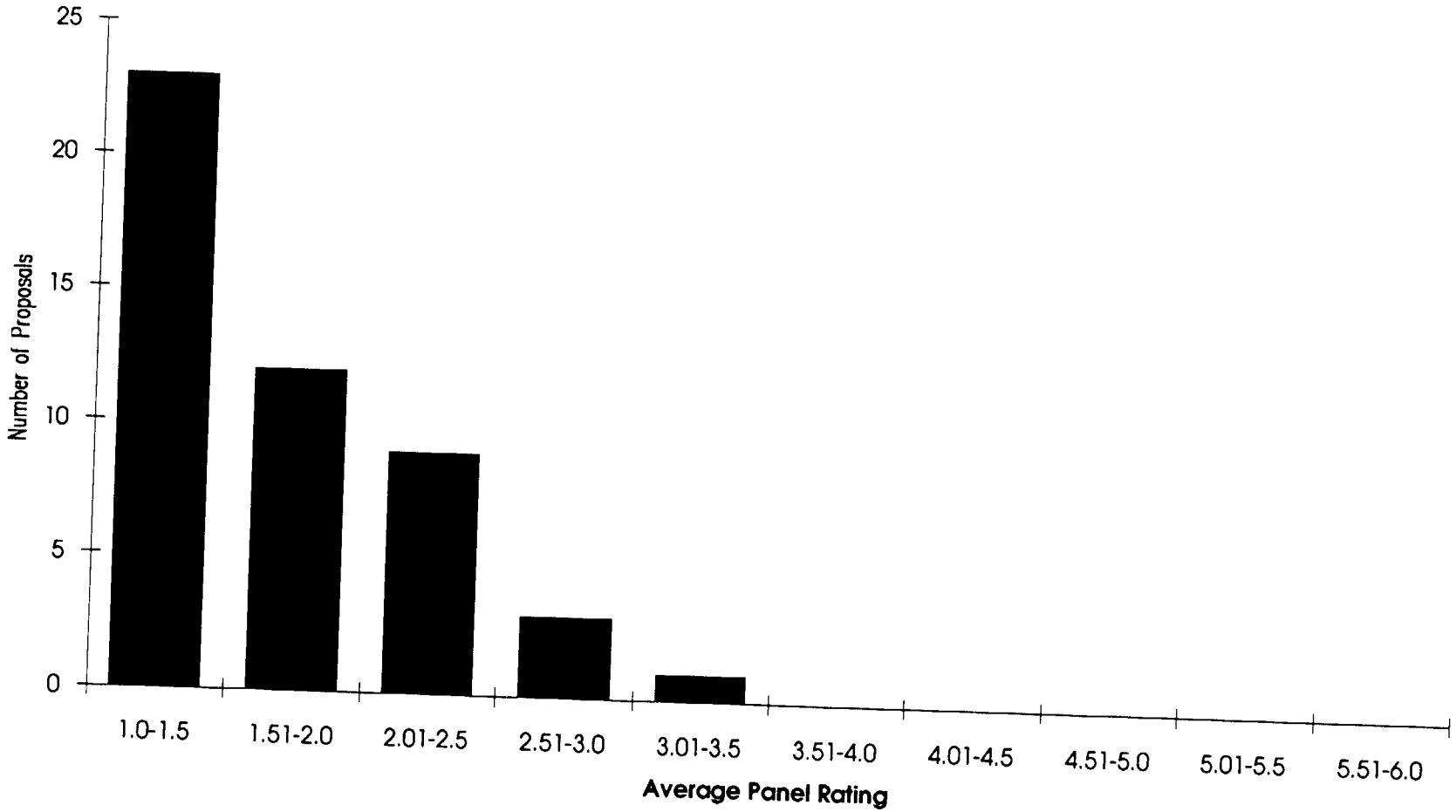
NAME	INSTITUTION
BASU, Abhijit	Indiana University
BLAKE, David F.	NASA/Ames Research Center
BLANFORD, George E., Jr.	University of Clear Lake
BOGARD, Donald D.	NASA/Johnson Space Center
BOYNTON, William V.	University of Arizona
BRADLEY, John P.	MVA, Inc.
BROWNLEE, Donald E.	University of Washington
BURNETT, Donald S.	California Institute of Technology
BUSECK, Peter R.	Arizona State University
CAMERON, A. G. W.	Harvard College Observatory
CHANG, Sherwood	NASA/Ames Research Center
CLAYTON, Donald D.	Clemson University
CLAYTON, Robert N.	University of Chicago
CYGAN, Randall T.	Sandia National Laboratories
DALRYMPLE, G. Brent	U.S. Geological Survey
DAVIS, Andrew M..	University of Chicago
DELANEY, Jeremy S	Rutgers University
DELANO, John W.	State University of New York
DOLLFUS, Audouin	Observatoire de Paris, FRANCE
DRAKE, Michael J.	University of Arizona
EUGSTER, Otto	University of Bern, SWITZERLAND
FLYNN, George J.	State University of New York
GANGULY, Jibamitra	University of Arizona
GOLDSTEIN, Joseph I.	Lehigh University
GOODING, James L.	NASA/Johnson Space Center

GROSSMAN, Lawrence	University of Chicago
GROVE, Timothy L.	Massachusetts Institute of Technology
HASKIN, Larry A.	Washington University
HERZOG, Gregory F.	Rutgers University
HESS, Paul C.	Brown University
HEWINS, Roger H.	Rutgers University
HOGENBOOM, David L.	Lafayette College
HOHENBERG, Charles M.	Washington University
HORZ, Friedrich	NASA/Johnson Space Center
JAMES, Odette B.	U.S. Geological Survey
JONES, John H.	NASA/Johnson Space Center
JULL, A. J. Timothy	University of Arizona
KEIL, Klaus	University of Hawaii
KERRIDGE, John F.	University of California, Los Angeles
LEWIS, Roy S.	University of Chicago
LINDSTROM, David J.	NASA/Johnson Space Center
LINDSTROM, Marilyn M.	NASA/Johnson Space Center
LIPSCHUTZ, Michael E.	Purdue University
LOFGREN, Gary E.	NASA/Johnson Space Center
LONGHI, John	Lamont-Doherty Geological Observatory
LUGMAIR, G. W.	University of California, San Diego
MACPHERSON, Glenn J.	Smithsonian Institution
MARTI, Kurt	University of California, San Diego
MARVIN, Ursula B.	Smithsonian Astrophysical Observatory
MCCALLUM, I. S.	University of Washington
MCKAY, David S.	NASA/Johnson Space Center
MCKAY, Gordon A.	NASA/Johnson Space Center

MCSWEEN, Harry Y., Jr.	University of Tennessee
MEYER, Bradley S.	Clemson University
MEYER, Charles	NASA/Johnson Space Center
MIDDLETON, Roy	University of Pennsylvania
MOORE, Carleton B.	Arizona State University
MORRIS, Richard V.	NASA/Johnson Space Center
NIER, Alfred O. C.	University of Minnesota
NISHIIZUMI, Kunihiko	University of California, Berkeley
NUTH, Joseph A.	NASA/Goddard Space Flight Center
NYQUIST, Laurence E.	NASA/Johnson Space Center
OLSEN, Edward J.	University of Chicago
PAPIKE, James . J.	University of New Mexico
PELLIN, Michael J.	Argonne National Laboratory
PEPIN, Robert O.	University of Minnesota
PHINNEY, William C.	NASA/Johnson Space Center
PIETERS, Carle M.	Brown University
PODOSEK, Frank A.	Washington University
PRINN, Ronald G.	Massachusetts Institute of Technology
PRINZ, Martin	American Museum of Natural History
REEDY, Robert C.	Los Alamos National Laboratory
REID, Archibald M.	University of Houston
RIETMEIJER, Frans J. M.	University of New Mexico
RUTHERFORD, Malcolm J.	Brown University
RYDER, Graham	Lunar and Planetary Institute
SCHMITT, Roman A.	Oregon State University
SEARS, Derek W. G.	University of Arkansas
SHERVAIS, John W.	University of South Carolina

SIGURDSSON, Haraldur	University of Rhode Island
STEELE, Ian M.	University of Chicago
STOLPER, Edward	California Institute of Technology
SUTTON, Stephen R.	University of Chicago
SWINDLE, Timothy D.	University of Arizona
TAYLOR, Hugh P., Jr.	California Institute of Technology
TAYLOR, Lawrence A.	University of Tennessee
TATSUMOTO, Mitsunobu	U.S. Geological Survey
THIEMENS, Mark H.	University of California, San Diego
WACKER, John F.	Battelle, Pacific Northwest Laboratories
WALKER, Richard J.	University of Maryland
WALKER, Robert M.	Washington University
WARREN, Paul H.	University of California, Los Angeles,
WASILEWSKI, Peter J.	NASA/Goddard Space Flight Center
WASSERBURG, Gerald J.	California Institute of Technology
WASSON, John T.	University of California, Los Angeles
WOOD, John A.	Smithsonian Institution Astrophysical Laboratory
ZARE, Richard N.	Stanford University
ZOLENSKY, Michael E.	NASA/Johnson Space Center

Ratings of FY 93 Funded PMG Proposals



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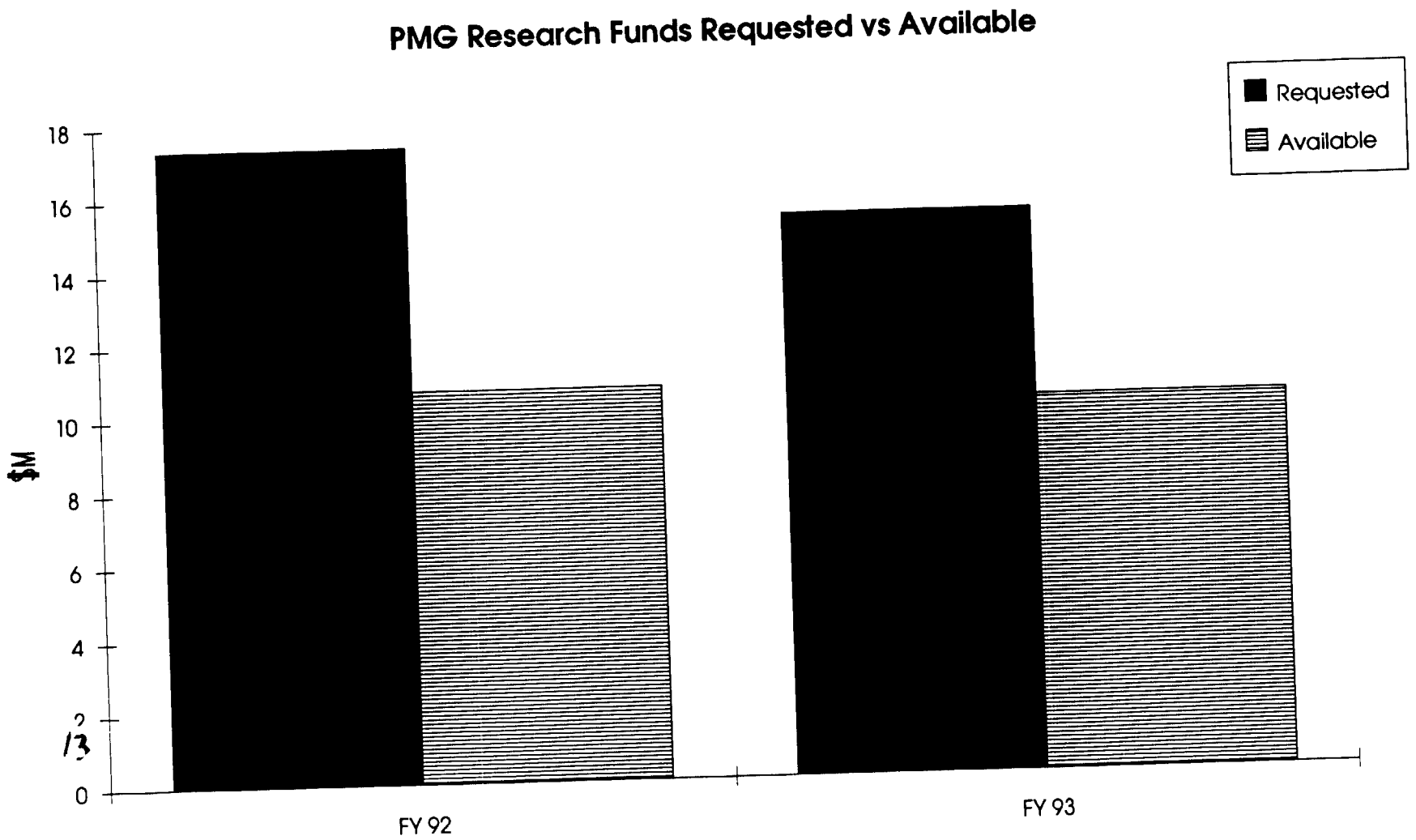
PMG Research Funds Requested vs Available
Requested
Available
$M
18
16
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8
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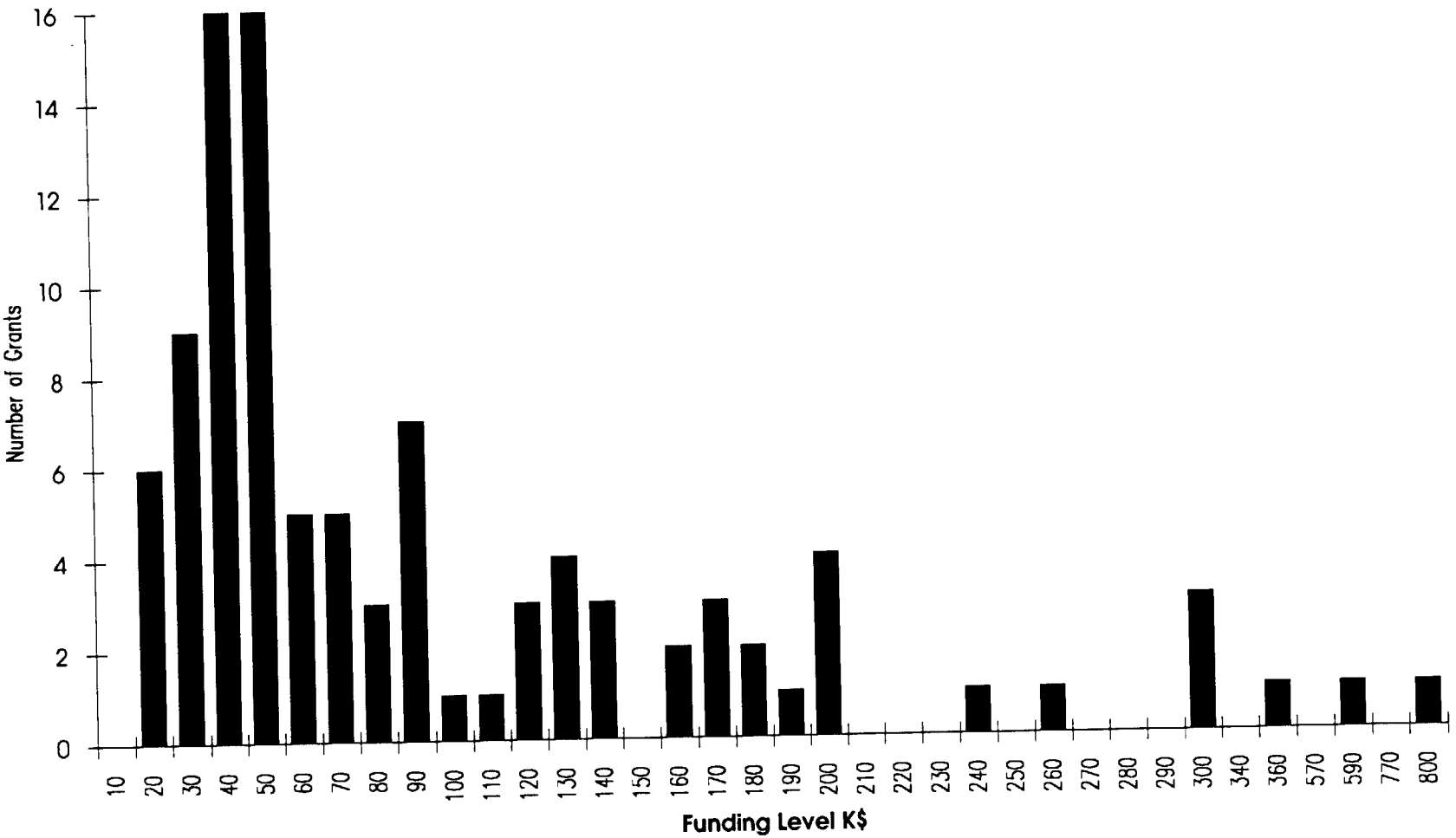
FY 92
FY 93

Distribution of Grant Sizes in FY 1993



3/24/93

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Abhijit Basu
(Name, Address, Telephone Number) Dept. of Geological Sciences, Indiana University
Bloomington, In 47405 (812)-855-6654

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Petrologic Evolution of Lunar and Meteorite Parent Body Regolith

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: Regolith is what has been sampled from the moon; regolith is what is sensed remotely with IR, γ-ray, and other detectors. A knowledge of the mechanisms and rates of processes of regolith generation through geologic time is essential in understanding the distribution of "lunar rocks" in space and time and hence the origin and geologic history of the moon. The principal objective of our research is to understand regolith evolutionary processes by investigating the petrology of regolith particles and their modification in response to micrometeoritic and solar wind bombardment.

b. PRIOR YEAR: Sieved six soils from the core 60014, the petrology of which indicates that the soils are on an average barely mature; plagioclases in the core were derived mostly from feldspathic fragmental breccias and anorthosites; regolith breccia/crystalline breccia ratio in these soils is about 0.25 regardless of maturity and probably reflect the Cayley Plain composition. IR spectra of clean agglutinate separates of soil 10084 do not show the absorption bands of common minerals nor do they show the characteristic red shift of pure glass. Yellow glass associated with Apollo 15 KREEP basalts is probably of igneous origin.

c. NEXT YEAR: Investigate (a) the petrology of highland lithics in the double drive tube core 60014/13; (b) the petrology of ropy glasses from different missions; (c) regolith stratigraphy near the Apollo 16 landing site; (d) the influence of agglutinate abundance on the IR spectra of lunar soils.

d. PUBLICATIONS: [1] Origin of yellow glasses associated with Apollo 15 KREEP basalt fragments by Abhijit Basu, Beth B. Holmberg, and Emanuela Molinaroli : Proc. Lunar Planet. Sci. Conf. 22nd, Lunar and Planetary Institute, Houston, pp. 365-372 (1992) [2] Preliminary results of a petrographic investigation of Apollo 16 core 60014 by Abhijit Basu, S.J. Wentworth and D.S. McKay : Lunar Planet Sci. XXIII, Lunar and Planetary Institute, Houston, pp. 71-72 (1992) [3] Spectral properties of agglutinate separates from soil 10084 by C.M. Pieters, E. Fischer, J. Mustard, S. Pratt, and Abhijit Basu : Lunar Planet Sci. XXIII, Lunar and Planetary Institute, Houston, pp. 1071-1072 (1992)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David F. Blake
MS 239-4, NASA/Ames Research Center
Moffett Field, CA 94035
(415) 604-4816

Co-INVESTIGATORS: Dr. Louis J. Allamandola
Dr. Andrew Pohorille
Dr. Dale Cruikshank

PROPOSAL TITLE: ULTRASTRUCTURAL AND MICROCHEMICAL INVESTIGATION OF COMETARY, PLANETARY AND INTERSTELLAR ICE ANALOGS.

ABSTRACT:

(a). The objective of this research is to develop a theoretical and empirical understanding of the mechanisms which underlie and control the ultrastructure, morphology and microchemistry of astrophysical ices. These submicroscopic properties fundamentally control phenomena such as gas release, vapor pressure, thermal conductivity and reaction rates in ices found on the surfaces of planets and satellites and in cometary and pre-cometary ices.

(b). During the previous two years, we have completed research on phase transitions in pure water ice and on one two-component mixed ice (H_2O:CH_3OH) relevant to comets. We found that water:methanol ice, vapor deposited in the amorphous state at 85 K, undergoes a sub-solidus phase transition at 121-130 K into methanol clathrate hydrate (structure type II) and a second amorphous phase. This phase change and others which occur as the clathrate is further warmed result in gas release at anomalous temperatures and high porosity in the resultant hexagonal water ice. These results may explain anomalous gas release from comets and provide insight into the structures, morphologies and phases present in cometary ice. Furthermore, we have identified features in the IR spectra of ices which are diagnostic of clathrate hydrate and which could perhaps be used to identify its presence on remote icy bodies.

(c). (1). We will follow up on our initial discovery of clathrate hydrate formation within mixed ices by studying other two-component systems pertinent to cometary ice. (2). We will perform similar vapor deposition and slow warming experiments in the H_2O:CO_2 system and the H_2O:CH_4 system (with application to Mars polar ice caps and Titan surface ice respectively). (3). We will study the α–β phase transformation of solid N_2 in the presence of water, in order to constrain models of cryovulcanism on Triton (4). We will compare the observed microstructure, micromorphology, etc. of pure amorphous water ice grown by vapor deposition under vacuum inside an Electron Microscope to similar properties of computer simulated ices using Monte Carlo and molecular dynamics calculations.

(d). Blake, D.F., L.J. Allamandola, Scott Sandford, Doug Hudgins and Friedemann Freund (1991). Clathrate Hydrate Formation in Amorphous Cometary Ice Analogs in Vacuo. *Science*, **254**:548-551. Blake, D.F. and Gary Palmer (1991). Analysis of Cometary and Interstellar Ice Analogs in the Electron Microscope, Proc. 25th MAS, pp. 293-298.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: George E. Blanford, Jr.
(Name, Address, Telephone Number) University of Houston-Clear Lake Box 19
2700 Bay Area Blvd. Houston, TX 77058

Co-INVESTIGATORS: -
(Name Only)

PROPOSAL TITLE: Cosmic Ray and Solar Flare Irradiation of Planetary 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) As Task 1, we are proposing to determine track densities in restricted classes of IDPs to determine whether they are of asteroidal or cometary origin. The source of IDPs is an important problem in planetary research because of how they are related to the history and origin of the solar system. As Task 2, we propose to measure track density profiles in the Apollo 17 deep drill core to constrain the possible geologic history of that site. Determining lunar geologic history was one of the principal objectives in retrieving lunar core samples.

b) new proposal

c) In Task 1, we will measure track density distributions using a high resolution, high voltage TEM for IDPs that have been selected by their chemistry and mineralogy to fall within a restricted class. Track density distributions for asteroidal particles should be distinct from those of cometary particles and we should be able to identify their origin. In Task 2, we will measure track density profiles in two sections (each about 10 cm in length) of the Apollo 17 deep drill core. We will use scanning electron microscope equipped with a digital imaging and analysis system which will increase the speed with which these data can be obtained. The track density profiles will give some time constraints on the geologic history of the core formation.

d) Thomas K.L., Blanford G., Keller L.P., Klöck W., and McKay D.S. (1992) Carbon abundance and silicate mineralogy of anhydrous interplanetary dust particles. Submitted to *Geochim. Cosmochim. Acta.*

Thomas K.L., Keller L.P., Blanford G., Klöck W., and McKay D.S. (1992) Carbon in anhydrous interplanetary dust particles: Correlations with silicate mineralogy and sources of anhydrous IDPs. In *Lunar and Planetary Science XXIII*, pp. 1425-1426.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald D. Bogard
Mail Code SN
NASA, Johnson Space Center
Houston, TX 77058
(713) 483-5146

CO-INVESTIGATOR: L.E. Nyquist

PROPOSAL TITLE: NOBLE GAS INVESTIGATIONS OF IMPACT METAMORPHIC AGES ON THE MOON AND METEORITE PARENT BODIES

Abstract: (Paragraphs (a) through (d) are (a) statement of objectives; (b) accomplishments of past year; (c) proposed work for next year; (d) short bibliography.

(a) The characterization of noble gas components in meteorites and lunar samples can aid in defining their origins, collisional events, regolith histories, and past thermal environments. In particular, ^{39}Ar-^{40}Ar age determinations and Ar diffusion properties can characterize the impact bombardment history of meteorite parent bodies in comparison to that of the moon. In addition, we are characterizing GCR- and solar-derived components in meteorites & lunar samples and the loss of radiogenic ^{40}Ar by shock heating and melting.

(b) ^{39}Ar-^{40}Ar determinations of achondrites indicate significant impact metamorphism over ~4.1-3.5 Ga. This time span is similar to that of lunar highland rocks and suggests a common source of bombarding objects for the moon and HED parent body. The ^{39}Ar-^{40}Ar age of the lunar crater Copernicus is more precisely determined at 800 $\pm$ 15 Ma and that of the Acapulco meteorite is 4.50 $\pm$0.01 Ga. ^{39}Ar-^{40}Ar studies of massive impact melt and chondrite phases in the Chico chondrite show lack of complete resetting. Chico shows evidence for a long cosmic ray irradiation under large shielding, including evidence for a high thermal neutron fluence of ~$2x10^{16}$, or about 9 n/sec. Amounts of excess ^{40}Ar and ^{129}Xe and GCR-produced He and Ne in the LEW88516 shergottite indicates pairing with ALH77005.

(c) We shall measure ^{39}Ar-^{40}Ar ages and Ar diffusion properties of selected phases from the following samples as part of detailed consortia studies: 1) clasts and melt matrix from several eucrites and howardites; 2) lunar meteorites MAC88105, Asuka-31, Y-86032, and EET87521; 3) ureilites and meteorites believed related to Acapulco and EL enstatite chondrites. We shall continue investigations of SCR components by analyzing depth samples from lunar rock 68815.

(d) "Composition of solar flare noble gases preserved in meteorite parent body regolith", *J. Geophys. Res.* **96**, 19,321-19,330, 1991; abstracts in LPSC XXIII, pp. 131, 133, 397, 1992.

PROPOSAL SUMMARY SHEET AND ABSTRACT

PRINCIPAL INVESTIGATOR:

William V. Boynton
Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721
Telephone (602) 621-6941

CO-INVESTIGATOR: David A. Kring

PROPOSAL TITLE:

Mineralogic and trace-element studies of meteorites and meteorite impacts

ABSTRACT:

a. The main objective of this work is to perform combined mineralogic and trace-element studies on Ca,Al-rich inclusions (CAI) and chondrules from chondrites to learn about processes that occurred in the earliest stages of the formation of our solar system. Secondary objectives are to study samples of other meteorites to understand planetary processes and to investigate large impacts sites to evaluate the effect of large impacts on planetary bodies.

b. We have completed the trace-element and petrographic analysis of our suite of 18 Allende chondrules. We have begun a combined trace-element and petrographic study of two new brachinites, LEW 88763 and Eagles Nest and we have begun our trace-element and petrographic study of a new shergottite, LEW 88516. A consortium has been established for the detailed study of the new lunar meteorite, Calcalong Creek, found in Australia. In our K/T research, we presented evidence that previously known anomalies in gravity and magnetic data in the Yucatan are due to a buried crater that is likely to be (one of) the K/T impact crater(s) and we demonstrated that the composition of the andesitic melt rock recovered from the crater is related in composition to the tektites that we identified in Haiti.

c. We propose to study rims on CAI using two approaches: (1) Theoretical modelling of the layer-forming episode to constrain the nature of the exchanging reservoir and the kinetics involved in the process, and (2) a petrologic and geochemical study of the rims and sub-rim areas of CAIs with an electron microprobe, SEM, and ion microprobe, to provide essential constraints to be used for the above modelling of the layer-forming process. We will complement our petrographic and trace-element study of CAIs and Ca-rich chondrules with data from the Caltech ionprobe. We shall continue our study of achondrites, concentrating on shergottites, brachinites, and ureilites, to gain insight on planetary fractionation processes.

d. Chicxulub crater: A possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico (1991). A.R. Hildebrand, G.T. Penfield, D.A. Kring, M. Pilkington, A. Carmargo Z., S.B. Jacobsen, and W.V. Boynton, Geology 19:867-871.

A lunar meteorite found outside the Antarctic (1991). D.H. Hill, W.V. Boynton and R.A. Haag, Nature 352:614-617.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John P. Bradley, Ph.D.
(Name, Address, Telephone Number) MVA, Inc., 5500-200 Oakbrook Pkwy., Norcross, GA 3009. (404) 662-8509

Co-INVESTIGATORS: Tim B. Vander Wood, Ph.D.
(Name Only)

PROPOSAL TITLE: Infrared and electron microscopic studies of interplanetary 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. The objectives of this proposal are to prepare and characterize electron-transparent thin sections of interplanetary dust particles (IDPs) using ultramicrotomy, analytical electron microscopy (AEM), and infrared (IR) microspectroscopy. IDPs are believed to include samples of comets, main belt asteroids, and other asteroidal parent bodies that are not represented among conventional meteorites.

B. An IDP containing tochilinite (PCP) was identified and characterized, establishing a direct petrogenetic link between a chondritic IDP, type CM meteorites, and an asteroidal origin. The IR 10 μm "silicate features" of thin sections of IDPs were evaluated in terms of their silicate mineralogy (determined from AEM studies) and then compared with the "silicate features" of several comets. IDPs exhibiting "comet-like" silicate emission characteristics were identified. These IDPs indicate that chondritic IDPs dominated by glass and submicrometer crystals are strong candidates for the dust responsible for silicate emission from comets.

C. The relationship between "comet-like" IDPs and other (IR) classes of IDPs will be investigated. IR silicate emission characteristics of specific components of IDPs (e.g. glasses) will be compared with IR emission from specific astrophysical objects. An AEM study of the nanometer scale mineralogy of chondritic IDPs will be completed. IDPs embedded and sectioned in sulfur (rather than epoxy) will be analyzed for total carbon.

D. J. P. Bradley and D. E. Brownlee, An asteroidal particle linked directly to type CM meteorites and an asteroidal origin, **Science**, 251, 549 (1991); J. P. Bradley, H. Humecki, M. S. Germani, Combined infrared (IR) and analytical electron microscope (AEM) studies of interplanetary dust particles (1992) **Ap. J.**, in press; J. P. Bradley (1990) Electron energy loss spectroscopy of the fine-grained matrices of interplanetary dust particles (Abs), **Meteoritics**, 26, 322-323, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald Brownlee
(Name, Address, Telephone Number) Astronomy Dept., FM-20, Univ. Washington
Seattle, WA 98195 (206) 543-8575

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: INTERPLANETARY 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:* The primary objective of the proposed program is to identify cometary and asteroidal interplanetary dust particles (IDPs) and analyze them with electron microscopes to determine the properties of comets and asteroids. The size range below 20μm is a "magic window" where fragile high velocity cometary dust can survive atmospheric entry and be collected for laboratory analysis. These particles provide the only direct information on cometary solids until a cometary sample return mission is flown. The major theme of the proposed program is to use the differences in velocity dependent atmospheric heating to distinguish between cometary and asteroidal particle types. In addition to cometary particles, asteroidal IDPs are also of interest because of the likelihood that IDPs can provide samples of asteroid types such as the P and D relectance classes that have not produced conventional meteorites. The research will provide information on the processes and environments that produced and influenced solids over an order of magnitude range of distance in the solar nebula and it will provide insight on the interrelationships between solar and pre-solar particles. B) *Accomplishments*: Work on <20μm stratospheric micrometeorites and Antarctic micrometeorites in the 25-50μm size range has provided strong links between several particle types and CI and CM chondrites, meteorites that are generally believe to be of asteroidal origin by virtue of parentbody alteration and solar flare effects. The link to CMs was made by detection of tochilinite-cronstedtite intergrowths unique to CM matrix and the link to CI was made by detection of magnetite framboids and other morphologies that are common in CI matrix. These features and other evidence of aqueous alteration such as carbonates and Ca depletion have been used to infer an asteroidal origin for a subset of IDPs and by default the other classes are obvious candidates for cometary origin, the prime focus of the presently proposed effort. We have done extensive atmospheric entry calculations to predict heating differences between cometary and asteroidal particles. C) *Publications*: Brownlee, D. E. and Kissel, J. (1991) The Composition of Dust Particles in the Environment of Comet Halley, in Comet Halley Investigations, Results and Interpretations, Horwood LTD , ed. J. Mason ,89-98; Love, S. and Brownlee, D. E. (1991) Heating and Thermal Transformation of Micrometeoroids Entering the Earth's Atmosphere, *ICARUS*, 89, 26-43; Bradley, J. P. and Brownlee, D. E.,(1991) An Interplanetary Dust Particle Linked Directly to Type CM Meteorites and an Asteroidal Origin, *Science*, 251, 250-251.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald S. Burnett

(Name, Address, Telephone Number): 170-25, California Institute of Technology, Pasadena, California 91125 (818) 356-6117

CO-INVESTIGATORS:

(Name Only)

PROPOSAL TITLE: Experimental and analytical studies of solar system chemistry

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.)

Our research involves several aspects of solar system chemistry, employing both experimental studies and analyses of extraterrestrial materials. Besides standard petrographic characterization with SEM and electron microprobe analyses, we employ fission, alpha, and beta track radiography in our experimental studies. Collaborative studies utilize synchrotron X-ray fluorescence and ion probe trace element analysis for individual mineral grains. A new collaborative effort involves transmission electron microscopy (TEM).

Research is focused on aspects of trace element partitioning and fractionation in three broad areas: (A) Ca-Al-rich inclusion (CAI) studies; (B) Basic studies of partitioning and trace element fractionation; (C) Solar system actinide chemistry. Each area has on-going and new research projects.

(A) Manuscripts are essentially complete on experimental studies of minor and trace element partitioning in anorthite and perovskite for CAI bulk compositions and a separate study of actinide and Ti partitioning into melilite and spinel. The former study suggests that our ability to model trace element partitioning in CAI liquids leaves a lot to be desired and that most perovskite grains in CAIs have a nebular origin. The latter study rules out trivalent U as an important species in the solar nebula. A detailed search for microscale correlations of U and Ti in CAI melilites gives no evidence for relict perovskite grains in CAI liquids. A major new experimental study of CAI trace element partitioning as a function of cooling rate is proposed.

(B) A graduate thesis involving individual grain comparisons of minor and trace element chemistry with TEM structure in both synthetic and natural crystals will test the importance of several plausible kinetic mechanisms for trace element partitioning. The importance of kinetic effects will also be tested by measurement of sector zoning effects in trace element partitioning. Several of the above experimental studies will be (or have been) done at various oxygen fugacities to check out suggestions of unexplained fO2 variations of partition coefficients for elements that are not multivalent. A major analytical study is in progress to determine the extent of, and possible mechanisms for, fractionation of Y and Ho, elements of the same charge and indistinguishable ionic radius, in various planetary materials variations. Consistent interplanetary differences might exist due to volatility differences for these two elements.

(C) Partition coefficients for U and Th in clinopyroxene in three different bulk compositions show that this mineral is not important in producing observed Th/U fractionations in terrestrial basalts. Garnet is also questionable. Aqueous fluids may play a major role on Earth and Mars, but low Th/U in Apollo 17 mare basalts remain unexplained. Study of the role of late stage, evolved lunar magmas in producing these fractionations is proposed. A collaborative study to measure Pb-U-Th ages on individual phosphate grains in ordinary chondrites is underway.

References: Appendix I and Kuehner et al. (Geochim. Cosmochim. Acta. **53**, 3115, 1989); Hagee et al. (Geochim. Cosmochim. Acta. **54**, 2847, 1990); Wiens et al. (Geophys Res Lett. **18**, 207, 1991); LaTourette and Burnett (EPSL, in press; Appendix H).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald S. Burnett

(Name, Address, Telephone Number) 170-25, California Institute of Technology
Pasadena, California 91125 (818) 356-6117

CO-INVESTIGATORS:

(Name Only)

PROPOSAL TITLE: Igneous origins for the sodium cloud 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.)

We are conducting experiments simulating crustal igneous processes on Io. Our goal is to understand how Na, S, and O cycle through the crust and atmosphere on present-day Io and how igneous interaction with silicate materials lead to this state. A specific objective has been to determine the phases on the surface which are the source of the Na in the cloud of Io, as well as the mechanism(s) by which these phases form and are transported to the surface. The Na is not bound in silicate minerals. We are testing the hypothesis that igneous interactions between silicate magmas and S compounds produce Na-S phases. A key issue is whether elemental S is required. This would be a strong indirect argument that elemental S magmatism is important for Io. However, it is also possible that crustal interactions of SO_2 and silicates (SO_2 weathering) can form compounds, e.g. Na_2SO_4 which could account for the surface Na enrichment. The viability of SO_2 weathering is dependent on redox conditions and silicate composition. FeS will tend to be formed under reducing conditions and, depending on silicate composition, $CaSO_4$ may form instead of Na_2SO_4.

Io could have an O_2-SO_2 atmosphere, so end member experiments have been carried out by interacting a variety of silicate compositions with a SO_2-O_2 gas mixture. A manuscript on this work has been submitted to JGR, Planets. All samples show clear evidence for interaction. Mixtures of Na_2SO_4 and $CaSO_4$ form for compositions with higher Ca/Na. Samples with low Ca/Na (<.3 atomic) show only Na_2SO_4, although KAl $(SO_4)_2$ is formed for K-rich samples. Na_2SO_4 formed by SO_2 interaction could explain the Io Na enrichment.

For these studies a new SEM analytical technique was devised for the analysis of grains that are inclined relative to the electron beam. This can be done simply and reliably by comparing two X-ray spectra of the same point for a 180° rotation of the SEM stage. From the changes with rotation, the tilt angle and the spectrum corrected to normal incidence can be obtained. A paper on this is in preparation.

Experiments have also been carried out with pure SO_2. When examined by photoelectron spectroscopy (XPS), clear S surface peaks are observed on all samples. 4/6 samples show Na-S and/or Ca-S phases on the SEM. Some samples show both oxidized and reduced XPS S peaks; whereas others show only an oxidized S peak. An oxidized peak is unexpectedly observed for a basalt sample. For Fe-free synthetic compositions, SO_2 interaction must occur by disproportionation or by sulfite formation. The two peak XPS spectra favor the disproportionation mechanism. Experiments to study the effects of laboratory oxidation on the reduced S peaks must be studied. A modern XPS instrument is now available to complete these studies.

New research includes: (1) study of the products and rates of SO_2 weathering at lower oxygen fugacities (HM buffer) and lower temperatures, (2) Na_2SO_4 - $CaSO_4$ competition during silicate melt crystallization, and (3) Characterization and formation rate measurements of Na-S products formed by interaction with S_2-SO_2 and pure S_2 gas mixtures.

References: M.L. Johnson and D.S. Burnett: Appendix A, submitted to JGR Planets, 1992; Abs. 23rd DPS Meeting, 1991, p130; Lunar, Plan. Science XXII, 649-650; Geophys. Res. Lett. **17**, 981, 1990.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Peter R. Buseck
Departments of Geology and Chemistry
Arizona State University
Tempe, AZ 85287
(602) 965-3945

PROPOSAL TITLE: Matrix Mineralogy of the Carbonaceous Chondrites

ABSTRACT:

A. We are using high-resolution and analytical transmission electron microscopy (TEM) to study the structure and chemistry of the carbonaceous chondrite (CC) meteorites, with emphasis on their fine-grained phases. Precise knowledge of their character is fundamental for acquiring a thorough understanding of the histories of the CCs. Much information contained in these phases is not accessible by conventional methods of analysis because of their small crystal sizes, while TEM provides the means for observing critical relationships.

B. We have: (1) found two Ca micas - clintonite and margarite - in Allende CAIs; contrary to theoretical studies, they provide evidence that hydration reactions occurred in the solar nebula; (2) identified a wide range of unusual phases on the TEM scale within Fremdlinge and refractory metal nuggets, including nanophase refractory metals within several host minerals; (3) completed a study of cathodoluminescence of highly forsteritic olivines and associated minerals in Allende; (4) initiated studies of fayalitic veins and rims in CC olivines.

C. We will continue TEM studies of: (1) nanophase refractory metals in Fremdlinge and refractory metal nuggets, with special emphasis on those most likely to be primitive condensates; (2) the unusual minerals in Fremdlinge and refractory metal nuggets; (3) the mineralogy of deformed inclusions in Leoville, emphasizing the perovskite and wollastonite; and (4) compositional zoning in the spindle-shaped fayalitic rims and halos in Kaba and Allende olivine.

D. Publications: (1) Calcic micas in the Allende carbonaceous chondrite meteorite: Hydration reactions in the early solar nebula, L. Keller and P.R. Buseck, *Science* 252, 946-949 (1991); (2) Packing of C_{60} molecules & related fullerenes in crystals - A direct view, Su Wang and P.R. Buseck, ***Chem. Phys. Letters 182***, 1-4. (1991); (3) Nanophase metals in Fremdlinge from Allende: "Smokes from the early solar system?", D. D. Eisenhour and P. R. Buseck, (abstr.) ***Meteoritics 26***, 58 (1991); (4) TEM cathodoluminescence spectra of meteoritic minerals, E.J. Benstock and P. R. Buseck, (abstr.) ***Meteoritics 26***, 317 (1991); (5) The multistage formation history of Fremdling AL-OA1, D. D. Eisenhour and P. R. Buseck, (abstr.) ***Lunar and Planet. Sci., XXII*** (1991); (6) Fayalitic halos around FeNi inclusions in forsterite in the Kaba carbonaceous chondrite, X. Hua, P. R. Buseck, and A. El Goresy, (abstr.) ***Meteoritics 26***, 347 (1991).

PRINCIPAL INVESTIGATOR: A. G. W. Cameron

Harvard College Observatory

60 Garden Street, Cambridge, MA 02138

617/495-5374

Co-INVESTIGATORS:

PROPOSAL TITLE: Theoretical Research in Planetary Physics

ABSTRACT:

a. *OBJECTIVE*: Long-term goal is understanding the origin and development of the solar system. Short- and intermediate-term goals are understanding the physics of solar nebula dissipation and formation of the Sun, the physics and chemistry of condensation products within the solar nebula, planetary formation processes including planetary collisions, and processes affecting the formation of planetary atmospheres.

b. *PROGRESS*: Papers on inviscid flybys of the early earth, dealing with tidal and rotational disruptions, and on our 41 simulations of the Giant Impact, exploring a range of parameter space, have appeared in *Icarus*. A paper reporting on our series of Giant Impact studies involving Uranus is in revision for *Icarus*. A chapter generalizing information about extinct radioactivities to produce a local galactic history preceding the formation of the solar system is in press for *Protostars and Planets III*. A new series of runs has started to further investigate the Giant Impact and the Giant Blowoff; the first results for a collision between two half Earths were reported at the Lunar and Planetary Science meeting. A substantial external atmosphere of rock decomposition products was found with only slight rotational flattening.

c. *PROPOSED WORK*: Additional cases in the new series of Giant Impact simulations will be run as quickly as computational resources permit. 10,000 particles are being used in the simulations, with 5,000 in the Impactor. The new version of the SPH code uses variable smoothing lengths and variable particle masses, and a full run typically takes several months in one of our computers. In a collaboration with Bruce Fegley, a detailed chemical analysis of the external rock decomposition atmospheres will be carried out. A study of hydrodynamic blowoff of the hot external atmosphere produced by the Giant Impact is planned.

d. *RELEVANT BIBLIOGRAPHY*: "The Origin of the Moon and the Single Impact Hypothesis IV", by A. G. W. Cameron and W. Benz, *Icarus*, **92**, 204–216 (1991); "Tidal Disruption of Inviscid Planetesimals", by A. P. Boss, A. G. W. Cameron, and W. Benz, *Icarus*, **92**, 165–178 (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Sherwood Chang
(Name, Address, Telephone Number) NASA Ames Research Center, MS 239-4
Moffett Field, CA 94035 415-604-5733

CO-INVESTIGATORS: N. Lerner
D. Blake

PROPOSAL TITLE: Carbonaceous Chondrites: Probes of Early Solar System Processes

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. Determine the contribution of parent body, nebular and interstellar processes to the organic chemistry of carbonaceous chondrites. b1. High molecular weight polycyclic hydrocarbons up to 750 amu in Murchison are composed of both aromatic and aliphatic compounds, and they exhibit excess deuterium indicating interstellar origin. b2. Laboratory studies of the Strecker synthesis in the presence of either Murchison- or Allende-type mineral phases showed that amino acids formed from deuterated carbonyl compounds, ammonia and cyanide retain from 80% to >95% of their deuterium. These results suggest that parent body synthesis of deuterated amino acids from deuterated interstellar precursors is feasible and that the D/H ratios of amino acids may reflect those of the interstellar precursors. b3. Simulations of asteroidal impacts on the Ames Vertical Gun Facility show that a significant fraction of the amino acids contained in projectiles would survive with this fraction decreasing to 0.001 at the high end of the 1-5 km/s range. c1. Determine the rate of D/H exchange between amino acids and water in the presence of minerals in order to set limits on the lifetime of aqueous phases during parent body aqueous alteration. c2. Gain insight into the origins and history of macromolecular carbon grains (MCG) in selected meteorites by characterizing *in situ* their location, structure, morphology and other properties using analytical electron microscopy techniques. d1. Lerner, et al., *Meteoritics*, **26**, 363 (1991). d2. Fomenkova et al., **LPSC-XXIII**, (1992). d3. Peterson et al., *Meteoritics*, **26**, 84-85 (1991).

PROPOSAL SUMMARY

Principal Investigator : Donald D. Clayton
Department of Physics and Astronomy
Clemson University
Clemson , SC 29634-1911

Title: ORIGIN OF THE SOLAR SYSTEM: Isotopic Anomalies and Chemical Memory

ABSTRACT:

a. Objective is to use both isotopic and chemical peculiarities of primitive solar-system objects (primarily meteorites) to illuminate how the solar system formed and to model astrophysical histories that are consistent with the initial conditions of the solar system as revealed by those anomalies. The research is theoretical but relies heavily on isotopic data from meteorites.

b. At the 54th Meteoritical Society we presented new calculations for Si isotopic composition (*Meteoritics* **26**, 347,1991) that cast new doubt on AGB origin. A new approach relevant only for massive AGB stars was presented at 23rd Lun PLanet Sci Conference, and it reopens that paradigm. The PI presented the Leonard Medal Lecture at the Monterey meeting and has submitted it to *Meteoritics*.

c.Work this year will concentrate on Si, C, Kr, Xe, Ba and Ti isotopes in SiC particles from AGB stars and on the isotopic anomalies within meteoritic diamonds. A student and Postdoc Lawrence E. Brown collaborate on SiC projects. Exciting new results will be submitted to *ApJ Letters*. Brad Meyer and Mike Howard collaborate on the model of Xe-HL implantation within diamonds in supernovae, which we have submitted to *Meteoritics*, but also plan to greatly extend. The rates of growth and survival of both particle types will be examined anew.

d."New Ideas for SiC: Mg Burning in AGB Shell Flashes"
Lun.PLanet.Sci. **23**, xxx (March, 1992).
"Meteoritics and the Origins of Atomic Nuclei" Leonard Medal paper
Meteoritics **27**, xxx (March, 1992).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert N. Clayton
Enrico Fermi Institute, University of Chicago
(312) 702-7777

CO-INVESTIGATORS: Toshiko K. Mayeda
Andrew M. Davis
Roy S. Lewis

PROPOSAL TITLE: Isotopic Studies of the Moon and Meteorites

ABSTRACT

(a) Isotopic measurements on several elements will be used to trace the history of matter from nucleosynthesis, through the interstellar medium into the solar system. Extinct radionuclides will be used as chronometers for early solar system processes. Volatile element cosmochemistry will be studied, with primary emphasis on potassium and nitrogen. Refractory element cosmochemistry will be studied through microanalysis of refractory inclusions in meteorites.

(b) We have developed the resonance ionization mass spectrometry (RIMS) method for measurement of titanium isotope anomalies in meteoritic hibonite gains. We have exploited the evaporative isotopic fractionation of magnesium and silicon to determine the thermal histories of individual CAI, including FUN inclusions. An improved analytical procedure has been developed for isotopic study of meteoritic and planetary potassium. Ion microprobe petrography has shown the behavior of trace-element fractionation during crystallization of CAI from melts.

(c) We shall determine potassium isotopic variations in terrestrial and lunar igneous rocks and in differentiated and undifferentiated meteorites to study volatility-related cosmochemical processes, including the origins of the Moon and planets. We shall continue to develop the application of RIMS to cosmochemical problems, and shall work with the group at Argonne National Laboratory in development of the next generation of instrumentation. RIMS will be used to measure isotopic anomalies in refractory elements in interstellar diamond and silicon carbide. We shall investigate the chemical state of nitrogen in rocks from the Earth's mantle in order to determine its global geochemical behavior. We shall further study nitrogen cosmochemistry through measurements of the metallic phase in ordinary chondrites and in stony irons.

(d) A.M. Davis and E.J. Olsen (1991) Phosphates in pallasite meteorites as probes of mantle processes in small planetary bodies. *Nature* **353**, 637–640.

D.R. Spiegel, W.F. Calaway, A.M. Davis, J.W. Burnett, M.J. Pellin, S.R. Coon, C.E. Young, R.N. Clayton, and D.M. Gruen (1992) Three-color resonance ionization of titanium sputtered from metal and oxides for cosmochemical analyses: measurements of selectivity and isotope anomalies. *Anal. Chem.* **64**, 469–475.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Randall T. Cygan
Geochemistry Division 6233
Sandia National Laboratories
Albuquerque, NM 87185
505/844-7216

CO-INVESTIGATOR: Mark B. Boslough

PROPOSAL TITLE: Application of NMR Shock Barometer to Naturally Shocked Minerals

ABSTRACT:

a. The objective of the proposed research is to quantify the effect of shock-loading experienced by silicate minerals subjected to natural impact. NMR spectroscopy will be used to analyze natural samples, primarily quartz and feldspar minerals, obtained from known and suspected impact sites. The NMR spectral characteristics of the minerals will be used to estimate the peak shock pressures based on a calibration of the NMR shock barometer using experimentally shocked minerals. NMR spectroscopy can also identify high pressure mineral polymorphs and evaluate the structural state of diaplecticand fused glasses associated with the terrestrial impacts.

b. Progress report; first year funding has not been received.

c. The second year research tasks will include follow-up collection of samples from Meteor Crater, Arizona and any other K/T boundary clay layers. Samples will be similarly characterized by X-ray diffraction, optical and electron microscopies, and then analyzed by magic-angle spinning ^{29}Si NMR. Quartz, feldspar, and glass peak characteristics will be evaluated after appropriate spectral deconvolution. The significance of NMR relaxation will be examined using the material collected during the first year.

d. Cygan, R. T., Boslough, M. B., and Kirkpatrick, R. J. (1990) NMR spectroscopy of experimentally shocked quartz: Shock wave barometry. In V. L. Sharpton and G. Ryder, Eds., Proceedings of the Twentieth Lunar and Planetary Science Conference, Lunar and Planetary Institute, Houston, 451-457.

Cygan, R. T., Boslough, M. B., and Kirkpatrick, R. J. (1992) NMR spectroscopy of experimentally shocked quartz and plagioclase feldspar powders. In V. L. Sharpton and G. Ryder, Eds., **Proceedings of the 22nd Lunar and Planetary Science Conference**, Lunar and Planetary Institute, Houston, 127-136.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: G. Brent Dalrymple
U. S. Geological Survey
345 Middlefield Rd. (ms 937)
Menlo Park, CA 94025
(415)329-4655 FTS 459-4655
FAX (415)329-4664

CO-INVESTIGATORS: Graham Ryder

TITLE: **$^{40}Ar/^{39}Ar$ Incremental Heating Ages of Submilligram Samples of Lunar Impact Melt Rocks Using a Continuous Laser System**

[a. objectives and justification; b. accomplishments of prior year; c. proposed work this year; d. relevant publications]

ABSTRACT:

a. We propose to continue measuring high resolution (20-50 steps) $^{40}Ar/^{39}Ar$ incremental heating ages on lunar impact melt rocks using the continuous laser system. The overall objectives are to determine: 1) precise ages of a wide variety of lunar impact melt rocks of different composition; 2) the ages of the major basin-forming impacts; and 3) whether the paucity of radiometric ages prior to 4.0 Ga is due to resetting by a continuous early bombardment of the lunar surface or reflects a heavy bombardment "spike" at about 3.9 Ga. The use of very small, carefully selected samples (<0.5 mg) allows us to: (a) avoid or eliminate the effects of contamination by older clasts; (b) to obtain age spectra with prominent plateaus that represent crystallization ages; (c) to verify results by replication where necessary; and (d) to target small clasts within the melt rocks.

b. As of Mar. 1, 1992, we are eight months into year two of the original proposal. We have completed the analytical work on the Apollo 15 melt rocks. We have obtained 26 high resolution (21-51 step) age spectra on 12 carefully selected fragments of Apollo 15 melt rocks of different composition and weighing less than 1 mg. Seven of these give reproducible, intermediate-T plateaus over >40% of the ^{39}Ar released; all of the melt rocks have ages that fall within the narrow range of 3,870 Ma to 3,836 Ma. None of the 12 melt rocks, including those that do not have plateaus, show any evidence of older events.

c. For the first (12 mos.) and second (9 mos.) years, we concentrated on a diverse suite of Apollo 15 melt rocks whose chemistry suggests that they represent five or more distinct impacts. For the third year (1992-93, funded) we proposed to begin work on a suite of melt rocks from Apollo 17. For the year (1993-94) covered by this renewal proposal we plan to continue work on the Apollo 17 suite. The A17 melt rocks are thought to represent mostly Serenitatis-basin material, but the geology of the site and the compositional diversity of the samples suggests that pre- and post-Serenitatis basin material is also present in the analyzed samples.

d. Dalrymple, G. B., and Ryder, G., 1991, $^{40}Ar/^{39}Ar$ Ages of Six Apollo 15 Impact Melt Rocks by Laser Step Heating: Geophys. Res. Lett., v. 18, p. 1163-1166.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Andrew M. Davis
Enrico Fermi Institute, University of Chicago
5640 South Ellis Avenue, Chicago, IL 60637

CO-INVESTIGATOR: Robert N. Clayton

PROPOSAL TITLE: Refractory Inclusions in Carbonaceous Chondrites

ABSTRACT: (a) Our objectives are to learn more about the highest temperature chemical fractionation events in the early solar system. This work involves: measurements of trace element concentrations and isotopic compositions of natural CAI's and cosmic spherules; measurement of isotopic mass fractionation of Mg, Si, Ca, Ti and Cr and elemental fractionation of REE in laboratory-produced evaporation residues; and measurement of crystal/liquid partition coefficients in appropriate systems. Asteroidal processes are being investigated through trace element and chromium isotopic analysis of pallasites and iron meteorites.

(b) We have performed evaporation experiments with single-crystal forsterite and found that grain boundary diffusion has a significant effect on the thickness of the heavy-isotope-enriched zone at the outside of residues. We have investigated major and trace element zoning in melilite from Allende Type B1 inclusions and found that concentrations of incompatible elements are higher than those predicted from simple fractional crystallization using literature melilite/liquid partition coefficients. This suggests that these inclusions may have cooled at 50-100°C/hr. We have completed the analytical portion of an isotopic and trace element study of spinel-rich inclusions in the Mighei CM2 chondrite. We have found that trace element analysis of phosphate minerals in pallasites is quite useful for inferring mantle processes in pallasite parent bodies. We have developed a technique for microbeam RIMS titanium isotopic analysis.

(c) We will continue our investigation of isotopic mass fractionation and chemical fractionation of REE by thermal evaporation under controlled conditions. We will determine iron isotopic compositions of a variety of sizes of deep-sea cosmic spherules. We will study the petrology and trace element and isotopic distributions in refractory inclusions with electron and ion microprobes, concentrating on the most refractory and unaltered inclusions from carbonaceous chondrites. We will use the ion microprobe to analyze the isotopic and trace element compositions of phosphates and silicates in pallasites and iron meteorites. We will continue collaborating with a group at Argonne National Laboratory to apply their resonance ionization ion microprobe to cosmochemical problems. In the coming year we plan to begin analyzing diamond and SiC interstellar grains from the Murchison CM2 chondrite.

(d) (1) DAVIS A. M. (1991) Ultrarefractory inclusions and the nature of the group II REE fractionation. *Meteoritics* **26**, 330. (2) DAVIS A. M. & OLSEN E. (1991) Phosphates in pallasite meteorites as probes of mantle processes in small planetary bodies. *Nature* **353**, 637-640. (3) DAVIS A. M. *et al.* (1992) Melilite composition trends during crystallization of Allende Type B1 refractory inclusion melts. *Lunar and Planetary Science XXIII*, 281-282. (4) SIMON S. B. *et al.* (1991) Fassaite composition trends during crystallization of Allende Type B refractory inclusion melts. *Geochim. Cosmochim. Acta* **55**, 2635-2655. (5) SPIEGEL D. R. *et al.* (1992) Three-color resonance ionization of titanium sputtered from metal and oxides for cosmochemical analyses: measurements of selectivity and isotope anomalies. *Analyt. Chem.* **64**, 469-475.

PROPOSAL SUMMARY.

PRINCIPAL INVESTIGATOR: **JEREMY S. DELANEY**
Department of Geological Sciences,
Rutgers University, New Brunswick,
New Jersey 08903.
908-932-3616

CO-INVESTIGATORS: S.R. Sutton
R.L. Hervig

PROPOSAL TITLE: Petrology and trace element geochemistry of polymict breccias and constituent lithologies on the Moon, the basaltic achondrite and other meteorite parent bodies.

ABSTRACT: (a) *[i]* The evolution with time of the lunar crust and the crust of the basaltic achondrite parent body is being investigated using trace element microprobe analyses (SXRF and ion microprobes) of mineral-chemical fractionation indicators: (I)Fe/Mn partitioning between coexisting phases and bulk Fe/Mn areindicators of fractionation in local magma bodies (correlated with Fe/(Fe+Mg)), of regional differences on parent bodies and of variable conditions in the nebula. (II) REE elements in phases from lithic clasts can be correlated with Fe/(Fe+Mg) in coexisting phases to monitor magmatic fractionation. Microbeam analyses of trace elements in coexisting phases in lithic clasts from polymict breccias permit significant inferences to be made about the petrogenesis of these clasts and of the breccia. *[ii] In situ* measurements of the valence states of transition elements in lithic clasts and inclusions in chondrites provide direct evidence about the oxygen fugacity of the environment in which the objects equilibrated. New microXANES spectrometric measurements for Fe and Cr are now providing some of this information and the technique is being further developed for use with Ti, Cr and Fe in a wide range of extraterrestrial samples. **(b)** *[i]* Recognition that various achondritic and nebular materials fall into relatively well defined groups with respect to Fe-Mn-Mg suggests that the ratios of these elements constrain the character of the chondritic precursors of achondritic meteorites and the Moon. Tests of these arguments based on redox relations and volatility considerations are under way. *[ii]* The VLT lithologies sampled by EET87521 were demonstrated to be from two distinct compositional groups with respect to Ti-Cr-Fe-Mg. Each group defines a series based on pyroxene-liquid fractionation. The correlation of REE microanalyses in lithic clast plagioclase and shock glass suggests that these lithic clasts each fractionated along parallel trends of REE enrichment. The overall low levels of REE in the lithic clasts require that the a significant KREEP component be present in the shock glass permeating the mare basalt dominated breccia. **(c)** Synchrotron microXANES techniques will be used to investigate the valence state of transition metals in phases from lunar, achondrite and various chondritic samples. Experiments on Fe-Mn-Mg partitioning at low pressure will be continued to calibrate the behavior of Mn in mafic mineral-plagioclase-liquid systems. REE measurements of coexisting phases in lithic clasts from both lunar and achondrite polymict breccias will be used to constrain magmatic processes on both the Moon and the basaltic achondrite planetoid.
(d) Boesenberg & Delaney (1992) LPSC XXIII, 127-128; Delaney, *et al.* (1992) LPSC XXIII, 301-302; Delaney, (1991) Meteoritics 26,331

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John W. Delano
(Name, Address, Telephone Number) Dept. of Geological Sciences; SUNY; Albany, NY 12222; (518) 442-4479

Co-INVESTIGATORS: **(Name Only)**

PROPOSAL TITLE: Physics and Chemistry of Natural Glasses

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) Evaluate the role of thermal (Soret) diffusion in producing microtektites and the compositional range of glasses observed in australite flanges; (2) Assess the abundances of volatile trace elements (e.g., Cu, Zn, Ga) dissolved in mare volcanic glasses using the synchrotron x-ray microprobe; (3) Use x-ray absorption near edge absorption (XANES) at Synchrotron Light Source for addressing the valence changes of Cr with redox state in synthetic lunar minerals for application to natural samples; (4) Explore the compositional range of lunar impact glasses with electron microprobe, ion microprobe, and INAA to constrain the geochemical nature of the lunar crust at remote, unvisited locations.

[B] THIS YEAR (1992): Four abstracts were submitted to the 23rd Lunar and Planetary Science Conference dealing with experiments on the redox dependency of Cr and V partitioning in mafic systems, geochemistry of australite flanges with evidence bearing on Soret diffusion, and the geochemical compositions of lunar and terrestrial impact glasses. High-precision microprobe analyses of olivine and pyroxene phenocrysts in phyric mare basalts will be completed to determine the V and Cr partition coefficients in natural samples for comparison with the experimental results. The author will attend and contribute abstracts to the LPI/LAPST-sponsored workshop in December 1992 dealing with the Apollo 17 landing site.

[C] NEXT YEAR (1993): Soret diffusion appears to have been an important physico-chemical process in controlling the geochemistry of australite flanges and microtektites. This may be the best natural example of Soret diffusion yet observed and may have implications for the geochemical compositions of other impact glasses on the Earth and Moon, as well as meteoritic ablation spheres. The synchrotron x-ray microprobe and XANES methods will be used to acquire state-of-the-art information about the trace-element abundances and Cr-valency in lunar and terrestrial samples.

[D] RECENT PUBLICATIONS: Delano J. W. (1991) Major-element compositions of impact glasses from lunar meteorites ALHA81005; MAC88105 and Apollo 16 regolith 64001: A comparison. Geochim. Cosmochim. Acta, 55, p. 3019-3029.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: DOLLFUS Audouin
(Name, Address, Telephone Number) OBSERVATOIRE DE PARIS, 92195 MEUDON Cedex-FRANC
45.07.77.47

Co-INVESTIGATORS: S. EBISAWA - M. WOLFF - L. DOUGHERTY
(Name Only)

PROPOSAL TITLE: PHOTOPOLARIMETRIC SENSING OF 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) The objective is to refine our knowledge about the surface texture of solid objects in the Solar System, by the remote sensing technique of photopolarimetry. Interpretation of the photopolarimetric measurements recorded at the planetary surfaces by spacecraft of ground-based telescopic observation is based upon laboratory simulation for which the lunar samples are widely used, and on simple physical models which are tested by laboratory measurements including the analysis of extra-terrestrial materials.

b) During the past two years, we made progress along the four approaches which were announced in our last proposal :

- Improved modelling of the polarization by rough surfaces.
- New photopolarimetric observations on planetary objects.
- Acquisition of new knowledge, particularly about regolith grain size at the lunar surface, cometary grains characterization, crystal clouds in the martian atmosphere.
- Physical texture recognition at the surface of Mars.

c) For the two years to come, it is proposed :

- To map and interpret grain sizes at the surface of the Moon.
- To analyse airborne dust in the martian atmosphere.
- To decipher azimuth asymmetries in the Saturn rings particles.

d) Nine recent publications by the Prime or Co-investigators are cited in the proposal.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:	Michael J. Drake
(Name, Address,	Lunar and Planetary Laboratory
Telephone Number)	University of Arizona, Tucson, AZ 85721
	(602) 621-6952
Co-INVESTIGATORS:	Christopher J. Capobianco
(Name Only)	Cyrena A. Goodrich

PROPOSAL TITLE: Geochemical Evolution of the Earth, Moon, Igneous Meteorites and Other Terrestrial Planetary 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.)

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a. Our research program involves (1) calculations investigating the geochemical evolution of the Earth, Moon, igneous meteorites, and other terrestrial planetary bodies; and (2) laboratory and analytical experiments designed to provide some of the data necessary for the successful prosecution of such calculations.

b. During the past award period, Jones, Capobianco, and Drake (1992) have used oxygen isotopes to investigate planetary accretion. Hillgren (1991) has conducted experiments to investigate the effect of oxygen fugacity on metal/silicate partitioning and has investigated a hypothesis for lunar origin and core formation. Musselwhite, Drake and Swindle (1991, 1992) have carried out mineral/melt/vapor partitioning and solubility studies for I and Ar and have developed new models to account for the Xe isotopic systematics of reservoirs in Earth and Mars. Goodrich, Patchett, Lugmair, and Drake (1991) and Goodrich and Lugmair (1992) have produced evidence of events which occurred on the ureilite parent body 3.74 Ga and 4.23 Ga ago. Other activities are also reported.

c. During the next award period, we propose to (1) continue investigations of the origin of the Moon; (2) conduct experiments germane to the Earth's accretion and primordial differentiation into core, mantle, primitive crust, and atmosphere. Increased emphasis will be on experiments at high temperatures and pressures; and (3) conduct analytical studies of meteorites.

d. Hillgren (1991) *Geophys. Res. Lett.*, **18**, 2077.
Musselwhite, Drake, and Swindle (1991) *Nature* **352**, 697.
Goodrich, Patchett, Lugmair, and Drake (1991) *Geochim. Cosmochim. Acta* **55**, 829.
Jones, Capobianco, and Drake (1992) *Jour. Geophys. Res. Planets* (to be submitted).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Otto Eugster
(Name, Address, Telephone Number) Physikalisches Institut, University of Bern
Sidlerstrasse 5, 3012 Bern, Switzerland
Phone +41 31 65 44 18

Co-INVESTIGATORS: Peter Eberhardt, Urs Krähenbühl
(Name Only)

PROPOSAL TITLE: Time scale and processes of planetary rock formation and history of planetary surface processes and irradiations

ABSTRACT

a. Our basic objective is the investigation of the detailed history of lunar and meteoritic material. We propose to date the times of rock formation, study the histories of rocks and soils based on cosmic-ray effects and determine the times, durations and burial depths during exposure to cosmic irradiation. The elemental and isotopic composition of the noble gases trapped during rock formation or by implantation of solar particles will be measured.

b. The following studies have been accomplished during the report period: (1) Four A-16 breccias were found to originate from the 2 Ma South Ray Crater. (2) Indigeneous lunar N and radiogenic ^{129}Xe from ^{129}I decay was identified in volcanic glasses from the 74001/2 drive tube. (3) We characterized the irreversible adsorption of atmospheric Kr and Xe for lunar anorthosites. (4) We studied the trapped noble gas record, formation and cosmic-ray exposure history of four lunar meteorites and numerous chondrites and achondrites. (5) Isotopic anomalies of C and N in grains of the Murchison carbonaceous chondrite were detected. (6) We analyzed He and Ne in the foils of the Interstellar Gas Experiment (IGE).

c. We propose to (1) continue our investigation of the history of lunar meteorites, shergottites, lodranites, and CK-chondrites, (2) characterize solar nitrogen in separates of the 74261 soil and of the Kapoeta howardite, (3) study the isotopic composition of C, N, and Si in the Ne-E carrier phase of the C1 - chondrite LEW90500, (4) complete the He and Ne analyses of the IGE.

d. O. Eugster, J. Beer, M. Burger, R.C. Finkel, H.J. Hofmann, U. Krähenbühl, Th. Michel, H.A. Synal, and W. Wölfli; History of paired lunar meteorites MAC88104 and MAC88105 derived from noble gas isotopes, radionuclides and some chemical abundances; Geochim. Cosmochim. Acta 55, 3139-3148 (1991)

S. Niedermann and O. Eugster; Noble gases in lunar anorthositic rocks 60018 and 65315; Anomalous acquisition of Kr and Xe indicating a chemical adsorption process; Geochim. Cosmochim. Acta 56, 493-510 (1992)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. George J. Flynn
(Name, Address, Telephone Number) Dept. of Physics, SUNY-Plattsburgh, Plattsburgh, NY 12901
(518) 564-3156

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Trace Element Abundance Measurements on Cosmic Dust 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.)

a) Trace element abundances will be determined on interplanetary dust particles collected from the Earth's stratosphere and the polar ices to determine the solar nebula conditions under which the particles formed,, to define genetic relationships between the particles and the various meteorite types, and to constrain the temperature reached by each particle on atmospheric entry (which can help distinguish asteroidal from cometary particles.

b) Trace element contents were measured on more than 30 chondritic interplanetary dust particles from the Earth's stratosphere and 20 micrometeorites from the polar ices. The average composition of the interplanetary dust from the Earth's stratosphere was shown to be enriched (by about a factor of 2 over the CI meteorites) in most volatile elements measured, suggesting the chondritic cosmic dust is a new and distinct chemical type of meteoritic material. In addition, depletions of the volatile element Zn were shown to be linked with the formation of magnetite on atmospheric entry, indicating that Zn depletion is a useful indicator of atmospheric entry heating.

c) Additional trace element abundances will be determined on all particles from an entire stratospheric collection surface, to provide an average composition unbiased by sample selection, and the effects of entry heating will simulated by laboratory pulse heating followed by SXRF trace element determinations.

d) Flynn, G. J. and Sutton, S. R., Trace Elements in Chondritic Stratospheric Particles: Zinc Depletions as a Possible Indicator of Atmospheric Entry Heating, Proc. 22nd Lunar and Planetary Science Conference, pp. 171-184 (1992).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jibamitra Ganguly
Department of Geosciences
University of Arizona, Tucson, AZ 85721

Co-INVESTIGATORS Subrata Ghose

PROPOSAL TITLE: Cation ordering and Compositional Zoning in Meteoritic Orthopyroxenes: Implications for Cooling Rates

ABSTRACT:

a. We have undertaken detailed crystallographic and transmission electron microscopic study of pyroxenes from selected meteorite samples to develop a comprehensive understanding of their thermal and shock history.

b. In the first one and a half year period since we began this project through NASA funding, we have accomplished the following tasks:

(I) We have completed the crystal structure refinement of 9 orthopyroxene crystals from the meteorites Estherville (2 crystals), Bondoc (2), Shaw (3) and Steinbach (2). None of these crystals show any exsolution or compositional zoning.

The site occupancies were determined with extraordinarily high precision (standard deviation ≤ 0.002 and $R_w \leq 0.03$) so that these data can be used for cooling rate calculations (cf. Ganguly et al., 1989, LPSC XX). This necessitated determination of the intensities of around 4,000 non-equivalent X-ray reflections for each sample, and extremely precise and accurate microprobe analysis of the samples, which in turn required the development of a set of synthetic stoichiometric microprobe standards for both major and minor elements.

(II) We have also carried out preliminary crystallographic study of orthopyroxene crystals from Emery and Padbury. Unlike the two other mesosiderites that we have studied so far (i.e. Estherville and Bondoc), these crystals show peak broadening suggesting shock effects that did not anneal during subsequent cooling.

c. Our plan for the next year of the funding cycle is as follows:

(a) We would experimentally determine the dependence of intracrystalline fractionation (K_D) of Fe and Mg in orthopyroxene on temperature and composition by using both natural and synthetic crystals. These data, combined with the recent calibration by Molin et al. (1991: EPSL, 105), will provide the necessary experimental data base to permit calculation of cooling rates of meteoritic (and also terrestrial) orthopyroxenes on the basis of their quenched Fe-Mg ordering states (Ganguly, 1982: Advances in Phys. Geochem. 2, 58 -99).

(b) The site occupancy data of the meteoritic pyroxenes determined already (see above) will be used to calculate their cooling rates. In addition, we will examine relatively high Ca-orthopyroxene from Shaw, which seems to have formed by reaction between low Ca-OPx and augite to understand more about its thermal history, and bring our on-going research on Potwar and Padbury to completion. These works will involve both TEM and X-ray diffraction studies. We will further explore the possibilities of constraining their cooling rates from the coarsening kinetics of exsolution lamellae. and characterization of shock effect from the x-ray peak broadening.

d. Ganguly, J., Hexiong, Y., and Ghose, S. (1991) Cation ordering in orthopyroxene in Estherville meteorite: implications for cooling rate and origin of mesosiderite. LPSC XXII.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Joseph I. Goldstein
(Name, Address, Telephone Number) Department of Materials Science & Engineering
Whitaker Lab #5, Lehigh Univ., Bethlehem, PA 18015
(215) 758-4207 FAX (215) 758-4244

Co-INVESTIGATORS: David B. Williams
(Name Only)

PROPOSAL TITLE: Shock and Thermal History of Iron and Chondritic Meteorites

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:
To determine the thermal history of chondritic meteorites by studying the microstructure and chemistry of the metallic particles. This will shed light on the thermal histories of parent asteroids or the planestismals from which the metal particles accreted and in which the host chondrites were metamorphosed or melted.

(b) Prior Year Accomplishments:
Developed several procedures for preparation of thin foils of chondritic metal particles and initiated experimental studies of the Fe-Ni-S phase diagram. Completed the writing of three papers on the experimental and electron microscope work on the formation of metallic phases in meteoritic metal particles. Established that interface reaction controlled growth controlled the formation of taenite during Fe-Ni martensite decomposition (plessite formation) at low temperatures (<450°C).

(c) Proposed Work:
1. To characterize the fine structure and microchemistry of metallic particles of ordinary chondrites by electron microscopy techniques. It should be possible to develop the low temperature shock and thermal history of the metal particles and their hosT chondritic meteorites.

2. To determine 2 and 3 phase boundaries in the Fe-Ni-S phase diagram and to perform slow cooling experiments on Fe-Ni-S alloys of chondritic meteorite composition. A better understanding of how chondritic metal microstructures develop and how Ni segregation occurs between metal and sulfide phases will allow for the determination of the thermal history of the host chondrites in the temperature interval between 700°C and 300°C.

(d) Recent Publication:
"The Structure and Composition of Metal Particles in Two Type 6 Ordinary Chondrites," Meteoritics 26, 97, 1991., "An APFIM/AEM Study of Phase Decomposition in Fe-Ni Alloys at Low Temperatures," Surface Science, in press, 1992.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James L. Gooding
SN2/Office of the Curator
NASA Lyndon B. Johnson Space Center
Houston, Texas 77058-3696 USA
FTS 525-5126 / (713) 483-5126

CO-INVESTIGATOR: Allan H. Treiman (SNC meteorite studies)

TITLE: AQUEOUS GEOCHEMICAL AND THERMODYNAMIC HISTORIES OF PLANETARY MATERIALS

ABSTRACT:

a. Objectives. Quantitatively assess thermal histories and water/rock reactions on meteorite parent bodies using a combination of electron microbeam and calorimetric studies of minerals in meteorites. Scanning electron microscopy (SEM), transmission electron microscopy (TEM; including lattice-fringe imaging and selected-area electron diffraction), and energy-dispersive X-ray spectrometry (EDS) of secondary minerals in shergottite, nakhlite, and chassignite (SNC) meteorites are used to diagnose aqueous geochemistry on the SNC parent planet. Calorimetry emphasizes measurement of heat-capacity functions and enthalpies of transitions that are needed for computing mineral equilibria during paragenesis in planetary environments.

b. Progress in FY1992. (1) High-resolution TEM/EDS on Nakhla revealed that clays previously documented by us probably include ultrafine iron-rich saponite and ferrimontmorillonite along with ferrihydrite and hematite. (2) SEM/EDS analyses on new polished sections of Lafayette confirmed that its "iddingsite" resembles that in Nakhla. Clear microstratigraphic evidence was found for pre-terrestrial origin (i.e., cross-cutting by fusion crust) as we previously documented for Nakhla. Lafayette clays were found to be similar to those in Nakhla but with greater crystallinity. (3) SEM/EDS analyses on new chips and thin sections of Chassigny (Paris Museum) confirmed our earlier discovery (samples from British Museum) of Ca-carbonate and Ca-sulfate; a new occurrence of Mg-carbonate was documented but no clays were found. (4) Early SEM/EDS reconnaissance of the newly recognized Antarctic shergottite, LEW88516, revealed Antarctic weathering products of the types we have previously reported from the exteriors of EETA79001 and various Antarctic achondrites. (5) Differential scanning calorimetry (DSC) on both falls and finds of L-chondrites, including Antarctic and non-Antarctic specimens, permitted definition of a new, quantitative calorimetric "weatherometer" for oxidative weathering.

c. Proposed Work for FY1993. (1) Publish separate papers describing the products of pre-terrestrial aqueous alteration in Lafayette and Chassigny, respectively. (2) Publish a paper describing the calorimetric "weatherometer" developed for ordinary chondrites. (3) Perform SEM/EDS reconnaissance for salt and clay minerals in Shergotty, Zagami, ALHA77005, and LEW88516. (4) Measure the heat-capacity function (100-1000 K) for terrestrial tochilinite and use those data to estimate the Gibbs free-energy of formation of tochilinite that occurs as a pervasive product of aqueous alteration in CM chondrites. (5) Experimentally reconnoiter calorimetric signatures of shock-metamorphic and thermal histories of selected chondrites and achondrites.

d. Summary Bibliography. (1) Treiman and Gooding (1991) *Meteoritics, 26,* 402. (2) Treiman, Barrett, and Gooding (1992) *Lunar. Planet. Sci. XXIII,* 1451-1452. (3) Wentworth and Gooding (1991) *Meteoritics, 26,* 408-409. (4) Spargur and Gooding (1992) *Lunar. Planet. Sci. XXIII,* 1337-1338.

e. Personnel. Principal Investigator (25% full-time), Co-Investigator (90%), and two support-contractor scientists (each 15%).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Lawrence Grossman, Dept. of the Geophysical Sciences
The University of Chicago, 5734 South Ellis Avenue
Chicago, IL 60637

CO-INVESTIGATORS: Steven B. Simon and Paul J. Sylvester

PROPOSAL TITLE: Chemical Aspects of the Origin 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.* a 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. We propose to continue our program of investigating primitive meteorites by petrographic, mineralogical, trace element and isotopic studies of separated inclusions. Objectives are to understand the behavior of the elements during condensation, infer the degree of physical, chemical and isotopic heterogeneity in the solar nebula and to determine what components were available in the nebula for accretion into meteorites and planets. *b.* Using the SEM, EMP and IMP, we showed that melilite in Type B1 inclusions in Allende crystallized from incompatible element-enriched boundary layers, implying cooling rates > 1-2 °C/hr; we showed that zoning of the Ti^{3+}/Ti^{tot} ratio within fassaite crystals in Type B inclusions was produced by fractional crystallization without re-equilibration of the liquid with the surrounding, solar nebular gas, implying rapid solidification of fassaite from isolated melt pockets; we determined anorthite/liquid partition coefficients for a variety of elements and found that anorthite in Type B1 inclusions has more Ti and less Mg than predicted using our data; we found exsolution lamellae of εRu-Fe in γNi-Fe and used them to confirm a phase boundary in the Fe-Ni-Ru system; we found five different chemical zoning patterns in spinel grains separated from Murchison and discovered several of these types in their original petrographic settings in thin sections, allowing us to determine that one type comes from chondrules while another is a condensate. We used INAA to analyze eleven S-rich Fremdlinge from a Type A inclusion and found that Ru is present in veins that cross-cut them. *c.* We will use the SEM, EMP and IMP to study the petrography and mineralogy of unusual refractory inclusions from members of the reduced subgroup of C3V chondrites, Leoville, Vigarano and Efremovka, and from the C2 chondrite, Murchison; to assess the quantitative significance of Ru-bearing veins in the re-distribution of siderophiles among Fremdlinge in Allende inclusions; to assess the role of anorthite crystallization on fassaite zoning profiles in Type B inclusions; to see if the isotopic compositions of alleged relict grains of perovskite in compact Type A inclusions and of fassaite in Type B's are distinctive; to determine the role of secondary alteration in redistributing refractory lithophiles within Allende refractory inclusions; and to determine zoning profiles across melilite crystals in compact Type A's to determine their origin. We will use INAA on newly-obtained, unusual Murchison inclusions, and on S-poor Fremdlinge to distinguish condensation-produced from later sulfidation-produced refractory siderophile fractionations. *d.* Simon, S.B., Grossman, L. and Davis, A.M. (1991) Fassaite composition trends during crystallization of Allende Type B refractory inclusion melts. *Geochim. Cosmochim. Acta* **55**, 2635-2655. Sylvester, P.J., Grossman, L. and MacPherson, G.J. (1992) Refractory inclusions with unusual chemical compositions from the Vigarano carbonaceous chondrite. *Geochim. Cosmochim. Acta.*

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Timothy L. Grove
(Name, Address, Telephone Number) MIT, 54-1220, Cambridge, MA 02139
(617) 253-2878

Co-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Phase Equilibrium Investigations of Planetary 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 proposed work consists of two projects. 1) Experimental petrology will be used to develop a framework for testing models of melting processes that led to the formation of picritic mare basalts. Melting experiments will be carried out on synthetic analogs of Apollo 15 green and Apollo 17 orange glass and on predicted compositions of low degree partial melts of bulk moon compositions over the pressure range of 20 to 30 kbar. The result of these experiments will be used to model the melting processes that led to the production of picritic mare glasses. 2) The methods of experimental petrology will be used to determine the partitioning behavior of siderophile elements under conditions of variable oxygen (f_{O2}) and sulfur (f_{S2}) fugacity. Partition coefficients will be determined for Ni, Co, Mo and Cr with an emphasis on the effect of variable f_{O2} and f_{S2} on silicate mineral / silicate melt partitioning. The experiments will be performed on synthetic analogs of a chondritic composition and on Apollo 15 green glass.

b. Experiments on the effect of variable f_{O2} on Ni and Co partitioning between olivine and silicate melt have been completed and a manuscript is in press. Elevated pressure experiments on a high Ti picritic glass composition have been initiated. A paper discussing the relation between diogenite cumulates and magnesian eucrite magmas and on the pressure/depth of fractionation recorded by diogenites has been published.

c. During this year the effects of variable f_{S2} on Ni and Co partitioning will be completed. The experimental work on the high Ti picritic composition will be completed, and a study of the low Ti picrite glasses will be initiated.

d. Selected References

TL Grove and KS Bartels (1992) The relation between diogenite cumulates and eucrite magmas. *Proceedings of Lunar and Planetary Science, volume 22,* pp. 437-445.

KE Ehlers, TW Sisson, TL Grove, SI Recca and DA Zervas (1992) The effect of oxygen fugacity on the partitioning of nickel and cobalt between olivine, silicate melt and metal. Geochimica Cosmochimica Acta (in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Larry A. Haskin
Washington University
Campus Box 1169
St. Louis, MO 63130
(314)-935-5613

Co-INVESTIGATORS: Randy L. Korotev, Bradley L. Jolliff, Russell O. Colson

PROPOSAL TITLE: Analytical, Experimental, and Modeling Studies of Lunar and Terrestrial Igneous Rocks

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 relevent to the proposed work.)

(a) We wish to identify the igneous rocks of the early lunar crust, determine their proportions in the crust, and learn how they formed. We wish to understand the compositional changes that result from impact mixing and regolith formation and reworking, to understand the compositional evolution of the regolith, and to improve our ability to relate surface regolith compositions to crustal geochemistry and mineralogy. (b) We have shown that compositions and mineralogy of many rocks from North Ray Crater derived from a single melt containing accumulated plagioclase, as in the Stillwater Complex. We have found Skaergaard-like compositional trends among Apollo 14 rocks. We have determined why the relative rare-earth concentrations of whitlockite and apatite vary and we have developed a geochemical model for whitlockite trace-element partitioning. We have found many compositional clusters for Apollo 16 melt rocks, suggesting their production in numerous local, small ($\sim$100 km?) events. We have shown that Apollo 15 green glasses might derive from a common source at low f_{O2} and that the Ni concentration of Earth's mantle is the equilibrium value for high temperature and low f_{O2}. (c) We will refine petrogenetic models for the Apollo 14 and the Apollo 16 rocks and extend them to other rocks series and to the highlands generally. We will prepare an interpretive review of Apollo 16 site geology and geochemistry based on our studies of soils, regolith breccias, and breccias. We will continue our search for time and provenance indicators (TAPIs) for defining local and regional stratigraphic relationships in the regolith. We will further refine our modelling of anorthosite and basalt petrogenesis to improve our interpretations of lunar geochemical data. (d) Jolliff B. L., Korotev R. L., and Haskin L. A. (1991) A ferroan region of the lunar highlands as recorded in meteorites MAC88104 and MAC88105. *Geochim. Cosmochim. Acta* 55, 3051-3071. Colson R. O. (1992) Mineralization on the Moon? *Proc. Lunar Planet. Sci.* 22, 427-436. Korotev R. L. and Kremser D. T. (1992) Compositional variations in Apollo 17 soils and their relationship to the geology of the Taurus-Littrow site. *Proc. Lunar Planet. Sci.* 22, 275-301. Haskin L. A. and Warren P. H. (1991) Lunar Chemistry, Chap. 8 in *Lunar Sourcebook*, Heiken et al., eds., Cambridge.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: G.F. Herzog
(Name, Address, Telephone Number) Dept. Chemistry, Rutgers Univ.
New Brunswick, NJ 08903
908-932-3955

Co-INVESTIGATORS: R. Middleton
(Name Only) J. Klein

PROPOSAL TITLE: Cosmogenic Radionuclides in Extraterrestrial 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. We describe a program aimed primarily at measuring cosmogenic radionuclides in meteorites by accelerator mass spectrometry. The main goals of the measurements are 1) to investigate the frequency and nature of multi-stage irradiations in order to probe the dynamical processes that bring meteoroids to Earth; 2) to continue to search for meteorites with exposure histories that link exposure ages with shock ages; 3) to study the exposure histories of selected groups of meteorites including the lodranites and certain irons, the latter by the $^{10}Be/^{9}Be$ technique; 4) to search the terrestrial record for evidence of a large lunar impact; 5) to measure ^{10}Be in LDEF samples in order to understand the source of the ^{7}Be observed by counting; and 6) to study the mass fractionation of nickel isotopes in extraterrestrial metal.

b. New proposal

c. For the purposes stated above we plan next to measure cosmogenic nuclides in samples from 1) a set of meteorites for which multi-stage histories have been suggested but not confirmed; 2) some meteorites with especially long exposure ages; 3) lodranites and selected iron meteorites; 4) dust separated from Antarctic ice; and 5) clamps flown on the LDEF spacecraft. We also propose to determine the isotopic composition of nickel in metallic spherules from the deep sea and in other metallic spherules associated with impact processes.

d. Vogt et al. (1991) *Geochim. Cosmochim. Acta* **55**, 3157-3165.
Herzog et al. (1992) *Lunar Planet. Sci.* **XXIII**, 527-528.
Albrecht et al. (1992) *Lunar Planet. Sci.* **XXIII**, 5-6.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Paul C. Hess
(Name, Address, Telephone Number) Box 1846 Brown University Providence, RI 02912
401 863 1929

Co-INVESTIGATORS: Malcolm J. Rutherford
(Name Only)

PROPOSAL TITLE: Experimental study of chemical, phase, and textural equilibrium of high TiO_2 mare basalts and peridotite

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

a) The proposed research is to investigate by experiment the chemical, phase and textural equilibria of TiO_2 -rich mare basalts with ilmenite-bearing to ilmenite-free peridotite to 30 kb. The results will be used to model the generation, segregation and transport of high TiO_2 mare melts within the cumulate mantle.

b) The results of dissolution experiments of anorthite in basaltic liquids were used to model the assimilation of anorthosite crust into mare basalt liquids and into the parent magmas to the lunar troctolites of the Mg-rich suite. We continued our effort to model the physics of the overturn of the lunar cumulate pile and the depleted mantle lithosphere on Venus and relate these events to magma petrogenesis.

c) Experiments will be initiated to determine the ilmenite solidus and the ilmenite-out and diopside out curves for ilmenite-bearing peridotite. The results will be used to define the P-T range for picrite-peridotite sandwich experiments in order to characterize the phase and textural equilibria of molten peridotite at high temperatures.

d) Hess, P.C. (1991) Diapirism and the origin of high TiO_2 mare glasses. GRL, 18, 2069-2072.

Hess, P.C., (1992) Dissolution of plagioclase and the origin of Mg-suite parent magmas. Lunar Planet. Sci. XXIII, 529-530

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Roger H. Hewins (908) 932 3232
Geological Sciences, Rutgers University
New Brunswick, New Jersey 08903

CO-INVESTIGATORS:
(NAME ONLY)

PROPOSAL TITLE: Simulation and analysis of meteoritic materials.

ABSTRACT: (Type single-space below line. Letttered 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 is to determine the physical and chemical conditions of chondrule precursor assembly, melting and rim formation, so as to determine the nature of the solar accretion disk and thermal events therein, by melting experiments and studies of natural chondrules.
(b) Chondrule textures have been duplicated in rapid heating experiments at temperatures much above the liquidus, with very little Na loss. When rims are sintered onto synthetic chondrules by reheating, glass devitrification results which, if recognized in natural chondrules, would provide proof of a reheating origin for chondrule rims. Experiments have been begun to duplicate features of metal in chondrules, e.g. oxidation of Cr, Si and P, homogenization and coalescence of metal droplets, as a test of conditions of chondrule origin.
(c) Flash heating experiments will be continued with shorter heating times and higher temperatures: duplication of chondrule textures and properties with retention of Na would lend support to the lightening model of chondrule origin. An independent test of assumed conditions for chondrule origins will be provided by attempting to simulate their metal melting and exsolution features, in conjunction with correlation of metal and silicate properties in natural chondrules.
(d) Connolly, H.C. Jr. and Hewins, R.H. (1991). The influence of bulk composition and dynamic melting conditions on olivine chondrule textures. Geochim. Cosmochim. Acta 55, 2943-2950.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David L. Hogenboom
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Easton, PA 18042
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CO-INVESTIGATOR: Jeffrey S. Kargel

PROPOSAL TITLE: Densities and Phase Equilibria to 1.4 GPa and 120K of Aqueous Systems and their Role in the Low-Temperature Igneous Evolution of Icy Satellites and Asteroids

ABSTRACT:

Icy satellites and asteroids are chemically complex mixtures of "rock" and volatiles including water, ammonia, and other water-soluble substances. The "rock" component either contains abundant water-soluble salts, if it resembles carbonaceous chondrites, or it at least yields soluble salts upon reaction with water. Water-soluble components are likely to play important roles in the low-temperature igneous differentiation of icy satellites and asteroids, affecting their interior structures, geologic evolution, and surface compositions. With appropriate data these effects can be modeled and tested against observations by spacecraft and Earth-based telescopes. Unfortunately, the current data base includes very few of the high-pressure phase equilibrium and thermodynamic data required for accurate quantitative modeling of icy satellite and asteroid evolution. We propose to remedy this situation in part by conducting a systematic study of solid-liquid phase equilibria in planetologically relevant chemical systems at pressures to 1.4 GPa (14 kbars) and temperatures as low as 120K. To accomplish this, **task 1)** will be to replace our existing obsolete pressure system with a modern air compressor/intensifier, a new pressure vessel with an internal thermometer, and a new volume/voltage transducer. We will then undertake **task 2)**, to use this system to measure the densities and determine the high-pressure phase diagrams of salt-water and ammonia-water systems over this pressure and temperature range. Finally in **task 3)**, these results will enable us to construct and evaluate specific models of the internal structure of icy satellites and asteroids and explore new experiments which can take advantage of the capabilities developed in task 1.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Charles M. Hohenberg; McDonnell Center for the Space Sciences
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314-935-6257

Co-INVESTIGATORS: T. J. Bernatowicz; F. A. Podosek & R. H. Nichols Jr.
(Name Only)

PROPOSAL TITLE: LUNAR AND PLANETARY SURFACE DYNAMICS AND EARLY 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.)

Major goals for this proposal include the following:

a) To study pre-compaction exposure records preserved in individual separated meteorite mineral grains. To interpret these records in terms of viable models for meteorite formation and the implications for the required activity of an early active (T-Tauri) sun or extremely long regolith exposure times. This work, applied to the CM meteorites will also attempt to identify common parent bodies (in collaboration with J. N. Goswami and D. Woolum).

b) To apply I-Xe dating to meteoritic components: inclusions, individual chondrules and separated minerals (initially phosphates) in order to study formation sequences, preformational histories and isotopic uniformity in the early solar system. To compare the I-Xe chronometer with the Rb-Sr and Pb-Pb chronometers.

c) To study the isotopic signatures and carrier phases of anomalous (pre-solar) noble gas components found in demineralized acid residues, both in bulk and in individual grains.

d) To measure and refine the absolute decay constants for the double β-decay of tellurium isotopes and investigate muon reactions in ancient Te samples, constraining the electron neutrino mass. Implications include dark matter in the universe and refinements in the understanding of neutrino physics and decay rates of heavy nucleii.

Work support by the current grant has contributed to 14 publications and abstracts during the past year (see appendix and attachments).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Friedrich Hörz
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CO-INVESTIGATORS:
(Name Only)
Mark J. Cintala
Thomas H. See
Ron P. Bernhard

PROPOSAL TITLE: Experimental Impact Studies

ABSTRACT: [Typed 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"; (c) brief listing of what will be done this year, as well as how and why; and (d) publications relevant to the proposed work.]

a) We continue to study hypervelocity impact as an important process in the accretion and subsequent evolution of planetary bodies. Our approach is largely experimental, yet complemented by natural crater studies and theoretical considerations.

b) We conducted multiple impact experiments into modally controlled regolith simulants composed of variable mixtures of Pl, Or, Px and Ol; differential comminution of feldspar leads to fractionated fine-fines (<63 μm). The fractionation of siderophiles, previously demonstrated at the Wabar Crater, was extended to Meteor Crater, yet the Canyon Diablo octahedrite fractionated less then the Wabar projectile; the melts and opaques at Meteor Crater are depleted only in Au. A substantial body of small-scale penetration experiments was summarized that support the interpretation of cosmic-dust studies in low-Earth Orbit. The mercurian impact environment was calculated to yield substantially more melts than equivalent impactor masses at the Moon. Furthermore, basin-scale craters produce relatively large amounts of melt and these calculations not only supported the re-interpretation of the Sudbury igneous complex as an impact melt, but also identified the Cleopatra Crater on Venus as a relatively "normal" event, contrary to other interpretations that draw on volcanic melt production to explain the relatively deep crater fill and expansive smooth deposits in the crater's vicinity.

c) We will conduct shock-recovery experiments on metal/silicate melt mixtures to further illuminate element partitioning and fractionation trends of siderophiles in impact melts, and we will attempt to constrain the depth in the Chicxulub Crater from which the Haitian melt spherules were derived. In addition, we will explore the role of fragmental glass in the evolution of planetary regoliths, and we will comminute an ordinary chondrite to address asteroidal regolith evolution. Low-strength targets will be impacted with clustered projectiles for comparison with previous studies, all relating to the emplacement of large scale, continuous ejecta deposits. The consequences of differences in scaling impact-melt volumes and crater dimensions will be examined for the lunar cratering record, and the effects of this process on interplanetary variations in crater morphology will also be explored. The thermal effects of impact on asteroidal regoliths will be modeled.

d) (1) Mittlefehldt, D.W., T.H. See, and F. Hörz (1992). Dissemination and Fractionation of Projectile Materials in the Impact Melts from Wabar Crater, Saudi Arabia. Submitted to *Meteoritics*, October, 1991. (2) Cintala, M.J., and F. Hörz (1992). An Experimental Evaluation of Mineral-Specific Comminution. Submitted to *Meteoritics*, February, 1992. (3) Grieve, R.A.F. and M.J. Cintala (1992). An Analysis of Differential Impact Melt-Crater Scaling and Implications for the Terrestrial Impact Record. Submitted to *Meteoritics*, February, 1992. (4) F. Hörz, R.P. Bernhard, J.L. Warren, T.H. See, D.E.Brownlee, M.R. Laurance, S. Messenger, and R.B. Peterson (1992). Preliminary Analysis of LDEF Instrument A0187-1: Chemistry of Micrometeoroids Experiment. *LDEF - 69 Months in Space. First Post-Retrieval Symposium, NASA Conference Publication 3134, in press.* (5) F. Hörz, M.J. Cintala, and M.E. Zolensky (1992). Hypervelocity Penetration Tracks in Very Low-Density, Porous Targets. *Proceedings of the Hypervelocity Impacts in Space Symposium*, Canterbury, Kent, United Kingdom, in press. (6) Zolensky, M.E., F. Hörz, D.J. Lindstrom, and E.K. Gibson (1992). Suitability of Silica Aerogel as a Capture Medium for Interplanetary Dust. *Proceeding of Lunar and Planetary Science, V. 22*, Lunar and Planetary Institute, Houston, Texas, p. 203-212. (7) Cintala, M.J. (1992). Impact-Induced Thermal Effects in the Lunar and Mercurian Regoliths. *Journal of Geophysical Research, V. 97, No. E1*, p. 947-973.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Odette B. James
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U. S. Geological Survey
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CO-INVESTIGATORS: James J. McGee

PROPOSAL TITLE: Genesis of Lunar Highlands Breccias

ABSTRACT:

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a. Work carried out under this proposal consists of petrologic studies, and leadership of consortium studies, of lunar rocks. The current emphasis is on ferroan anorthosites, mare basalts, and Apollo 16 dimict breccias. Goals of the studies are: to aid understanding of the formation and evolution of the lunar crust; to elucidate the processes that formed highlands breccias and melt rocks; and to aid interpretation of Apollo 16 site geology.

b. 1) Collaborative ion-microprobe studies of the minerals in "typical" ferroan anorthosites were completed and the results were presented in a thesis by Christine Floss (Washington University, St. Louis). These studies demonstrate that the "typical" ferroan anorthosites can all be derived by crystallization of a single parent magma, but that other types of anorthosites (mafic magnesian, mafic ferroan, sodic anorthositic) cannot be simply related to the "typical" anorthosites. 2) Studies of distribution of minor elements in the plagioclase of two Apollo 15 mare basalts defined distinctive differences in variation trends in plagioclase formed by normal crystallization and plagioclase formed by crystallization of plagioclase-supersaturated liquids. The results suggest that characteristics of minor-element variation patterns can be used to deduce crystallization conditions in rocks where textures are ambiguous.

c. 1) Detailed electron-microprobe studies of the minerals in ferroan anorthosites will be continued, emphasizing types of anorthosite not previously studied (mafic magnesian, mafic ferroan, sodic anorthositic). The data will be used to evaluate the nature of the crystallization and postcrystallization processes that operated during formation of the rocks and determine whether there are any igneous processes that would permit derivation of all these types of anorthosite from a single parent magma. 2) Detailed electron microprobe studies of the distribution of FeO and MgO in mare basalt plagioclase will be continued. Samples that represent differing crystallization conditions and differing parent magma compositions will be analyzed, to define the effects of these differences on minor-element variations in plagioclase. 3) Electron-microprobe studies of the distribution of minor elements in the plagioclase of granulitic breccias will be initiated. The aim of these studies is to define the sorts of minor-element variations that are produced in lunar minerals by metamorphic processes. 4) Petrographic studies of Apollo 16 rocks will be continued, to set constraints on the subsurface geology at the site. 5) Study of petrology and mineralogy of consortium samples of dimict breccias will be continued.

d. James, O.B., and McGee, J.J., 1991, FeO and MgO trends in the plagioclases of two Apollo 15 mare basalts: Abstracts, 54th Annual Meeting, Meteoritical Society, p. 106, and Meteoritics, v. 26, p. 351-352.

James, O.B., and McGee, J.J., 1992, Compositional variations in mare-basalt plagioclase produced by differing crystallization regimes: Lunar and Planetary Science XXIII, Lunar and Planetary Institute, Houston, p. 603-604.

McGee, J.J., Lunar ferroan anorthosites: Mineralogy, compositional variations, and petrogenesis: Submitted to JGR Planets.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John H. Jones
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(713)-483-5319

Co-INVESTIGATORS: A.J.G. Jurewicz

PROPOSAL TITLE: Geochemical and Petrologic Studies of Igneous Meteorites and the Terrestrial Planets

a. The researches described in this proposal involve investigations of experimental trace element partitioning and experimental petrology in metallic and silicate systems, with application of these data to problems in the planetary sciences.

b. Metallic Systems. (i) Trace element partition coefficients in metallic systems have been explored at high pressure (7-80 kbar) and found to be similar to those measured at one bar. A ms. has been published in *Earth Planet. Sci. Lett.* (ii) The Soret effect in metallic liquids was found to be quite strong in high-sulfur compositions. This work was published in *Proceedings of Lunar and Planet. Sci., vol. 21.* (iii) Partitioning of elements important to iron meteorite chronologies has been performed near the Fe-Ni-S-P eutectic. Solid metal/sulfide liquid, troilite/sulfide liquid, and schreibersite/sulfide liquid partition coefficients have been determined for Ag, Au, Mo, Ni, Pb, Pd, and Tl. A ms. has been submitted to *Geochim. Cosmochim. Acta.* (iv) A critique of calculations by Murthy (1991) for siderophile trace element partitioning at elevated temperatures (~3500 K) has been submitted to *Science.* Silicate systems. (i) Partial melting experiments have been performed on Allende and Murchison. Eucritic liquids are produced at low oxygen fugacity and angritic liquids are produced at high oxygen fugacity. A ms. has been published in *Science* and a second ms. is near submission to *Geochim. Cosmochim. Acta.* (ii) Volatility experiments have been performed on V, Cr and Mn. At low pressure (< 1 bar) and low fo_2 (~IW) V can be rather volatile. (iii) Carbonate liquid/silicate liquid partition coefficients have been determined for a suite of highly incompatible elements — Nb, Mo, Ba, Ce, Pb, Ra, Th, Pa, and U. Uranium, Th and Pb can be fractionated by liquid immiscibility.

c. (i) The V volatility experiments will be continued. (ii) Low-pressure partial melting of ordinary chondrites will be initiated. (iii) Carbonate liquid/silicate liquid partitioning will be continued. (iv) Other continuing projects, such as Sc in eucrites, will be completed.

d. Jones J.H. and Hood L.L. (1990) In *Origin of the Earth*, pp. 85-98. Jones J.H. and Malvin D.J. (1990) *Metallurg. Trans.* **21B**, 697-706. Jones J.H. and Walker D. (1991) *Proc. Lunar Planet. Sci. Conf. 21st.* Lunar and Planetary Institute, Houston. pp. 367-373. Jones J.H. and Walker D. (1991) *Earth Planet. Sci. Lett.* **105**, 127-133. Jurewicz A.J.G., Mittlefehldt D.W. and Jones J.H. (1991) *Science* **252**, 695-698. Jones J.H., Hart S.R., and Benjamin T.M. (1992) *Geochim. Cosmochim. Acta.* Submitted. Jones, J.H., Capobianco C.J. and Drake M.J. (1992) *Science.* In preparation.

PRINCIPAL INVESTIGATOR: A. J. Timothy Jull
NSF Accelerator Facility for Radioisotope Analysis
University of Arizona,
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CO-INVESTIGATORS: D. J. Donahue and G. S. Burr

TITLE: Cosmogenic ^{14}C in Antarctic and non-Antarctic meteorites and lunar samples.

ABSTRACT:

a.) We propose the following: (a.) Study the ^{14}C ages of Antarctic meteorites, for the purpose of understanding the terrestrial-age distribution of meteorites from sites where most meteorites collected in the last 40,000 years; (b.) Study the terrestrial-age distribution of meteorite falls from desert areas, such as Roosevelt County (New Mexico), Western Australia and North Africa. (c.) Study the ^{14}C depth profile in lunar rock 68815 and core 76001, to understand ^{14}C production from solar cosmic rays, and implanted ^{14}C; (d.) Study ^{14}C in weathering products in meteorites, in order to assess whether these materials can be used to date the time a meteorite has been exposed to weathering on an ice surface. In addition, these products can be used to determine if extraterrestrial carbonates represent pristine material, such as in SNC meteorites.

b.) **Progress.** Meteorites: We are continuing systematic survey of ages in the Allan Hills Far Western and Middle Western icefields. A paper on Roosevelt County terrestrial ages is in preparation. Initial research on weathering products in carbonates from EETA 79001 has been reported. These results suggest a strong terrestrial component to the isotopic signal. Lunar samples: Lunar rock 68815 has been studied and a ^{14}C profile obtained, this work was also presented at the Lunar & Planetary Science Conference. The profile show solar-cosmic-ray production of ^{14}C at levels of about 17dpm/kg, and typical galactic-cosmic-ray production. The SCR flux calculated (based on the existing cross-section data) is similar to that found for other radionuclides, and ^{14}C in cores.

c.) **Plans for this year:** (1) Survey ^{14}C measurements across the Middle Western Icefield and other sites, and on terrestrial ages of meteorites from desert regions; (2) Improve ^{14}C analyses of weathering carbonates. (3) Produce a ^{14}C depth profile from lunar rock 68815 and core 76001 using an etching technique; (4) Use simulation studies with high-energy protons to improve our knowledge of ^{14}C production in meteorites and the moon.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Klaus Keil, Planetary Geosciences
(Name, Address, Telephone Number) Department of Geology & Geophysics, SOEST
University of Hawaii at Manoa
Honolulu, HI 96822 (808)956-3898

Co-INVESTIGATORS: G.J. Taylor, E.R.D. Scott
(Name Only) M. Norman, H. Haack

PROPOSAL TITLE: Origin of Meteorite Parent Bodies and 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) Our studies of planetary materials are aimed at understanding the processes that operated in the solar nebula, inside planets and asteroids heated during and soon after accretion, and in and on planets and asteroids after initial heating and differentiation.

b) (1) The low plagioclase abundance in aubrites was caused by explosive volcanism; such volatile-driven volcanism may have affected ureilites as well. (2) Petrologic reasoning suggests that core formation in asteroids required substantial amounts of melting (50%) of the associated silicates. (3) Asteroid cores formed by inwards dendritic crystallization. (4) Thermal modeling demonstrates that chondrite metamorphism could not have been caused by accretion of hot material. (5) Lunar Mg-suite rocks formed from numerous separate magmas. (6) Sodic anorthosites in lunar breccia 67016 have compositions between those of ferroan anorthosites and alkali anorthosites; they might be related to sodic ferrogabbros. (7) LKFM basaltic impact melts exhibit a wide range in MgO/FeO, REE contents, and REE/K; this may reflect variations in the composition of the lower lunar crust. (8) The Zagami SNC meteorite formed in a magma that experienced a two-stage history: the first was in a deep (> 1 kb) magma chamber, the second in a thick (10 m) lava flow or dike.

c) We plan petrologic studies in the following areas: (1) Geological processes on asteroids, with emphasis on igneous processes, but also including studies of impact and metamorphism. (2) Origin of primitive components in chondrites, with emphasis on metals and fine-grained matrix materials. (3) Lunar and planetary evolution, including study of pristine lunar highland rocks, granulitic breccias, LKFM basaltic impact melts, and the nature of mare basalt fractionation.

d) Wilson L. and Keil K. (1991) Consequences of explosive eruptions on small Solar System bodies: The case of the missing basalts on the aubrite parent body. *Earth Planet. Sci. Lett.* **104**, 505-512. Norman M.D., Taylor G.J. and Keil K. (1991) Additional complexity in the lunar crust: Petrology of sodic anorthosites and sulfur-rich, ferroan noritic anorthosites. *Geophys. Res. Lett.* **18**, 2081-2084. Stöffler D., Keil K. and Scott E.R.D. (1991) Shock metamorphism of ordinary chondrites. *Geochim. Cosmochim. Acta* 55, 3845-3867.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John F. Kerridge
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Co-INVESTIGATORS: _____
(Name Only) _____

PROPOSAL TITLE: Isotopic analysis of light elements in extraterrestrial 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) Our objective is to elucidate the source(s) of nitrogen in the lunar regolith and the processes that have affected its isotopic composition. Immediate goals include interpretation of the thermal release pattern of regolith N in terms of likely differences in implantation energy, and improved definition of the nature and chronology of the long-term variation in $^{15}N/^{14}N$. Recent results point towards a solar origin for that variation, but a viable explanation for the phenomenon is still lacking.
(b) In the past year we have analysed plagioclase grain-size fractions from soil 67601 exposed to the solar wind during the past 49Myr. Measured $\delta^{15}N$ values for solar wind implanted in that time interval apparently lie in the range +48 to +70^{o}/oo. Even with its short surface exposure, 67601 plagioclase exhibits the two-component release of trapped N previously observed in older samples, showing that it is an intrinsic feature of lunar surface exposure.
(c) In the coming year, we plan to analyse solar wind N implanted during the past 2Myr in the surface of rock 68815, and to determine the depth distribution of different N components by stepwise etching of 71501 ilmenite.
(d) Evolution of isotopic signatures in lunar-regolith nitrogen: noble gases and nitrogen in grain-size fractions from regolith breccia 79035
J.F.Kerridge, J.S.Kim, Y.Kim & K.Marti
Proc.Lunar Planet.Sci.Conf.22nd., 215 (1992)
Modeling the evolution of N and $^{15}N/^{14}N$ in the lunar regolith: Mixing models involving two components
J.F.Kerridge, P.Bochsler, O.Eugster & J.Geiss
Proc.Lunar Planet.Sci.Conf.22nd., 239 (1992)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR Roy S. Lewis
Enrico Fermi Institute, University of Chicago
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CO-INVESTIGATOR Robert N. Clayton

PROPOSAL TITLE Presolar Grains and the Early Solar System

ABSTRACT

a) Noble-gas rich mineral fractions are separated from primitive meteorites and are studied by mass-spectrometry, SEM, ion microprobe, TEM, and other techniques to identify trapped noble gas components and to characterize their carriers. Special emphasis is given to interstellar grains tagged with isotopically anomalous gases. These test theories of nucleosynthesis, stellar evolution, interstellar processes, solar system formation, and early solar system evolution.

b) The past years work has increased the number of elements measured, the number of samples measured, the number of meteorites sampled, and the number of individual grains sampled. The latter point is quite significant as the most highly purified sub fractions are still not homogenous. Evidently, we have in hand for analysis samples of many kinds of stars.

c) The isotopic compositions will be determined of trace and major elements in separated and further purified interstellar grains by noble gas and ion-probe mass spectrometry. When advantageous, and as the capabilities are developed, microprobe resonance ionization mass spectrometry will also be used. Other techniques will be applied to these samples, as: TEM, micro Raman, solid-source mass-spectrometry, and n-activation. Additional presolar materials as well as other primitive materials will be searched for in primitive meteorites and similarly studied.

d) RECENT PUBLICATIONS

Noble Gases in "Phase Q": Closed System Etching of an Allende Residue
R. Wieler, E. Anders, H. Baur, R. S. Lewis, and P. Signer
Geochim. Cosmochim. Acta **55**, 1709-1722 (1991).

^{26}Al and ^{16}O in the Early Solar System: Clues from Meteoritic Al_2O_3.
E. Anders, A. Virag, E. Zinner, and R. S. Lewis
Astrophys. J. (Lett..) **373**, L77-80 (1991).

Interstellar Grains within Interstellar Grains
T. J. Bernatowicz, S. Amari, E. Zinner, and R. S. Lewis
Astrophysical J. (Lett.) **373**, L73-76 (1991).

s-Process Ba, Nd, and Sm in Presolar SiC from the Murchison Meteorite.
E. Zinner, S. Amari, and R. S. Lewis
Astrophys. J. Lett. **382**, L47-L50 (1991).

PROPOSAL SUMMARY SHEET

PRINCIPAL INVESTIGATOR: David J. Lindstrom
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CO-INVESTIGATOR: Michael E. Zolensky

PROPOSAL TITLE: Instrumental Neutron Activation Analysis of Individual Cosmic Dust Particles

ABSTRACT:

a. This study uses specially developed instrumental neutron activation analysis (INAA) techniques to obtain abundances of trace and major elements in individual interplanetary dust particles (IDPs) and other interesting small samples of geochemical interest. The abundances obtained are used to interpret the processes responsible for the formation and evolution of the samples.

b. Over 100 microscopic samples have been analyzed using our ultra-high precision INAA techniques. The techniques allow reliable abundances to be obtained for about fifteen elements of varying geochemical affinities in chondritic IDPs weighing 10-100 ng, and up to twice that number in larger or more chemically evolved samples.

c. Trace element analyses of about 50 individual IDPs and/or Antarctic micrometeorites will be done by INAA and the results used to evaluate models for the formation and evolution of IDPs. Similar procedures will be applied to a variety of other small samples obtained using a new microcoring device.

d. 1) Lindstrom D.J. (1992) LPSC XXIII, 779-780. 2) Lindstrom D.J. (1992) Meteoritics 26(4), in press. 3) Zolensky M. E. and Lindstrom D.J. (1992) Proc Lunar and Planetary Science 22, 161-169

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR

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SN2 Office of the Curator
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CO-INVESTIGATOR

David W. Mittlefehldt

PROPOSAL TITLE

Geochemical and Petrologic Studies of Planetary Differentiation on the Moon and Meteorite Parent Bodies

ABSTRACT:

a) Objectives: The processes of planetary differentiation on the Moon and meteorite parent bodies will be investigated using geochemical and petrologic studies of lunar samples and differentiated meteorites.
b) Progress in FY92: Our lunar studies emphasized evolved rocks from the Apennine Front and lunar meteorites. We described several new fragments of quartz monzodiorite and granite and discussed their relationship to KREEP basalts. We led the consortium studying lunar meteorite MAC88104/5 and reported geochemical studies of anorthositic lunar meteorites. We began studies of the basaltic lunar meteorites. Studies of differentiated meteorites included analyses of HEDs (howardites, eucrites, diogenites), mesosiderites, angrites and shergottites. We conducted experimental studies aimed at understanding mesosiderite textures and partial melting to produce basaltic achondrites.
c) Plans for FY93: Lunar studies will focus on evolved rocks and model petrogenesis and relationships among KREEP basalts, quartz monzodiorite and granite. We will study the geochemistry of two gabbroic lunar meteorites and evaluate relationships among the basaltic lunar meteorites. Meteorite studies will continue to focus on the basaltic achondrites through petrogenetic studies of howardites, eucrites and diogenites and comparison to mesosiderites, angrites and shergottites. We will initiate a study of primitive achondrites.
d) Publications: Lindstrom M.M. et al. (1991) *Geochim. Cosmochim. Acta 55*, 3089-3103. Marvin U.B. et al. (1991) *Proc. Lunar Planet. Sci. 21*, 119-135. Mittlefehldt D.W. and Lindstrom M.M. (1990) *Geochim. Cosmochim. Acta 54*, 3209-3218. Rubin A.E. and Mittlefehldt D.W. (1992) *Geochim. Cosmochim. Acta 56*, 827-840.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael E. Lipschutz
(Name, Address, Telephone Number) Department of Chemistry, Purdue Univ., W. Lafayette, IN 47907 (317) 494-5326

Co-INVESTIGATORS: R. O. Sack
(Name Only)

PROPOSAL TITLE: Chemical Studies of Meteorites

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 study genetic and evolutionary histories of meteorites as model systems for formation of Solar System objects. We measure labile trace elements by neutron activation analysis (RNAA) and AAS in selected meteorites, determining alteration of primary compositions by specific later episodes. Compositionally unique primary materials are identified and characterized by neutron activation analysis and other techniques: EPMA data for igneous samples are interpreted using phase relationships to establish conditions of formation. We correlate trace element and other data to study flux changes of extraterrestrial material on Earth.

Among 9 papers published, in press or submitted are: 3 solicited by journal editors covering specific research areas or applications; 4 separate consortium studies, 2 of lunar meteorites from the Yamato Mts. and Macalpine Hills regions of Antarctica, a study of a putative C3 clast in the LEW 85300 eucrite demonstrating its unique nature, and one on the Fayetteville regolith breccia describing relationships between constituent portions; a mineral chemical study of two olivine diogenites demonstrating origin by partial melting; a survey of chondrites demonstrating a compositional continuum rather than quantized compositions.

By February 1994 we propose to: write up a number of papers on data already obtained; complete and write up results on Antarctic and non-Antarctic H4-6 chondrites chosen to represent different putative populations; initiate RNAA measurements on additional consortium samples (especially lunar meteorites), L4-6 chondrites (including Mocs meteorite shower) and eucrites exhibiting REE loss by terrestrial weathering in Antarctica. We also propose to continue mineral chemical studies of various meteorites of igneous origin, completing these where possible: in particular we propose to write up results for angrites. Representative publications include "Olivine Diogenites: ..." by R. O. Sack, W. J. Azeredo and M. E. Lipschutz, Geochim. Cosmochim. Acta 55, 1111-1120 (1991) and "... Fayetteville Chondrite Parent", by X. Xiao and M. E. Lipschutz, ibid. 55, 3407-3415 (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael E. Lipschutz
(Name, Address, Telephone Number) Department of Chemistry, Purdue Univ., W. Lafayette, IN 47907 (317) 494-5326

Co-INVESTIGATORS: David Elmore, Frank Rickey, Paul Simms
(Name Only)

PROPOSAL TITLE: National Facility for AMS

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

a. We determine cosmogenic radionuclides by accelerator mass spectrometry (AMS) in extraterrestrial materials to determine irradiation histories and/or terrestrial ages, thereby providing information on the recent history of planetary bodies and impact-produced ejecta from them.

b. During the past year, we have developed chemical separation and measurement techniques which allowed us to measure ^{10}Be, ^{26}Al and ^{36}Cl in a number of meteorites. We also began the upgrading necessary to produce a National AMS Facility serving the planetary science community.

c. In the coming year, the facility improvement process will continue as will measurements of additional meteorites. We also plan to complete at least 2 projects – on Canyon Diablo specimens, and very recent ordinary chondrite falls – and submit the papers to scientific journals.

d. PRIME Lab: A dedicated AMS facility at Purdue University, D. Elmore, F. A. Rickey, P. C. Simms, M. E. Lipschutz, K. A. Mueller and T. E. Miller, Proc. Fourteenth International Radiocarbon Conf., in press (1992).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gary Lofgren
SN4/NASA Johnson Space Center
Houston, TX 77058
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CO-INVESTIGATORS: None

PROPOSAL TITLE: Dynamic Crystallization Studies of Melts of Planetary Origin

ABSTRACT:

a. Kinetically controlled crystallization processes are observed in many planetary materials such as chondrules. Understanding these processes is integral to modelling their petrogenetic histories. Dynamic crystallization experiments will be used to duplicate and model the formation of textures and mineral chemistries associated with these processes. Efforts will continue to develop a model for chondrule crystallization based on the experiments of the past few years. The ultimate goal is to develop a universal model for kinetically controlled crystallization processes in any planetary environment.
b. During the past year we completed the dynamic crystallization study of the textures in enstatite chondrite chondrule melts and began to characterize the cathodoluminescence (CL) properties of enstatite. Using the CL properties of enstatite we established criteria for recognizing relic crystals in enstatite chondrite chondrules. The annealing study of the low-Fe, type I chondrule composition designed to alter the CL properties is also complete. The identity of the phosphor as anthorite has been established. The CaO partitioning between olivine and liquid is complete. The study of the REE partitioning between sulfides and the silicate melt in enstatite chondrites and the partial melting study of the enstatite chondrite, Indarch continued. A strong temperature relationship between Si in FeNi metal in partial melts of Indarch has been determined. A study of the trace and minor element partitioning between crystal and melt for olivine and orthopyroxene in chondrule melts was initiated.
c. During the next year we plan to continue the study of the CL properties of enstatite and to compare the experimental results with the properties of the natural chondrules. To make this comparison we need to characterize the E-3 and E-4 enstatite chondrite chonrules and matrix features. We will study most of the existing E-3 and E-4's. We will also continue the kinetics of partitioning studies in chondrule melts and look at partitioning of a similar set of elements in hibonite and perovskite. We will continue the dynamic crystallization studies of angrite LEW 87051.
d. Lofgren (1989) Geochim. Cosmochim. Acta, 53, 461-470; Lofgren and Lanier (1990) Geochim. Cosmochim. Acta, 54, 3537-3551..

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John Longhi
(Name, Address, Telephone Number) Lamont-Doherty Geol. Observ., Palisades, NY 10964
914-359-2900 X659

Co-INVESTIGATORS: Vincent Salters
(Name Only)

PROPOSAL TITLE: Early Differentiation of the Moon: Experimental and Modeling Studies

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

a. The phase equilibria that governed the petrogenesis of lunar and achondrite parent magmas are accessible through low- and high-pressure melting experiments. However, many of the petrogenetic processes that may have occurred -- fractional fusion, fractional crystallization, assimilation -- are not directly amenable to experiments. Consequently, we are gathering phase equilibrium and crystal/melt partitioning data from melting experiments on a wide range of basaltic compositions, incorporating these data into quantitative models of high-pressure partial melting and low-pressure fractional crystallization, and applying these models to problems of lunar and achondrite petrogenesis.

b. Projects in the past year have included: [1] modeling of polybaric partial melting as a means of producing lunar picritic magmas; [2] investigation of systematically distinct fractionation patterns of high field strength elements (HFSE) from rare earths (REE) in the Earth, Moon, eucrite, and SNC parent bodies; [3] investigation of apparent enrichments of Sr relative to the light REE in the Antarctic shergottites.

c. We propose to continue to try to constrain planetary magmatism through experimental and modeling studies by 1) extending our present experimental study of silicate liquid immiscibility to include the range of 1-3 kb; 2) mapping out the liquidus equilibria at 0-3 kb of low-Mg', silica-saturated liquids pertinent to evolved pristine rocks and the magmas residual to the crystallization of lunar ferroan anorthosites; 3) mapping out the liquidus equilibria in the range of 5-40 kb relevant to the melting of the mare basalt source region and magma ocean evolution; and 4) measuring HFSE and Sr crystal/liquid partition coefficients appropriate to SNC parent magmas at natural concentration levels with the ion microprobe.

d. [1] Longhi, J. (1992) Origin of green glass magmas by polybaric fractional fusion. *Proc. Lunar Planet. Sci. 22,* 343-353. [2] Longhi, J. (1991) A comparison of incompatible trace element patterns in terrestrial, lunar, and martian basalts, *EOS, 72,* p.281. [3] Longhi, J. (1992) Volatiles in SNC petrogenesis: a Sr signal? in *Lunar and Planetary Science XXIII,* The Lunar and Planetary Institute, pp. 805-806.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John Longhi
(Name, Address, Telephone Number) Lamont-Doherty Geol. Observ., Palisades, NY 10964
914-359-2900 X659

Co-INVESTIGATORS: **(Name Only)**

PROPOSAL TITLE: Experimental and Modeling Studies of Massif Anorthosites

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. New chronologic, petrographic, and geochemical evidence indicate that the formation of lunar ferroan anorthosite (LFA) may not have been a homogeneous event, distinctly separable in time from the formation of the oldest members of the Mg-suite of pristine rocks. Several possible scenarios emerge to explain the newly appreciated complexity of LFA, including variations on the magma ocean theme; however, there are important insights to be gleaned from the study of terrestrial massif anorthosites, which appear to be promising analogs, not only because they are the most voluminous terrestrial anorthosites, but also because they crystallized from evolved liquids and their emplacement appears to have involved multiple, two-stage anorthositic intrusions. One of the keys to understanding igneous rocks is to investigate the petrogenesis of their parent liquids. I propose to continue experimental and modeling studies of basaltic systems to constrain the petrogenesis of massif anorthosites and coeval monzonorites. I also propose to determine the pressure dependence of Ab/An, FeO and MgO plagioclase/liquid partition coefficients appropriate to lunar compositions.

b. We have investigated the liquidus phase relations of an anorthositic dike (Nain) and a marginal gabbro (Harp Lake) composition in the range of 0 to 20 kb [1]. The liquidus temperature of the dike is too high for it to be a plausible liquid, whereas the gabbro not only has the composition of a plausible liquid, but is capable of producing the mineral compositions observed in the Harp Lake Massif. We have also investigated the pressure dependence of the Ab/An exchange coefficient between plagioclase and liquid[2] and calibrated the variation of the Al2O3 concentration in orthopyroxene megacrysts with pressure [3]. We also have predicted that pressure variations are unlikely to account for the most albitic plagioclase in LFA or for the anomalously low concentrations of FeO and MgO in LFA plagioclase.

c. In the coming year I propose to continue melting experiments in the range of 2 - 15 kb to map out the liquidus equilibria appropriate to parent magmas of massif anorthosites and monzonorites in order to constrain their petrogenesis. I also propose to verify our predictions about the pressure dependence of plagioclase/liquid partitioning for Ab/An, FeO, and MgO in lunar systems by direct experiments.

d. [1] Fram, M. S. and J. Longhi (1992) Phase equilibria of dikes associated with Proterozoic anorthosite complexes, *Am. Mineral.*, in press; [2] Fram, M.S. and J. Longhi (1991) Plagioclase/melt partitioning as a function of pressure, *EOS, 72*, p. 304-305; [3] Longhi, J., Fram, M. S., Vander Auwera, J., and Montieth, J. (1992) Pressure effects in anorthositic and related magmas. In *Lunar and Planetary Science XXIII*, The Lunar and Planetary Institute, pp. 803-804.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: G.W. Lugmair
(Name, Address, Telephone Number) Scripps Institution of Oceanography
La Jolla CA 92093-0212 (619) 534-2746

Co-INVESTIGATORS: J.D. Macdougall
(Name Only)

PROPOSAL TITLE: Isotopic, chemical and mineralogical investigations of extraterrestrial 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.)

This proposal is for continuation, on multi-year status, of isotopic, chemical and mineralogical studies on meteoritic and other extraterrestrial materials. Our investigations will focus on the evolution of condensed matter in the early solar system. The required high purity chemical and high precision mass spectrometric techniques for elements such as Mg, Ca, Ti, Cr, Ni, Zn, Rb, Sr, Ba, Nd, Sm, Pb and U have been developed in our laboratory under NASA support during previous years and some were refined in the past year. Major topics addressed by our research include: a) questions concerning the occurrence, magnitude and correlation of isotopic anomalies in carbonaceous and other chondrites and their bearing on nucleosynthetic models; b) extinct radioactive isotopes such as ^{146}Sm, ^{60}Fe and ^{53}Mn and their use as short-lived chronometers for early planetary evolution; c) formation age and isotopic evolution of some rare meteorite types using the Rb-Sr, Sm-Nd and U-Th-Pb systems; d) isotopic patterns of various elements in acid insoluble residues (diamonds) from Allende to study the origin of Xe-HL, the possible presence of r- and s-process components, $^{146}Sm/^{144}Sm$ in the early solar system, and the time of formation of volatile rich components; and e) the origin of ureilites.

References:

1. Loss, R.D. and Lugmair, G.W., Zinc isotope anomalies in Allende Meteorite inclusions. Astrophys. Jour. 360, L59-L62 (1990). 2. Lewis, R.S., Huss, G.R. and Lugmair, G.W., Finally, Ba & Sr accompanying Xe-HL in diamonds from Allende. Abstract, LPSC XXII, 807-808 (1991). 3. Goodrich, C.A., Patchett, J., Lugmair, G.W. and Drake, M.J., Sm-Nd and Rb-Sr isotopic systematics of ureilites. GCA 55, 829-848 (1991). 4. Lugmair, G.W. and Galer, S.J.G., Age and isotopic relationships among the angrites Lewis Cliff 86010 and Angra dos Reis. In press, GCA. 5. Lugmair, G.W., MacIsaac, C. and Shukolyukov, A., The ^{53}Mn-^{53}Cr isotope system and early planetary evolution. Abstract, LPSC XXIII. 6. Shukolyukov, A. and Lugmair, G.W., First evidence for live ^{60}Fe in the early solar system. Abstract, LPSC XXIII.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Glenn J. MacPherson
Dept. of Mineral Sciences, NHB 119
Smithsonian Institution,
Washington, D.C.
(202) 357-2260

CO-INVESTIGATORS:

PROPOSAL TITLE: STUDIES OF CORRELATED ISOTOPIC/PETROLOGIC/TRACE ELEMENT SYSTEMATICS IN REFRACTORY INCLUSIONS IN PRIMITIVE CHONDRITES

ABSTRACT:

[a] Correlated Mg-Sr-O-isotopic, bulk chemical, and petrologic studies of refractory inclusions (CAI) in primitive chondrites are used to evaluate various nebular processes, and unravel complex CAI histories and chronologies. Specific goals include: (1) establishing the heterogeneity or homogeneity of ^{26}Al, both within individual CAI and in the early solar system as a whole; (2) evaluating the relative contributions of condensation, evaporation, alteration and other processes to the formation and evolution of CAI; and (3) measuring timescales for events within the lifetime of the early solar nebula.

[b] Studies during the past year have concentrated on Leoville CAI evolution in the nebula and in the parent body; all four CAI measured so far had ~canonical initial $(^{26}Al/^{27}Al)_o$ $\sim 5 \times 10^{-5}$ at the time of formation but are now disturbed to differing degrees. One of these is a hibonite-rich CAI, which thus shows no evidence of the anomalously-high $^{26}Al/^{27}Al$ reported over 14 years ago by J.C. Lorin and colleagues for another Leoville CAI. Two Leoville CAI show effects of localized shock melting in the parent body, but which had little effect on their Al-Mg isotope systems. Several Vigarano and Leoville CAI have insufficient Rb to support their high $^{87}Sr/^{86}Sr$ ratios; late loss of Rb (parent body processing?) seems indicated. Ion microprobe studies now completd on ~two dozen well-characterized CAI in Mighei (CM) reveal only volatility-controlled rare-earth element abundance patterns and small positive mass dependent isotopic fractionation effects, $\Delta^{25}Mg$ up to ~6‰. They clearly formed by nebular processes.

[c] Ion microprobe, Rb-Sr bulk isotopic, and petrologic studies will begin on several Efremovka (CV3) inclusions, especially with a view toward possible parent body effects. Petrologic and ion microprobe work will continue on Vigarano and Leoville CAI.

[d] F.A. Podosek *et al.* (1991), *G.C.A.* 55 2121-2132; C. Caillet *et al.* (1991), *Meteoritics* **26**, 326; P.J. Sylvester *et al.* (1992), *G.C.A.* **56**, 1343-1363. ; G.J. MacPherson et al. (1992), *Meteoritics* (submitted); C. Caillet *et al.* (1992), *GCA* (submitted).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Kurt Marti
(Name, Address, Telephone Number) Univ. of Calif., San Diego, 9500 Gilman Dr., La Jolla, 92093-031
(619) 534-2929

Co-INVESTIGATORS: Dr. Thomas Graf
(Name Only)

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) The general objective of the proposed research projects is an improved understanding of the solar system environment, of the processes involved in the nebula, and the early and recent evolution of solid bodies. The research program will focus on (1) isotopic signatures of noble gases and nitrogen in solar system reservoirs, the degree of isotopic homogenization of presolar components and the fossil evidence for the early radiation environment; (2) the meteorite-asteroid link, the collisional, thermal and orbital evolution of meteorite parents; and (3) the fossil records regarding isotopic evolution of N and of noble gases in the solar wind.
(b) High resolution Xe isotopic studies revealed interrelationships among known solar system reservoirs; Xe in metal suggested particle radiation effects by the early sun; the records of solar wind N indicate that the evolution of the isotopic signature was not linear in time as previously assumed; the noble gas records of chondrites show evidence for collisional fragmentation and complex thermal and orbital evolutions.
(c) We attempt to identify major carriers of volatiles, the degree of isotopic homogenization and implied formation conditions. A major effort will be carried out, as part of the Acapulco consortium, to delineate the environment and the chronology of the unique parent asteroid, for which the present evidence indicates a strong but short heat pulse. We will study the cosmic ray record, evolutionary history and indicated meteorite-asteroid links of the enstatite achondrites vs. those of enstatite chondrites. The major H-parent collision, 7 Ma ago, and the implied differential orbital evolutions of H-subgroups will be studied in detail. The recent make-up of N in the solar wind will be studied in South Ray material and ion implantation and gas release systematics studied using a simulation experiment.
(d) Kim J.S. and K. Marti, Solar-type Xenon: Isotopic Abundances in Pesyanoe, Proc. Lunar and Planetary Science, 22, 145-151 (1992); Marti K and Th. Graf, Cosmic-Ray Exposure History of Ordinary Chondrites, Annu. Rev. Earth Planet. Sci., preprint (1992); B. Lavielle and K. Marti, Trapped Xenon in Ordinary Chondrites, submitted to JGR Planets (1992); J.F. Kerridge et al, Evolution of Isotopic Signatures in Lunar-Regolith Nitrogen: Noble Gases and Nitrogen in Grain-size Fractions from Regolith Breccia 79035, Proc. Lunar and Planetary Science, 22, 215-224 (1992).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Ursula B. Marvin
(Name, Address, Telephone Number) Smithsonian Institution Astrophysical Observatory
60 Garden Street, Cambridge, MA 02138
(617)495-7270 or FTS 830-7270

Co-INVESTIGATORS: Dr. John A. Wood
(Name Only)

PROPOSAL TITLE: Mineralogical Investigations of Lunar Samples and Meteorites

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. I propose to continue mineralogical-petrological research, devoting 65% of my efforts to lunar samples and 15% to meteorites and related topics.

b. and c. Petrology of Apollo 15 Highland Rocks. I carry out lunar sample research in collaboration with Dr. M. M. Lindstrom who measures trace elements by INAA on splits of the samples I study in thin sections. **1.** Last year I analyzed compositions and textures of polygonized lunar dunites in an effort to deduce their igneous and metamorphic histories. I am making additional analyses and plan to publish the results next year. **2.** As part of a study of the quartz monzodiorite-granite suite, I arranged for ion microprobe dating by Dr. Trevor Ireland, of Australian National University, of zircons in Apollo 15 QMDs and an Apollo 12 potash rhyolite. The results, expected this spring, should help to confirm or confound our ideas on the petrologic lunar time scale. **3.** I currently await thin sections of a new selection of Apollo 15 crystalline clasts that have been identified as of interest by INAA analyses. An ultimate aim of this study is to work out genetic relationships between QMDs, granites and KREEP basalts and to search for lithologies that may be common ancestors of all these rock types.

Meteorites and Related Topics. 1. I began a petrologic study of the Calcalong Creek lunar meteorite as part of a consortium study led by Prof. Wm. V. Boynton of the University of Arizona. It is a regolith breccia with a glassy impact-melted matrix and mineral and lithic clasts from both highland and mare sources. The main highlands lithologies are gabbroic anorthosites; mare clasts are of late-stage, Fe-rich basalts. Next year, I will analyze additional samples of this meteorite and, if possible, excavate some of the larger clasts for INAA analyses by the Arizona group. Similarities are recognizable between clast materials in this meteorite and those in Apollo 15 and 17 soil samples. **2.** I coauthored a paper with D. A. Kring on impactites from the New Quebec Crater. We present the first petrographic descriptions of relict accessory minerals as well as of silica minerals and feldspars in progressive stages of shock metamorphism. **3.** I wrote an invited review paper on the 500-year history of the Ensisheim meteorite, scheduled for publication in the March, 1992, issue of *Meteoritics*. Next year, I will review the U.S. Antarctic meteorite program at the IGC in Kyoto and complete a history of *The Meteoritical Society* for publication as an invited review in the June, 1993, issue of *Meteoritics*.

d. U. B. Marvin and B. B. Holmberg (1992) "Highland and Mare Components in the Calcalong Creek Lunar Meteorite." *Lunar and Planetary Science XXIII*, LPI. U. B. Marvin and D. A. Kring, (in press) "Authentication Controversies and Impactite Petrography of the New Quebec Crater." *Meteoritics*, 32 ms. pp. U.B. Marvin (in press) "The Meteorite of Ensisheim: 1492 to 1992." *Meteoritics*, **27**, March, 1992, 115 ms. pp.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: I. S. McCallum
Department of Geological Sciences
University of Washington
Seattle, WA 98195
(206)543-9494

CO-INVESTIGATOR: Hugh E. O'Brien

TITLE: The Formation of Cumulate Rocks

ABSTRACT:

(a) The objective of our research is to understand the processes involved in the formation of terrestrial and lunar cumulates by a petrological, geochemical, and isotopic study of the Stillwater Complex and selected lunar crustal samples. Continued documentation of the similarity between the Stillwater Complex and the lunar crust in terms of lithologies, mineral compositions, geochemistry, fractionation trends and petrogenesis provides a validation of the Stillwater Complex as a lunar analog.

(b) Pb isotopic ratios of multiple leaches of sulfide and plagioclase separates from all major zones of the Stillwater Complex have revealed a history of multiple events. On Pb-Pb diagrams, data from both sulfides and plagioclases define linear trends corresponding to ages of 2.7 Ga (the crystallization age) and a range of secondary "ages". A component of "younger" radiogenic lead has mixed with common lead in sulfides and plagioclases. Plagioclase cores have preserved the initial Pb isotopic ratios whereas most sulfides have not. Recrystallization of sulfides some time after emplacement in response to hydrothermal events has resulted in the redistribution of Pb (+ other elements) throughout the sulfide crystal structure. Other results of our research on the Complex: infiltration metasomatism has been documented in anorthosites and a quantitative model developed for this process; the oxygen fugacity during crystallization has been precisely constrained by new thermodynamic solution models; a model of anorthosite genesis has been developed.

(c) In the next grant period, we propose to (1) determine cooling rates of Stillwater samples and lunar highlands samples using compositional profiles and site occupancies in exsolved pyroxenes, (2) extend our study of Pb isotopic ratios in sulfides and plagioclases to include the Bushveld Complex and the Great Dike, (3) initiate a study of S isotopes on Stillwater sulfides for which Pb isotopic data have been determined, (4) determine Nd isotopic ratios in clinopyroxenes across key lithologic boundaries in the Stillwater Complex, (5) determine D_{Cr} (pyroxene/liquid) as a function of T, X, fO_2.

(d)Thurber, M.W., Nelson, B.K., and McCallum, I.S. (1992) Lead isotopes in sulfides from the Stillwater Complex, Montana: Evidence for subsolidus remobilization. Contrib. Mineral. Petrol, in review

Boudreau, A.E. and McCallum, I.S. (1992) Infiltration metasomatism in layered intrusions--An example from the Stillwater Complex, Montana. Jour. Volcan. Geotherm. Res, in press

McCallum, I.S., Thurber, M.W., Bosch, D. and Nelson, B.K. (1992) Lead isotopic compositions of plagioclases and sulfides in the Stillwater Complex: Evidence for isotopic disequilibrium. Lunar Planet. Sci. XXIII, 867-868

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David S. McKay
SN/Johnson Space Center
Houston, TX 77058
(713) 483-5048

CO-INVESTIGATORS: Donald D. Bogard
Richard V. Morris

PROPOSAL TITLE: A Multidisciplinary Study of the Characteristics and Evolution of the Lunar Regolith

a. Objectives: Our major objectives are to understand the lunar regolith and the complex processes which formed it. In addition, the lunar regolith is a key to understanding the near-surface processes that were important in the evolution of many meteorites. Clues to the nature and history of the solar wind, micrometeorites, and large impactors are also present in the lunar regolith. We analyze samples from regolith breccias, cores, and surface soils using a multidisciplinary approach which includes SEM, TEM, energy dispersive X-ray analysis, electron microprobe analysis, FMR (ferromagnetic resonance), magnetic hysteresis loop, rare gas isotope mass spectrometry, and INAA. Samples include bulk regolith breccias and soils, disaggregated regolith breccias, grain size separates, and individual components such as glass fragments.

b. Accomplishments: We published the results of petrological and geochemical investigations of lunar meteorite MAC88104/5 in collaboration with M. Lindstrom's group. TEM/EDS studies of the finest fractions of lunar soils gave further evidence for impact-induced volatilization and vapor condensation, and showed that amorphous grain coatings on submicron-sized feldspar grains are, at least in part, the result of vapor deposition. We obtained rare gas isotope and petrologic data for Apollo 12 ropy glasses which yielded important clues to their origin.

c. This year: We will complete studies of Apollo 12 ropy glasses and continue Apollo 14 and 17 ropy glass studies. We will continue multidisciplinary studies of lunar meteorite regolith breccias. We will continue TEM studies of the finest fractions of lunar soils by studying the submicrometer-size fractions of immature mare and highlands soils for comparison to their mature counterparts. We will continue our study of amorphous rims on lunar regolith grains.

d. Bibliography: Keller L. P. and McKay D. S. (1992) Micrometer-sized glass spheres in Apollo 16 soil 61181: Implications for impact volatilization and condensation. *Proc. Lunar Planet. Sci. 22*, pp. 137-141. Lindstrom M. M. et al. (1991) Geochemistry and petrography of the MacAlpine Hills lunar meteorites. *Geochim. Cosmochim. Acta 55*, pp. 3089-3103.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. David S. McKay
(Name, Address, Telephone Number) SN4, NASA-Johnson Space Center, Houston, TX 77058
(713) 483-5048

Co-INVESTIGATORS: Dr. Lindsay P. Keller
(Name Only)

PROPOSAL TITLE: Carbon in Primitive Interplanetary Dust 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.)

A. We propose an electron microscope study of the abundance, distribution, and chemical state of carbon in primitive interplanetary dust particles (IDPs). The major goal of this research is to study in detail a significant group (~20) of IDPs in order to determine 1) accurate and reliable bulk carbon abundances in a group of IDPs, 2) the spatial distribution, the phase compositions and proportions, and the degree of order (crystallinity) of the carbonaceous material, 3) the major and trace element composition of IDPs, and 4) their mineralogy and mineral chemistry. The results of this study are important for understanding the formation and evolution of carbonaceous materials from the time they were produced to when they were incorporated into primitive bodies in the early solar system.

B. New proposal. We have determined bulk C abundances in anhydrous IDPs and have found that carbon abundance is correlated with the silicate mineralogy. These results have been used to discriminate cometary from asteroidal particles. We have also reported the first quantitative analyses of bulk carbon in hydrated IDPs.

C. We will: 1) quantitatively analyze 12 IDPs, including both anhydrous and hydrated types, for elements Z>5, 2) characterize the carbonaceous material in the IDPs using high-resolution TEM imaging, electron diffraction, and electron energy-loss spectroscopy, and 3) determine the mineralogy and mineral chemistry of the crystalline phases in each particle.

D. Thomas, K. L., Blanford, G., Keller, L. P., Klock, W., and McKay, D. S. (1992c) Carbon abundance and silicate mineralogy of anhydrous interplanetary dust particles. *Geochimca et Cosmochimica Acta*, in review. Keller, L. P., Thomas, K. L., and McKay, D. S. (1992) An interplanetary dust particle with links to CI chondrites. *Geochimica et Cosmochimica Acta* 56, 1409-1412. Thomas, K. L., Keller, L. P., Blanford, G., Klock, W., and McKay, D. S. (1992a) Carbon in anhydrous interplanetary dust particles: Correlations with silicate mineralogy and sources of anhydrous IDPs. *XXIII LPSC.*, 1425-1426. Thomas, K. L., Keller, L. P., Flynn, G. J., Sutton, S. R., and McKay, D. S. (1992b) Bulk compositions, mineralogy and trace element abundances of six interplanetary dust particles. *XXIII LPSC.*, 1427-1428.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gordon A. McKay (713-483-5041)
SN4 / NASA Johnson Space Center
Houston, TX 77058

CO-INVESTIGATORS: None

PROPOSAL TITLE: Experimental and Theoretical Studies of Planetary Differentiation

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"; (c) brief listing of what will be done this year, as well as how and why; and d. publications relevant to the proposed work.)

a. The broad strategy of this investigation involves the experimental determination of phase equilibria and elemental distributions which constrain planetary differentiation and magma evolution. The investigation is currently focused on experimental studies of trace element partitioning behavior and application of these studies to the modeling of natural systems. Work is particularly focused on understanding the origin, evolution, and chronology of angrite meteorites, and on measuring partition coefficients to help constrain the origin of Nakhla, one of the SNC meteorites believed to be from Mars.

b. In the past year, we have (1) performed experimental crystallization studies of angrite LEW 87051 and used these to develop a model for the crystallization of this sample from a high-temperature melt; (2) compared this high-temperature melt with partial melts of carbonaceous chondrites to investigate chondrite melting as a potential origin for LEW 87051; (3) measured augite/melt partition coefficients for two compositions proposed as parent melts of Nakhla; and (4) determined the bulk composition of shergottite LEW 88016 by measuring average mineral compositions and mode, and found that it closely resembles that of ALHA77005.

c. During the coming year we plan to (1) continue studying augite/melt partition coefficients for application to the petrogenesis of Nakhla; (2) prepare manuscripts reporting results of our investigations of Antarctic angrites; and (3) investigate pyroxene partition coefficients at 10-15kb.

d. Crozaz G. and McKay G. (1990) Rare earth elements in Angra dos Reis and Lewis Cliff 86010, two meteorites with similar but distinct magma evolutions. *Earth Planet. Sci. Lett.*, 97, 369-381.

McKay G. (1989b) Partitioning of REE Between Major Silicate Minerals and Basaltic Melts. In *Reviews in Mineralogy 21: Geochemistry and Mineralogy of Rare Earth Elements*, B. Lipin and G. McKay, ed., 45-74. Min. Soc. Am., Washington, D.C.

McKay G., Le L., and Wagstaff J. (1991) Olivines in angrite LEW 87051: Phenos or xenos? (abstract). In *Meteoritics*, 26, 370.

Jurewicz A. and McKay G. (1992) Chondrite melting experiments: Can angrite LEW 87051 be produced by partial melting of a CV or CM chondrite? (abstract). In *Lunar and Planet. Sci XXIII*, 643-644.

McKay G., Le L., and Wagstaff J. (1992) REE partition coefficients for the Nakhla parent melt (abstract). In *Lunar and Planet. Sci XXIII*, 889-890.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Harry Y. McSween, Jr.
Department of Geological Sciences
University of Tennessee
Knoxville, TN 37996-1410

CO-INVESTIGATORS:

TITLE: Meteorite Petrogenesis

ABSTRACT:

a. The objective of this proposal is to characterize the petrologic features of meteorites, and to understand the nebular and parent body processes that produced them.

b. During the past year, we have completed a microprobe study of mineral zoning in the three nakhlites, to understand the crystallization of these cumulates, and have used melt inclusions in nakhlites to constrain parental magma compositions. We have also collaborated with G. Crozaz in an ion microprobe study of trace elements in shergottites. All of these studies of putative Martian crustal samples provide basic information that allows improved estimates of magma compositions. We also collaborated with R. Singer to use SNC meteorites as a basis for understanding Mars spectrophotometry. We have completed an investigation of redox variations in metamorphosed ordinary chondrites, which has important implications for unraveling the nebular and parent-body chemical records in these meteorites. We have also determined that oxidation during metamorphism cannot account for observed variations in S-asteroid rotational spectra.

c. During the next year, we will analyze a newly discovered Antarctic shergottite, as part of a consortium effort. We will continue studies of nakhlites, to constrain the trace element signatures of their parental magmas, and expand the mass-balance technique used for nakhlite melt inclusions to shergottites. We will also continue a comparison of Mars spectra with SNC data. Several graduate students will initiate new petrologic studies of chondrites. One will focus on the mineralogy of CM chondrites using alkylammonium ion treatment for phyllosilicates. Another will perform a thermobarometric study of ordinary chondrites, to assess equilibration temperatures and to try to develop new thermometers using Ca-Al chondrules. We will also explore the transition from metamorphism to melting in type 7 chondrites.

d. Relevant publications:

Grimm R.E. and McSween H.Y. (1989) Water and the thermal evolution of carbonaceous chondrite parent bodies. Icarus 82, 244-280.

McSween H.Y., Bennett M.E. and Jarosewich E. (1991) The mineralogy of ordinary chondrites and implications for asteroid spectrophotometry. Icarus 90, 107-116.

Lundberg L.L., Crozaz G. and McSween H.Y. (1990) Rare earth elements in minerals of the ALHA77005 shergottite and implications for its parent magma. Geochim. Cosmochim. Acta 54, 2535-2547.

PROPOSAL SUMMARY

Principal Investigator:

Bradley S. Meyer
Department of Physics and Astronomy
Clemson University
Clemson, SC 29634-1911

Title: The History of the Nuclei Comprising Planetary Materials

ABSTRACT:

a) The objective of this research is to study and describe the physical and chemical history of the nuclei that comprise the planetary materials of our solar system from their formation in stars to their incorporation in the solar nebula. This work will increase our knowledge of the formation of the solar system, the nature of the interstellar medium, and the processes of stellar nucleosynthesis. It will be theoretical but will fundamentally rely for direction and for evaluation of its conclusions on data of isotopic anomalies in meteorites.

b) New proposal.

c) Work this year will in part be directed towards cataloging the astrophysical sites of origin of isotopes of interest for the study of isotopic anomalies in meteorites. The catalog will include distinguishing isotopic and chemical features of the matter bathing each isotope at its place of origin. Along with this work, models will be made to explore the survivability and transport of the grains that then carry these isotopes to the solar nebula. Don Clayton will collaborate in both of these efforts. Detailed, dynamical network nucleosynthesis calculations will be made to study the freeze out from neutron-rich nuclear statistical equilibrium in an effort to explain the isotopic anomalies in CAIs, including the recently discovered ^{60}Fe anomaly. Dieter Hartmann and a student, James H. Walsh, will collaborate on this project. The p-process, and its implications for isotopic anomalies in diamonds and for ^{53}Mn, will be thoroughly studied with Walsh, Clayton, and Mike Howard.

d) "A New Site for the Astrophysical Gamma-Process"
Howard, W. M., Meyer, B. S., and Woosley, S. E. *Astrophys. J. Lett* **373**, L5 (1991).

"The R-Process in the High-Entropy Supernova Bubble"
Meyer, B. S. *et al.*, submitted to *Astrophys. J.*

SUMMARY SHEET - - ABSTRACT

PRINCIPAL INVESTIGATOR:
Charles Meyer
SN2/Planetary Science Branch
NASA Johnson Space Center
Houston, TX 77058
713-483-5133 or FTS 525-5133 or FAX 713-483-5347

CO-INVESTIGATOR:
Ian S. Williams
William Compston
Research School of Earth Sciences
Australian National University

Richard Hinton
Grant Institute
University of Edinburgh
Edinburgh, Scotland

PROPOSAL TITLE:
The Mineral Chemistry and Chronology of Zircon-containing Lunar Rock Fragments by Ion and Electron Microprobe Analysis.

ABSTRACT:
a. The history of part of the original lunar crust can be studied by microprobe analysis of zircon-containing rock fragments that are found as clasts in lunar breccias. Zircons are found as isolated grains in the lunar soils and breccias and as euhedral inclusions in minute fragments of late-stage-differentiates (including urKREEP and granite). Lunar zircons are important because they can be precisely dated by the ion probe, U/Pb method. It is also important to establish the compositions of the zircons and the attached minerals in order to establish the rock types that have been dated.
b. By dating numerous zircon-containing rock fragments we have shown that there was continuous magmatism in the lunar crust throughout the time span 4370 to 3900 Ma. We have established that zircons formed in a wide variety of lunar rock types including norites and two kinds of lunar granophyre. We have determined the initial Pb in feldspars attached to lunar zircons and found that lunar granites are also formed from Pb-depleted lunar magma. We have found that REE patterns of lunar zircons can be used to establish their source. We have found a positive Ce anomaly in zircons from "young" lunar granites which is due to relatively oxidized lunar magma whereas most lunar zircons lack a Ce anomaly.
c. We propose to use both electron and ion probe analyses to determine the age and understand the origin of small, zircon-containing lunar rocks. At JSC the complete mineral chemistry of mineral phases attached to lunar zircon will be determined in order to know what lithology has been dated. Additional lunar zircons, baddelyite and U-rich yttrobetafite will be isotopically analyzed by ion probe at ANU. REE, U and Nb will be determined by ion probe at Edinburgh with the purpose to internally type zircons and their source rocks and discuss their oxidation state.
d. (1) Compston, Williams and Meyer (1991) Initial Pb Isotopic Compositions of Lunar Granites as Determined by Ion Microprobe (Stable Isotope Geochemistry, Geochem. Soc. Spec. Pub. 3). (2) Meyer, Williams and Compston (1991) Age of Lunar Granite by Ion Microprobe. New views of the Moon, Geological Society of America, San Diego. (3) Meyer, Williams and Compston (1992) The Age of Lunar Granite by Ion Microprobe. EPSL (submitted). (4) Meyer (1992) The Lunar Sample Collection. (Buttersworth)

• PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Roy Middleton
Department of Physics
University of Pennsylvania
209 S. 33rd Street
Philadelphia, PA 19104

CO-INVESTIGATORS: Jeffrey Klein
Gregory F. Herzog

PROPOSAL TITLE: AMS measurements of ^{41}Ca, ^{36}Cl, and ^{59}Ni: application to extraterrestrial materials

ABSTRACT:

a. We propose using ^{41}Ca and ^{59}Ni, two new additions to the list of radionuclides measurable by accelerator mass spectrometry, and ^{36}Cl to study cosmic-ray interactions in extraterrestrial materials. ^{41}Ca and ^{59}Ni enrich the science based on measurements of radionuclides in two important ways: First, they fill in the 'half-life gap' at around 100 ka. Second, because their concentrations in extraterrestrial materials are measurably affected by production from thermal neutrons and SCRs, they provide useful measures of the pre-atmospheric sizes of meteorites, and archive past solar output. ^{59}Ni is the only proxy of the solar α flux. We are already making measurements of ^{41}Ca and ^{36}Cl, and have begun exploring procedures for measuring ^{59}Ni.

b. Renewal

c. The goals of our ^{41}Ca and ^{36}Cl program during the first year include 1) a study the systematics of neutron-induced ^{41}Ca production in several meteorites including Dhajala, St. Severin, and Keyes, with measurements of ^{36}Cl and ^{41}Ca in metallic phases; 2) to resample lunar rock 74275 and several samples from Apollo 11 and 17 to further study the production of ^{41}Ca by solar protons; 3) to measure ^{41}Ca in a number of Antarctic meteorites in which ^{36}Cl has already been measured to study the constancy of the GCR flux; and 4) to determine whether the calcium in the weathering products on LEW85320 comes from the meteorite, or is of terrestrial origin. We also plan to modify an existing magnetic spectrograph and build a new detector to explore the effectiveness of a gas-filled magnet in reducing ^{59}Co when measuring ^{59}Ni, and so begin our program of measurements of ^{59}Ni in extraterrestrial materials.

d. Fink, *et al.*, *^{41}Ca: Measurement by accelerator mass spectrometry and applications*, Nucl. Inst. and Meth, **B47**,79 (1990).

Fink, *et al.*, *^{41}Ca: past, present, and future*, Nucl. Inst. and Meth., **B52**, 601-607, (1990).

Klein, *et al.*, *Determination of the half-life of ^{41}Ca from measurements of Antarctic meteorites* Earth Planet. Sci. Lett. **103**, 79-83 (1991).

Klein, *et al.*, *Average SCR flux during past 10^5 years: Inference from ^{41}Ca in lunar rock 74275*, Lunar Planet. Sci. **21**, 635-636 (1990)

Nishiizumi, *et al.*, *Depth profile of ^{41}Ca in the Apollo 15 long core*, Lunar Planet. Sci. **21**, 893-894 (1990).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Carleton B. Moore, Center for Meteorite Studies
(Name, Address, Arizona State University
Telephone Number) Tempe, AZ 85287-2504 (602) 965-3576

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: A PROGRAM TO CURATE, INVESTIGATE & DESCRIBE METEORITES

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) A major function of the Center for Meteorite Studies to prepare and provide samples for research continues to be important. To support this, investigations of the chemistry and mineralogy of meteorites are done to provide better base data. The Center also provides a very useful service to the meteoritic community by acquiring new specimens that will be made available to others under the conditions of our operating regulations.

b) In 1991, 269 specimens were provided to 73 investigators including NASA scientists and grantees.

Fifty-four specimens were transferred for destructive investigations, 27 were exchanges and 188 were loaned for study.

Twenty new specimens were acquired for collections. Of these, 11 were new previously not represented specimens.

The total number of meteorites falls/finds now represented in the Arizona State University collection is 1391.

c) We are continuing the development and testing of formic acid and other organic molecules in carbonaceous chondrites and in the K-T boundary samples. During 1992 a major effort will be made to publish much of the accumulated meteorite data we have. This will include data from two recent M.S. and Ph.D. theses on meteorites.

d) "The Cerro los Calvos and La Banderia Chondrites", Randall Whitlock, Charles F. Lewis, James C. Clark and Carleton B. Moore: METEORITICS, Vol. 26, #2, p. 169, 1991.

"Maralinga, A Metamorphosed Carbonaceous Chondrite Found In Australia", Lindsay P. Keller, James C. Clark, Charles F. Lewis and Carleton B. Moore: METEORITICS (in press), March 1992.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Richard V. Morris
Code SN4, NASA-JSC, Houston TX 77058
(713) 483-5040 or -5093

CO-INVESTIGATORS: None
(Name Only)

PROPOSAL TITLE: Mineralogy of the Martian Surface Based on Spectral, Magnetic, and Compositional Data

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"; c. brief listing of what will be done this year, as well as how and why; and d. publications relevant to the proposed work.)

a. The general objectives of this investigation are (1) to obtain spectral, magnetic, Mössbauer, XRD, and compositional data on synthetic, terrestrial analogue, and meteorite samples that are relevant to Mars, (2) to use these data, together with equivalent data for Mars, to infer the mineralogy of Martian surficial materials, and (3) to determine the time and type of weathering processes that modify the Martian surface. Weathering-derived mineralogies are important in constraining not only Martian soil-forming process but also climate and volatile evolution. Emphasis is placed on multidisciplinary analyses to provide different types of data for model definition and to maximize overlap with the data base available for Mars. Facilities include UV-VIS-IR spectroscopy, Mössbauer spectroscopy, magnetics, x-ray diffraction, FMR, and INAA.

b. Study of spectral, Mössbauer, and magnetic properties of nanophase hematite (np-Hm) was completed; evidence for hematite on Mars was presented. Study of effect of matrix properties on spectral data of np-Hm was completed. Projects on the effect of Al^{3+} and Mn^{3+} as substitutional impurities in ferric oxides were completed with a paper in press (for Al^{3+}) and a paper to be submitted (for Mn^{3+}). Similar projects involving Ti^{3+}, Ti^{4+}, and Cr^{3+} are underway. Three studies involving palagonites as Martian spectral and magnetic analogues were completed with the results published or submitted. Additional projects involving palagonitic soils are underway.

c. During this proposal period, we plan (1) to synthesize and to determine the physicochemical properties of nanophase goethite and ferrihydrites, (2) to complete studies of Ti and Cr substituted hematites and goethites, (3) to determine, with an emphasis on the techniques of soils science, the iron mineralogy of Martian spectral and magnetic analogues (Hawaiian palagonites and Brazilian magnetic soils), and (4) obtain Mössbauer and spectral data for SNC meteorites. As these studies are completed, the results will be submitted for publication.

d. 3 papers published; 2 papers in press; 2 papers submitted; 1 paper to be submittted; 24 abstracts published.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Alfred O.C. Nier, School of Physics and Astronomy,
(Name, Address, University of Minnesota, 116 Church St. S.E.,
Telephone Number) Minneapolis, MN 55455 (612) 624-6804

Co-INVESTIGATORS: --
(Name Only)

PROPOSAL TITLE: Anomalous Isotopic Abundances in Extraterrestrial 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 primary objective is to study helium and neon isotopic abundances in interplanetary dust particles with the hope that the results will shed light on the origin and history of the particles. Also of interest are helium isotopic ratios in other materials and anomalous mercury isotopic ratios in selected meteorites.

b. During the past year, a study of the removal by step-heating of helium and neon from 20 individual IDPs was completed. An investigation was initiated of the removal of gas by pulse-heating using pulses simulating the heat pulses experienced by IDPs in their deceleration in the earth's atmosphere. Results were obtained on 6 IDPs. A study of the removal by pulse-heating of helium and neon from lunar grains was instituted to see if the method had merit for distinguishing between solar wind and SEP implantation.

c. Continuation of pulse-heating experiments on IDPs and lunar grains. Also, a joi program with Don Brownlee of the University of Washington will be undertaken of the helium in extremely small IDPs (< 5 μm), since there is reason to believe such small particles suffer little heating in the atmosphere if they are of asteroidal origin. As a result of the improvements made in apparatus during the past year, a repeat of some of the earlier measurements on deep Pacific and native metal samples appears justified.

d. 1) Extraction of Helium from Individual Interplanetary Dust Particles by Step-Heating (In press, Meteoritics).

2) Helium Release from Interplanetary Dust Particles in Laboratory Studies Simulating the Hot Pulse Experienced by Particles during Atmospheric Entry (Abstract, LPSC, 1992).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Kunihiko Nishiizumi
Space Sciences Laboratory
University of California
Berkeley, California 94720
(510) 642-1374 (temporary)

CO-INVESTIGATORS: James R. Arnold
Masatake Honda
Robert C. Reedy

PROPOSAL TITLE: Historical Studies on Extraterrestrial Materials

ABSTRACT:

(a) Our program involves measurement of radionuclides produced by cosmic rays in extraterrestrial materials, with the goal of understanding the history of both the target (lunar rock or soil, meteorite, cosmic spherule or fragment) and the radiation (cosmic rays or solar flare particles). We measure long-lived radionuclides, with AMS collaborators (^{41}Ca, ^{36}Cl, ^{26}Al, ^{10}Be, ^{129}I) or by neutron activation (^{53}Mn). We can study events and periods on time scales comparable to the half-life of each species.

(b) This is a one-year proposal, following on a three-year grant, for a transition period at the end of which Dr. K. Nishiizumi will be the Principal Investigator. Significant achievements in the last year include (1) measurements on lunar meteorites, confirming that usually they have been ejected from the top few meters of regolith, (2) the first demonstration that non-magnetic Antarctic spherules are extraterrestrial, (3) exposure histories of Kapoeta, LEW88001 and Tsarev, (4) many terrestrial ages of meteorites -- Lewis Cliff objects are typically quite old, (5) large numbers of unpublished ^{10}Be, ^{26}Al, ^{36}Cl and ^{53}Mn meteorite data.

(c) In the coming year, with colleagues at AMS centers, we will continue measurement of cosmogenic nuclides in meteorites and Antarctic spherules. We hope to begin ^{59}Ni AMS measurements, and to make many more ^{41}Ca measurements, especially for terrestrial age work. We will complete our study of the depth profile in glass-covered lunar rock 64455. We will do depth variation studies in large objects to determine neutron capture profiles. A major ^{53}Mn run is planned at NIST.

(d) References

Nishiizumi, K., Arnold, J. R., Fink, D., Klein, J., Middleton, R., Brownlee, D. E. and Maurette, M., Exposure history of individual cosmic particles, *Earth Planet. Sci. Lett.*, *104*, 315-324, 1991.

Nishiizumi, K., Kohl, C. P., Shoemaker, E. M., Arnold, J. R., Klein, J., Fink, D. and Middleton, R., *In situ* ^{10}Be-^{26}Al exposure ages at Meteor Crater, Arizona, *Geochim. Cosmochim. Acta*, *55*, 2699-2703, 1991.

Nishiizumi, K., Arnold, J. R., Klein, J., Fink, D., Middliton, R., Kubik, P. W., Sharma, P., Elmore, D. and Reedy, R. C., Exposure histories of lunar meteorites: ALHA81005, MAC88104, MAC88105, and Yamato791197, *Geochim. Cosmochim. Acta*, *55*, 3149-3155, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Joseph A. Nuth
Code 691, NASA-GSFC
Greenbelt, MD 20771
(301) 286-9467

Co-INVESTIGATORS: Dr. Marla Moore
Dr. Robert Nelson
Dr. Ashraf Ali

PROPOSAL TITLE: Laboratory Studies of Pre-Solar Grain Analogs

a. We propose a comprehensive laboratory investigation of a number of processes which eventually determined the chemical and isotopic composition, morphology, crystal structure and spectral properties of solids in the pre-solar nebula. In particular we propose to use a differentially-pumped cluster beam system to study the precondensation cluster distribution of refractory vapors, a condensation-flow apparatus to study the nucleation, spectral properties and morphology of various refractory condensates as a function of C/O ratio in the vapor. We propose a study of the solar wind reduction of and hydrogen ion implantation into natural silicates to test the hypothesis that the SiH feature can be used as an indicator of the exposure age of asteroidal regolith. We will use a low temperature cryostat to study the spectra, crystal structure and morphology of refractory smokes and "ice" residues formed during irradiation. b. Over the last year we have investigated the effects of reaction kinetics on the morphology of grains condensed from mixed refractory vapors. We have found that the frequency of the SiH vibrational stretch can be used as an indicator of the oxidation state of the "silicate" lattice and that this might serve as a useful indicator of the length of time asteroidal surfaces have been exposed to the reducing effects of the solar wind. We have observed a unique property of very small iron grains which causes an extreme enhancement in their coagulation rate and morphology and have completed a series of experiments which show that Kr and Xe can be very effectively trapped in defect sites in amorphous silicates. c. We will begin a series of experiments to determine the equilibrium cluster distribution in mixed refractory vapors as a function of temperature. In addition we will begin a series of experiments to study the kinetics of the vapor-phase hydration of amorphous smokes, and another to understand the morphology and chemical composition of smokes formed in the Condensation Flow Apparatus as a function of the C/O ratio of the vapor. d. "The SiH stretch as an indicator of the oxidation state of silicon in a cometary or asteroidal regolith", J. A. Nuth, M. Moore and T. Tanabé, and G. Kraus, Icarus, submitted; "Supernovae as sources of interstellar diamond", J. A. Nuth and J. E. Allen, Astrophys. Space Sci., accepted; "Trapping of noble gases in proton-irradiated silicates smokes," R. H. Nichols, J. A. Nuth, C. M. Hohenberg, C. T. Olinger, and M. H. Moore, Meteoritics, submitted.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address,
Telephone Number)

Laurence E. Nyquist
SN4/NASA Johnson Space Center
Houston, TX, 77058
(713) 483-5038 FTS 525-5038

CO-INVESTIGATORS:
(Name only)

D. Bogard, C.-Y. Shih, G. McKay

TITLE:

Isotopic and Chemical Studies of Lunar and Planetary Evolution

ABSTRACT: (Paragraphs numbered (a) through (d) include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the past year; c. brief listing of what will be done this year; d. two recent publications relevant to the work.)

a. We will study the evolution of the moon and meteorite parent bodies as recorded in the isotopic compositions of Ca, Cr, Sr, and Nd. High precision Ca, Sr, and Nd isotopic analyses will determine the absolute ages and isotopic compositions of the sources of igneous rocks. The short-lived chronometers ^{146}Sm and ^{53}Mn will be used to resolve events occurring near the beginning of planetary evolution. Isotopic data will be combined with trace element abundances to constrain petrogenetic processes. Variations in Sm isotopic abundances will be applied to constrain the cosmic ray exposure histories of meteorites.

b. (i) We completed a review of the isotopic record of lunar volcanism which summarized areas of consensus and identified gaps in the lunar data base. The unusual isotopic systematics of Apollo 14 aluminous mare basalts were interpreted as suggestive of lunar crust/mantle mixing, possibly during a basin-forming impact. (ii) Rb-Sr and long- and short-lived Sm-Nd systematics of a eucrite clast from an Antarctic howardite showed it was derived from early volcanism on the HED parent body. Rb-Sr and ^{147}Sm-^{143}Nd internal isochron ages are concordant at ~4.52 Ga. ^{146}Sm was live when the clast crystallized with initial $^{146}Sm/^{144}Sm$ = 0.0073±0.0015. These age and $^{146}Sm/^{144}Sm$ values are consistent with solar system initial $^{146}Sm/^{144}Sm$ ~0.008. (iii) Small, but resolved, anomalies in ^{142}Nd were found for SNC meteorites and lunar basalts. These anomalies appear to be inherited from the mantle sources of the basalts and to reflect Sm-Nd partitioning during primary igneous differentiation of Mars(?) and the moon. (iv) The K-Ca chronometer was applied to lunar granites to determine their ages and the K/Ca ratio of their source materials. (v) Evidence for live ^{53}Mn was found in a "primitive" achondrite, suggesting Cr-isotopic closure ~17 Ma after formation of Allende inclusions. These analyses are continuing.

c. (i) The Rb-Sr and Sm-Nd methods will be applied to (a) eucrite clasts in howardites and polymict eucrites, (b) angrites, (c) shergottites, (d) lunar norites and anorthositic norites. (ii) The K-Ca method will be applied to additional lunar granites. (iii) The ^{146}Sm and ^{53}Mn short-lived chronometers will be applied to angrites, primitive achondrites, and eucrite clasts from HED meteorites. (iv) High precision $^{142}Nd/^{144}Nd$ measurements will be applied to obtain a record of lunar and martian(?) differentiation.

d. (i) Nyquist, L.E. and Shih, C.-Y. (1992) GCA (in press) (ii) Shih, C.-Y. et al. (1992) EPSL 108, 203-215. (iii) Nyquist L.E. et al. (1992) LPSC XXIII, 1009-1010.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Edward J. Olsen
(Name, Address, Dept. of Geophys. Sci., 5734 S. Ellis, Univ. of Chicago, Chicago, IL 60637
Telephone Number) 312-702-8164

Co-INVESTIGATORS: Andrew M. Davis
(Name only)

PROPOSAL TITLE: Trace element and isotope studies in oxide/phosphate/silicate inclusions of iron meteorites

ABSTRACT: 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. It is proposed to continue study of oxide/phosphate/silicate inclusions in the iron meteorites by the multiple approach which has provided quite good results for the past three years: petrography, SEM, electron microprobe, ion microprobe, oxygen isotope analyses, image analyses, x-ray diffraction.

b. We have found the first occurrence of a silicate inclusion in a IIIAB (Puente del Zacate, IIIA) iron; the silicate rock appears to be unique in terms of its oxygen isotope composition, mineral compositions and REE pattern. We have determined that phosphate phases in the pallasites exhibit two kinds of REE patterns; one is a primary igneous pattern, the other is a subsolidus reaction pattern. We have determined that phosphate phases in many IIIAB irons have excesses of radiogenic ^{53}Cr correlated with their Mn/Cr ratios, that the spread in the values of the excesses indicates a 6 m.y. differential in the formation interval among them, and that core formation was completed within less than 30 m.y. We have completed work on a unique new IIE iron, Watson, that provides a petrological link between the chondrule-bearing silicates in Netschaëvo (IIE ANOM) and those IIE irons with fractionated globular silicate inclusions such as Kodaikanal, Weekeroo Station and Elga.

c. We propose to examine additional specimens of the IIIA Puente del Zacate to locate other samples of the silicate rock included in it. We propose to examine all remaining pallasites we can obtain to determine if the two observed REE patterns characterize all pallasites, and to determine the implications of this for the genesis of pallasites and the related IIIAB irons. We propose to continue our search for ^{53}Cr excesses to determine the time frame for the formation of the core bodies and core-mantle boundary pallasites in the parent body. We propose to extend this research to some members of other irons groups, IAB, IIC, IICD, IIE, IVA, IVBD, IRANOM, for which we already have samples available.

d. "Phosphates in pallasite meteorites as probes of mantle processes in small planetary bodies", *Nature* v.353, 637-640.

PROPOSAL SUMMARY

PRINCIPAL INGESTIGATOR: J.J. Papike
(Name, Address, Telephone Number) Institute of Meteoritics/Dept. of Geology
Univ. of New Mexico, Alb, NM 87131

Co-INVESTIGATORS: A. Brearley R. Jones G. Layne
(Name Only) C. Shearer M. Spilde

PROPOSAL TITLE: Microbeam Studies of Planetary 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) SIMS and PIXE studies of lunar volcanic glass beads are used to determine details of lunar volcanic processes and the nature and compositional variability of the lunar mantle. Volatile trace elements (e.g. Zn, Cu, Pb) will be emphasized in addition to F, Cl, B and Be. SIMS analyses of silicates in achondritic meteorites will be used to interpret fractionation processes, crystallization kinetics and variability of source regions. EPMA and TEM studies of chondrule, matrix and isolated grains in chondritic meteorites are directed towards understanding nebular and parent body processes.
(b) SIMS trace element results demonstrate that most of the lunar volcanic glass beads are unrelated by fractional crystallization to sampled mare basalts. A substantial KREEP component occurs in many of the picritic glasses. Trace element studies of achondrites have been used to examine mantle processes in the EPB and crystallization processes in the Zagami shergottite. TEM and EPMA studies of CI and CM chondrites suggest that aqueous alteration is more likely to have taken place in the parent bodies than in the nebula. EPMA analysis of isolated olivine grains in CO3 chondrites shows that they are strongly related to chondrules, and that thermal metamorphism in this chondrite group occurred *in situ* on the parent body.
(c) SIMS and PIXE techniques will be developed and applied for analyses of Zn, Cu, Pb, Ni, Ga, B, Be, F and Cl in lunar glasses. Trace element analyses of silicates in HED meteorites will continue. Studies of aqueous alteration and matrix mineralogy of carbonaceous, ordinary and unique chondrites will also continue. Properties of pyroxene in ordinary chondrites will be examined, to interpret chondrule formation and metamorphism processes. A petrographic study of a suite of chondrules from Mokoia (CV3) will be initiated.
(d) (1) Brearley et al. (1991) Meteoritics 26, 287-300 (2) Jones and Rubie (1991) EPSL 106, 73-86 (3) Jones (1992) GCA 56, 467-482 (4) McCoy et al (1991) Meteoritics 26, 301-310 (5) McCoy et al (1991) GCA 55, 601-609 (6) McKay et al (1991) Lunar Sourcebook, 285-356 (7) Papike et al (1991) Lunar Sourcebook, 121-181 (8) Shearer et al (1991) EPSL 102, 134-147.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael J. Pellin
Chemistry/Materials Science Divisions
Argonne National Laboratory
Argonne, Illinois 60439
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CO-INVESTIGATORS: Charles E. Young
Wallis F. Calaway

TITLE: Isotopic and Trace Analysis of Meteoritic Samples Using Resonance Ionization Mass Spectrometry

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of 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 work is to develop instrumentation capable of exploiting the tremendous increases in detection sensitivity available by resonant laser ionization of neutral atoms from surfaces following energetic ion bombardment. Resonant laser ionization can be both efficient and discriminative, allowing complete ionization of the dominant neutral channel for trace atoms while discriminating against backgrounds of bulk atoms by factors in excess of 10^{10}. Instrumentation, utilizing resonant ionization of sputtered atoms, has been under intensive development for the last nine years. This work has resulted in the SARISA IV instrument which takes advantage of a sophisticated energy- and angle-refocusing time-of-flight mass spectrometer to combine useful yields in excess of 5% with detection sensitivities of less than 100 ppt.

(b) During the past nine months, the ability of the SARISA IV instrument to make sensitive, precise isotopic measurements of planetary samples (Ti anomalies in meteoritic hibonite grains) has been demonstrated. In this process, the instrument has been significantly upgraded and new methodologies for laser excitation and data collection have been developed that significantly extend the precision possible with laser-based methods. These improvements also demonstrate that insulating oxide materials can be investigated.

(c) We shall continue to develop RIMS for cosmochemical problems working with our collaborators at the University of Chicago. These improvements will include a submicron resolution sample viewing system and an improved microprobe capability. We shall investigate isotopic anamolies in refractory elements in interstellar diamond and silicon carbide. These studies will employ the high useful yields of the RIMS instrumentation to extend isotopic studies to minor and trace elements that have not been investigated previously.

(d) THREE-COLOR RESONANCE IONIZATION OF Ti SPUTTERED FROM METAL AND OXIDES FOR COSMOCHEMICAL ANALYSES: MEASUREMENTS OF SELECTIVITY AND ISOTOPIC ANOMALIES
D. R. Spiegel, W. F. Calaway, A. M. Davis, J. W. Burnett, M. J. Pellin, S. R. Coon, C. E. Young, R. N. Clayton, and D. M. Gruen, Analytical Chemistry, **64,** 469-475 (1992).
MICROBEAM TITANIUM ISOTOPIC ANALYSIS BY RESONANCE IONIZATION MASS SPECTROMETRY
D. R. Spiegel, M. J. Pellin, W. F. Calaway, J. W. Burnett, S. R. Coon, C. E. Young, D. M. Gruen, A. M. Davis, and R. N. Clayton, Lunar and Planetary Science Conference XXII, 1303-1304 (1991).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert O. Pepin
(Name, Address, Telephone Number) School of Physics and Astronomy
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Co-INVESTIGATORS: Richard H. Becker
(Name Only)

PROPOSAL TITLE: Rare Gas and Nitrogen Studies on Lunar, Meteoritic, and Selected Terrestrial 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) Research objectives are to determine distributions, compositions, and origins of noble gas and nitrogen isotopes implanted in lunar and asteroid regolith grains by solar ion irradiation, trapped in meteoritic carrier phases, or dissolved in mantle-derived terrestrial minerals. The work relates in general to the compositions of solar wind and flares, the sun, and the early solar nebula, to the origin and evolution of volatiles in meteorites and in planetary atmospheres and interiors, and to processes of fractionation and mixing leading to elemental and isotopic evolution in solar system volatile reservoirs through time.

(b) During the past year, we have [1] applied closed-system acid etching techniques to examine implanted solar wind gas distributions in bulk samples of lunar soil 67701 and sized plagioclase separates of 60051, and found that diffusive losses of light SW noble gases from plagioclase are very large, even for grains with apparently recent and simple irradiation histories; [2] continued and extended measurements, in collaboration with T. Ahrens at CalTech, of shock devolatilization of noble gases, hydrogen and carbon from carbonaceous chondrite material, finding evidence for differential volatile release depending on the physical properties of their host phases; and [3] shown that noble gases in the present atmospheres of Earth and Venus could have evolved from compositionally identical primary atmospheres on the two planets if Earth experienced an episode of hydrodynamic loss driven by giant impact.

(c) We propose as primary tasks to continue experimental studies of the solar wind record in lunar and meteoritic regolith materials, emphasizing utilization of acid etching techniques for high-depth-resolution extraction of implanted solar particle components from separated mineral grains; to address the question of impact-degassing of planetesimals via a continuing collaborative investigation of laboratory shock-induced release of volatiles from meteoritic materials; to apply these and other data to infer the composition of primordial solar-system volatile reservoirs and the evolution of contemporary reservoirs from them; and to initiate smaller-scale projects such as measurement of nitrogen and noble gases in the glassy phase of the LEW 88516 shergottite in search of signatures of trapped martian atmospheric gases.

(d) P. E. Rider *et al.* (1992), in *Lunar and Planetary Science* **XXIII**, 1149-50; T. J. Ahrens *et al.* (1992), in *Lunar and Planetary Science* **XXIII**, 3-4; Pepin, R. O. (1992), Origin of noble gases in the terrestrial planets, *Annu. Rev. Earth Planet. Sci.* **20**, 389-430.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William C. Phinney
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PROPOSAL TITLE: Early Evolution of Planetary Crusts

ABSTRACT:

a. The primary objective of this proposal is to continue our efforts to understand the early evolution of planetary crusts. Major investigations include: 1) the use of minor and trace elements in minerals to deduce the petrogenesis of lunar crustal rocks and their terrestrial counterparts, 2) the influence of pressure on calcic plagioclase stability in melts associated with calcic anorthosites and magma ocean evolution, and 3) the role of basaltic dike swarms in the thermal and mechanical evolution of stable crusts.

b. Accomplishments of the past year: 1.) Completion and publication of studies of partition coefficients for FeO between natural calcic plagioclase and basaltic melts as a function of oxygen fugacity. The results were applied to terrestrial Archean anorthosites and corroborate earlier suggestions that they formed under conditions of the quartz-fayalite-magnetite oxygen buffer. However, attempts to apply the results to lunar anorthosites produce unreasonable melts reflecting the effects of recrystallization of the anorthosites during early evolution of the lunar crust. 2.) Compilation of several hundred analyses of minerals from lunar crustal rocks. A study of the partitioning of elements between the minerals indicates that Cr, Mn and Ti have been significantly redistributed in olivine, some pyroxenes and plagioclase of lunar anorthosites, troctolites and norites during the early high temperature metamorphism of the lunar crust and are not useable for models of igneous petrogenesis. 3.) Completion of the analyses and preliminary petrogenetic modeling of the giant swarm of Matachewan dikes in Ontario. The results indicate a complex multistage evolution involving assimilation of a wide variety of materials at depth and replenishment in magma chambers at shallow levels, thereby rendering rather unacceptable the concept of simple lateral intrusion of the dikes at shallow depths. A hot spot, or plume, having a diameter of nearly 1000km with ascending dikes over an extensive area is the favored model. 4.) Completion of a set of initial experiments at 10 kilobars for a tholeiitic basalt to determine the sequence of phase relations from liquidus to solidus.

c. Proposed work includes: 1.) analyses of minor and trace elements in plagioclase and other phases in early lunar crustal rocks and terrestrial rocks to deduce which samples can be used to model the petrogenesis of lunar crustal rocks and their terrestrial counterparts, 2) experimental studies of the influence of pressure on calcic plagioclase stability in melts associated with calcic anorthosites, and 3) preparation of a paper on the use of analyses of suites of basaltic dikes and their petrogenetic models to deduce the role of basaltic dike swarms in the thermal and mechanical evolution of stable crusts.

d. Recent publications: Phinney, W.C. (1991) Lunar anorthosites, their equilibrium melts and the bulk moon. In: Proc. 21st Lunar Planet. Sci. Conf., p.29-49, Lunar Planetary Inst., Houston. Phinney, W.C. (1992) Partition coefficients for iron between plagioclase and basalt as a function of oxygen fugacity: Implications for Archean and lunar anorthosites. Geochim Cosmochim Acta, v. 55, May issue. Also 5 abstracts.

PROPOSAL SUMMARY

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

TITLE: Mineralogy of Lunar Materials from Reflectance Spectroscopy
NAG9-184

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) Laboratory analyses of the spectral properties of lunar samples provide the foundation for a strategy to explore and evaluate the composition of the Moon using advanced remote sensors, such as those envisioned to be flown later this decade. The focus of the research program described here is the measurement and analysis of spectral properties of lunar materials. Visible and near-IR reflectance spectra (0.3 to 2.7 μm) of lunar samples are obtained using RELAB bidirectional spectrometer (a high precision, high spatial and spectral resolution reflectance spectrometer which mimics the geometry of measurements made from remote sensors), and a Nicolet FTIR spectrometer to obtain coordinated mid-IR spectra (1.0 to 25μm). A primary analysis goal is to develop the capability to extract quantified compositional information from reflectance spectra of complex lunar materials in a form that is useful to lunar geochemists and geologists and that can be used to address lunar science and exploration issues.
b) Bi-directional reflectance measurements over a range of geometric configurations were completed for mature soils 10084, 12070, 14259, and 62231. The initial phase of a collaborative effort to derive full photometric parameters for lunar materials using these data is near completion and will be submitted for publication. Initial mid-infrared spectra (1.0 - 25 μm) were successfully obtained for two lunar samples. Most efforts concentrated on analyses of the optical properties of alteration and alteration products. Spectra of agglutinates and size separates of Apollo mature soil 10084 were obtained and exhibit several unexpected properties. It appears the finest fraction of the soil (<25μm, which accounts for ~25 wt %) rather than the agglutinates (~50+ wt%) carries the component(s) responsible for the distinctive 'red' sloped continuum of mature lunar soils. This undefined component of the fine fraction may also be responsible for the much of the decrease in strength of mafic absorption bands with maturity.
c) Three projects will be continued as minor efforts: photometric analysis of lunar materials, deconvolution and mixing analyses of lunar minerals and rocks, and mid-infrared measurement of lunar samples. Most of our efforts will be spent investigating alteration issues raised by the 10084 study and analyzing a suite of particle size separates from Luna 16, 20, and 24 soils in collaboration with scientists from Vernadsky Institute. Our objective is to identify the causes of optical alteration: darkening, reduction of absorptions, and creation of red continuum. Currently agglutinates, *per se*, can only account for the first and perhaps the second optical alteration effect.
d) **Pieters C.M.**, Pratt S., Hoffmann H., Helfenstein P., and Mustard J. (1991) Bidirectional Spectroscopy of Returned Lunar Soils: Detailed "Ground Truth" for Planetary Remote Sensors, *Lunar and Planet. Sci. XXII*, LPI, Houston. **Pieters C. M.**, E. Fischer, J. Mustard, S. Pratt, and A. Basu (1992) Spectral Properties of Agglutinate Separates from Soil 10084. *Lunar and Planet. Sci. XXIII*, LPI, Houston

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: FRANK A. PODOSEK; McDonnell Center for the Space Sciences
(Name, Address, Telephone Number) Washington University, St. Louis, MO 63130
314-935-6204

Co-INVESTIGATORS: Joyce C. Brannon
(Name Only)

PROPOSAL TITLE: Isotopic structures and fine-scale chronology in planetary 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) Our basic objective is an improved understanding of processes and conditions involved in the formation and early evolution of the solar system. We address this objective experimentally through isotopic analyses of planetary materials, primarily meteorites, which provide high resolution chronological constraints and characterization of pre-solar history and early solar system processes.

(b) We have begun the study of the Rb-Sr system, in conjunction with Al-Mg and petrographic studies, of CAIs in Leoville; in two of three CAIs elevated initial $^{87}Sr/^{86}Sr$ suggests formation several Ma after Allende CAIs, a timescale incompatible with observations of ^{26}Al in the same inclusions. We have completed the first phase of our study of the Rb-Sr in individual oldhamite and djerfisherite grains from unequilibrated enstatite chondrites, from which it appears that parent body activity continued on a time-scale much longer than previously expected. We have examined Cr isotopic compositions in a suite of unusual spinels from Murchison for which very large Cr isotopic anomalies have been reported; our results indicate normal composition within limits substantially smaller than the claimed anomalies.

(c) We will continue the study of initial $^{87}Sr/^{86}Sr$ in CAIs and include analyses of unspiked Sr to check on the possibility that chronologic interpretations are complicated by isotopic anomalies; we will also examine Sr in Murchison inclusions of the type which led to the suggestion of grossly heterogeneous distribution of ^{26}Al. Our studies of enstatite chondrite chronology by individual mineral grains will be extended to additional EH3 and EL3 chondrites. We will examine the Sr isotopic system in size-separated fractions of metal from Ste. Marguerite and explore its implications for early solar system chronology. We will perform more precise Cr isotopic analyses of the unusual Murchison spinels to determine whether they have even the "endemic" isotopic effects of typical CAI spinels. We expect delivery of a new thermal ionization mass spectrometer in the summer of 1992 and we will bring this machine on line to significantly enhance our capabilities for planetary material research.

(d) Podosek *et al* (1991a) GCA 55, 1083-1110 (see Appendix)
Podosek *et al* (1991b) Meteoritics 26, 385 (see Appendix)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Ronald G. Prinn
Department of Earth, Atmospheric & Planetary Sciences
MIT, Bldg. 54-1312
Cambridge, MA 02139
(617) 253-2452

TITLE: Non-equilibrium chemistry of the early solar system

ABSTRACT: 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 this proposed work.

(a) This proposal addresses theoretical studies of non-equilibrium (kinetic inhibition) chemical processes in the solar nebula and early solar system. My major objectives are to understand the important non-equilibrium chemical processes in the solar nebula and early solar system and to incorporate them into a holistic model of the origin of the solar system. (b) Prinn (1992) computes eddy mixing velocities in the solar nebula forced by accretion to be up to 1% of the sound speed yielding mixing times for trace chemicals as short as 300 years. He also addresses models for the ice-to-rock ratio in outer-planet satellites in light of the differing cosmic abundances of C and O deduced by Cameron (1982) and Anders and Grevesse (1989). Prinn (1990) pointed out the role of nonaxisymetric accretion as a mechanism for nonlinear momentum transport and for inducing significant mixing in the solar nebula. Prinn and Fegley (1989) modeled non-equilibrium chemistry of H, C, N, O compounds in the solar nebula. They showed that certain volatile ratios (e.g. CO/CH_4, N_2/NH_3, H_2O ice/silicate) are potentially diagnostic of the origin of ice-rich bodies. They also theoretically studied the kinetics of gas-grain reactions in the solar nebula. They showed that the formation of hydrated silicates and of FeO-rich silicates are kinetically inhibited in the solar nebula. They also showed that some gas-grain reactions (e.g., FeS formation) are kinetically facile while some others (e.g., Fe_3O_4 formations) are borderline cases. (c) I will carry out a critical study of recent evidence for and against the Prinn and Fegley (1987) hypothesis for acid rain following large asteroidal or cometary collisions. I will incorporate considerations of interstellar as well as solar nebula material in my nebular models. I will continue studies of proto-solar uv (innermost dust-free nebular regions) and of interstellar uv (nebular skin and outermost nebular regions) as drivers of photochemical reactions. I will continue studying important non-equilibrium effects relevant to volatile retention (e.g., H_2O, FeO, S, P) by solid grains in the solar nebula. (d) Prinn (1992) in *Protostars and Protoplanets III*, Univ. of AZ press, in press; Prinn (1990) *Astrophys. J.* **348**, 725-729; Prinn and Fegley (1989) in *Planetary and Satellite Atmospheres: Origin and Evolution*, Univ. of AZ press, p. 78-136; Fegley and Prinn (1989) in *The Formation and Evolution of Planetary Systems*, Camb. Univ. Press, p. 171-211; Fegley and Prinn (1991) in *Interaction of the Solid Planet with the Atmosphere and Climate*, Gordon and Breach, in press.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Martin Prinz
(Name, Address, Telephone Number) American Museum of Natural History
New York, NY 10024-5192, 212-769-5381

Co-INVESTIGATORS: Michael K. Weisberg, C.E. Nehru
(Name Only)

PROPOSAL TITLE: Petrologic-Geochemical Studies of Meteorites

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 research program consists of problem-oriented petrologic and consortia studies of specific meteorites or groups to gain a better understanding of early nebular and planetary formational processes.

B. Projects completed and/or in progress include: (1) Enstatite chondrites. FeO-rich silicates in E3 chondrites, reduced along fractures and twin planes, and rimmed by pure En, were probably major components in the early history of E chondrites. (2) Acfer 182/207 chondrite is a new ALH85085-type. Compared to 85085 it shows many similarities, but important differences such as larger chondrule size, more variable textures, more oxidized compositions, and presence of hydrous matrix lumps and matrix coexisting with anhydrous chondrules. The unusual metal composition is similar. (3) Antarctic Micrometeorites. Micrometeorites were collected by Maurette by melting 100 tons of Antarctic ice. The micrometeorites are all relatively similar, consist mainly of hydrated matrix, and while similar to CM chondrites, appear to be unique. Atmospheric entry effects were studied by SXRF (with S. Sutton) and found to be complex and similar to that in IDP's. (4) Semarkona Chondrules. Work with D. Sears group on these chondrules was completed. Four chondrule groups were discerned and an origin for certain types of chondrules was formulated. (5) CR2 Chondrites. Work was completed on all CR2 chondrites and a ms. completed. Dark inclusions were studied (with M. Zolensky) and found to be more hydrous than host matrix.

C. Projects proposed for petrologic and consortia studies include: (1) Enstatite Chondrites. We shall study mineralogic relations of oxidation and reduction using CL techniques. The early history of E3 chondrites will be explored. (2) Acfer 182 and LEW85332. Both are ALH85085-type chondrites with hydrous matrix and anhydrous chondrules. Their history will be further explored with detailed petrologic and consortia studies (ion probe, SXRF, stable isotopes). (3) Unusual Chondrites. Ningqiang and LEW90500 are unusual and require better understanding of parent body vs. nebular processes. Other unusual chondrites will also be studied. (4) CAI's will be studied in CR, CK and unusual carbonaceous chondrites, using CL and ion probe techniques. (5) Antarctic Micrometeorites will be studied further. (6) Brachinites and other primitive achondrites will be studied petrologically and in consortia. Their relationships to one another and/or HED meteorites will be explored. (7) Matrix and Unusual Clasts of all types will be studied to determine their relationship to known chondritic groups and/or to micrometeorites and IDP's. (8) CR2 chondrites. Layered chondrules, metal and dark inclusions will be studied in greater detail to further our understanding of nebular processes.

D. (1) Brearley, A. and Prinz, M. (1992) CI chondrite-like clasts in the Nilpena polymict ureilite. GCA 56, 1373-1386. (2) Weisberg, M. et al. (1992) The CR2 carbonaceous chondrite group and its implications. GCA (Submitted).

PROPOSAL SUMMARY

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CO-INVESTIGATOR: Jozef Masarik

EXTRATERRESTRIAL STUDIES USING NUCLEAR INTERACTIONS

ABSTRACT:

a. *Objectives*: Cosmic-ray-induced nuclear interactions are studied and used to investigate the history of meteorites, cosmic dust, lunar samples, the Sun, and cosmic rays.

b. *Some recent accomplishments*: (1) Improved models were developed for cosmogenic-nuclide production rates in large meteoroids. (2) Measured profile of ^{14}C in lunar rock 68815 was compared with those from several cores and used to determine the fluxes of solar protons over the last $\sim 10^4$ years. (3) New ^{10}Be cross sections imply that the old solar-proton production rates were good, confirming earlier estimates that the solar-proton spectrum averaged over the past 10^6 years was not hard. (4) Production rates for stable isotopes of neon and argon show that these isotopes can be used to determine solar-proton fluxes and spectral shapes. (5) Fluxes of modern solar protons were evaluated and are similar to average fluxes recently inferred from nuclides measured in lunar samples.

c. *Plans*: (1) Study the cosmic-ray histories of small and large meteorites and of various meteorite classes, especially SNCs, lunar meteorites, and certain achondrites. (2) Apply Monte Carlo codes to calculate the products of cosmic-ray interactions in meteorites and the Moon. (3) Derive improved production rates of cosmogenic nuclides, including models for very small and large meteorites, nonspherical meteoroids, iron meteorites, and volatile-rich material; and study the effects of bulk composition on cosmogenic-nuclide production systematics. (4) Work on determining fluxes of solar cosmic rays over the past few decades and last several million years. (5) Collaborate with others on comparing cosmogenic-nuclide production rates calculated with various models.

d. *Some recent publications*: (1) R. C. Reedy and K. Marti, "Solar-Cosmic-Ray Fluxes During the Last Ten Million Years," in *The Sun in Time* (C. P. Sonett, M. S. Giampapa, and M. S. Matthews, Eds.), Univ. of Arizona Press, Tucson, pp. 260–287, 1991. (2) K. Nishiizumi, J. R. Arnold, J. Klein, D. Fink, R. Middleton, P. W. Kubik, P. Sharma, D. Elmore, and R. C. Reedy, "Exposure Histories of Lunar Meteorites: ALHA81005, MAC88104, MAC88105, and Yamato 791197," *Geochim. Cosmochim. Acta*, **55**, 3149–3155, 1991. (3) D. S. McKay, G. Heiken, A. Basu, G. Blanford, S. Simon, R. Reedy, B. M. French, and J. Papike, "The Lunar Regolith," in *The Lunar Sourcebook* (G. H. Heiken, D. T. Vaniman, and B. M. French, Eds.). Lunar & Planetary Institute and Cambridge Press, pp. 285–356, 1991. (4) J. Masarik, P. Chochula, and P. Povinec, "Model for Calculation of Production Rates of Cosmogenic Nuclides in Extraterrestrial Bodies," *J. Phys. G: Nucl. Part. Phys.*, **17**, S493–S504, 1991.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Arch Reid
(Name, Address, Telephone Number) Department of Geosciences
University of Houston, Houston TX 77204-5503
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Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: EUCRITES, HOWARDITES AND CV CHONDRITES

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 objectives of this investigation are to study the nature of lithic clasts and matrices in howardites and polymict eucrites as guides to the magmatic evolution of the HED parent body and to the origin and evolution of components of achondrite regoliths. Immediate objectives are an expansion of the program to include clasts from other Antarctic and non-Antarctic HED meteorites and their matrix minerals; modeling of the petrogenetic relationships among the eucrite types we have recognized; experimental duplication of eucrite thermal histories; and the study of carbonaceous chondrite clasts in HED meteorites and of 'basaltic' clasts in CV carbonaceous chondrites.

b)A petrologic study of the Antarctic achondrites EET87509, EET87513, and EET87531 has shown the presence of a diverse group of eucrite and diogenite clasts. The eucrite clasts display a range of compositions with several that are intermediate beween diogenite and common eucrite. The intermediate eucrites include both equilibrated (trend A) and unequilibrated (trend B) varieties. Correlation of matrix pyroxene data from 10 Antarctic polymict eucrites and howardites, and the meteorites Bholghati, Brient, Nobleborough, and Petersburg, with mineral data from separated clasts, has allowed estimates of the nature and proportions of clast types contributing to the individual HED regolith samples. Examination of carbonaceous clasts in Antarctic HED meteorites has provided temperature constraints on regolith evolution after aggregation.

c)In the coming year we plan to expand the detailed clast studies to additional achondrites, using surveys of matrix mineral compositions as guides to nature of the components present; to model the relationships among the eucrites utilizing the data from the intermediate clasts; to examine in detail the nature and composition of matrix and clast pyroxenes as indicators of thermal annealing; and to attempt to duplicate in the laboratory the primary characteristics of eucrites and examine the effects of limited high temperature annealing. We also plan petrographic and mineralogical analysis of selected carbonaceous clasts in HED meteorites and of 'basaltic' clasts in CV carbonaceous chondrites.

d)Reid A.M., Buchanan P.C., Zolensky M.E. and Barrett R.A.: The Bholghati howardite: petrography and mineral chemistry. Geochim. Cosmochim. Acta, 54, 2161-2166, 1990. Buchanan P.C. and Reid A.M.: Eucrite and diogenite clasts in three Antarctic achondrites. LPSC 1991. Buchanan P.C. and Reid A.M.: Matrix pyroxenes in howardites and polymict eucrites, LPSC 1992. Reid AM., Jakes P, Zolensky M.E. and Miller R.M.: Three new chondrites from Namibia, LPSC 1992. Jakes P., Reid A.M. and Casanova I.: Excess heat and early planet evolution, LPSC 1992. Jakes P., Sen S., Matsuishi K., Reid A.M., King E.A. and Casanova I.: Silicate melts at super liquidus temperatures: reduction and volatilization, LPSC 1992.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Frans J.M. Rietmeijer
(Name, Address, Telephone Number) Department of Geology, University of New Mexico, Albuquerque, NM 87131; (505) 277 - 4204

Co-INVESTIGATORS: none
(Name Only)

PROPOSAL TITLE: Layer silicates and Carbonaceous Materials in Chondritic Porous Interplanetary 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. The primary aim of this research is characterisation of layer silicates and carbons, and their interrelationships in ultrafine-grained chondritic porous [CP] interplanetary dust particles [IDPs]. The mineralogy and petrological assemblages in these most primitive Solar System materials are evidence for the important mineral reactions during solar nebula accretion and protoplanet diagenesis. Both layer silicates and carbons are common to all primitive fine-grained extraterrestrial materials which suggest an intimate interrelationships among these materials in the early solar system. Analytical electron microscopy [AEM] is well suited for *in situ* microstructural and chemical characterisation of crystalline and amorphous areas < 100nm in size which is on the scale of CP IDP minerals. The AEM characterisation of layer silicates and carbons in CP IDPs provide the data to constrain the physico-chemical environments of early Solar System processes.
b. In the prior year AEM analyses of CP IDPs W7029E5, U2011C2 & U2022C7/C8 were completed and full AEM characterisation was obtained for iron-rich chondritic IDPs L2005T12L, 2005T13 & L2005U6 and nonchondritic low-nickel IDPs L2001-18, L2001-20, L2002*C2 & L2004-3. These analyses provide new data on layer silicate and carbon mineralogy, dynamic pyrometamorphism during atmospheric entry heating and identified the mineralogy of a rare iron-rich IDP of the type CM meteorite petrogenesis.
c. Continue AEM analyses of serial ultrathin sections of large CP IDPs from the JSC Cosmic Dust Collection to determine the interrelationships and interactions among layer silicates and carbons in an effort to define the physico-chemical environment in primitive ultrafine-grained Solar System materials. This study will involve high resolution imaging and high spatially resolved in situ chemical analyses and fine-scale diffraction analyses. Emphasis is on constraining and developing models for the onset of mineralogical activity in the early Solar System.
d. Rietmeijer FJM, Aqueous alteration in five chondritic porous interplanetary dust particles, *Earth Planet. Sci. Lett. 102*, 148, 1991; Rietmeijer FJM, Pregraphitic and poorly graphitised carbons in porous chondritic micrometeorites, *Geochim. Cosmochim. Acta* 56, in press, 1992; Rietmeijer FJM, A detailed petrological analysis of hydrated, low-nickel, nonchondritic stratospheric dust particles, *Proc. Lunar Planet. Sci. 22*, 195-201, 1992

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Malcolm J. Rutherford
(Name, Address, Telephone Number) Department of Geological Sciences
Brown University Providence, RI 02912
401 863-3338

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: Experimental Study of Lunar and SNC Magmas: Role of Volatiles

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

a) The overall objectives of this research, which has been funded to begin about April 1 1992, remain the same: (1) to evaluate the role of C-reduction and S-loss models in the vesiculation, reduction and fire fountaining of lunar magmas by analyses of the lunar glass and spherules and by experimental determination of equilibrium abundances and diffusion of C and S species. (2) to determine possible primitive SNC magma compositions and evaluate P, T, X_{H_2O} etc conditions at which they crystallize to form the SNC meteorites.

b) Progress report for proposal to be funded approximately April 1, 1992. Writing and publication of research results obtained prior to 7/90 have been carried out over the past year.

c) Two research tasks are proposed. (1)(a) Primitive lunar volcanic glass samples have been requested and will be analyzed by F.T.I.R., EMP etc for C and S abundances across individual spherules, (b) Experiments on synthetic lunar glasses to determine C and S abundances as a function of P. (2)(a) It is proposed that the Chassigny parent magma be synthesized and the olivine saturated phase equilibria be determined dry and with 1 wt % water for pressures up to 5 kb. (b) Analytical work and experiments are proposed for EETA 79001A and ALHA 77005 analogous to the work completed on Chassigny.

(d)

--Johnson, M.C., Rutherford, M.J., and Hess, P.C., (1991) Chassigny Petrogenesis: Melt Composition, intensive parameters and water contents of Martian (?) magmas, Geochimica Cosmochimica Acta, 55, 349-366.

--Fogel, R.A., and Rutherford, M.J., (In Press); A hard-sphere equation of state for the C-O-H system: Theoretical foundations and application to graphite-fluid Equilibria, Contrib. Min. Pet.

--Rutherford, M.J., 1991, The abundances and role of H_2O in SNC (MARS) vs Earth and Moon magmatic processes. EOS, 74, 44, p281.

--Fogel, R.A. and Rutherford, M.J., 1992, C-O-S-Cl volatiles in primitive lunar glasses: FTIR and EM analyses of A15 green glass, LPSC XXIII.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Graham Ryder
(Name, Address, Telephone Number) Lunar and Planetary Institute
3600 Bay Area Blvd., Houston, TX 77058
713 486-2141

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE: EVOLUTION OF THE MOON: INSIDE AND OUT

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) Petrographic, chemical, and radiometric work is proposed, with the goal of better understanding the internal (magmatic) evolution of the Moon, the flux of impacting bodies in the 4.5 to 3.8 Ga period, and any relationships among the internal and external influences. Neither the endogenic nor exogenic histories are yet well understood, the first because it is complex and our samples poorly constrained and described, the second for similar reasons and because of the uncritical acceptance of assumptions and limitations of perceptions.

b) Ar analyses on A15 melt samples were completed; no melts older than 3.87 Ga were found. Petrographic and chemical work started on A17 melt and related samples, including a gabbro sample from 73155. A glass ball from A15 was dated at 1.6 Ga. The data was used to evaluate endogenic and exogenic influences on lunar evolution.

c) Analytical work on Apollo 17 samples, particularly 72255, 73155, and impact melts, as well as other samples, will continue. We will use the data to evaluate the structure and evolution of the lunar crust and the dating of its bombardment.

d) **Ryder G.** (1992) Chemical variation and zoning of olivine in lunar dunite 72415.. PLPS 22, 373. Dalrymple B.G. and **Ryder G.** (1991) 40Ar/39Ar ages of six Apollo 15 impact melt rocks....GRL 18, 1163. **Ryder G.** (1991) Lunar ferroan anorthosites and mare basalt sources: the mixed connection. GRL 18, 2065.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number) R.A. Schmitt
Depts. of Chemistry and Geosciences and the Radiation Center, Oregon State University, Corvallis, OR 97331-5903, (503) 737-7075

CO-INVESTIGATORS: (Name Only) Y.-G. Liu

PROPOSAL TITLE: Chemical Studies of Lunar, Meteoritic, and Terrestrial Samples

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

---

a. We propose to continue our collaboration with Dr. J.W. Delano (S.U.N.Y. Albany) for a study of lunar impact glasses, separated from a large variety of soils, deep-drill cores, and lunar meteorites in order to extend the selenochemical data on a regional and possibly global scale and to obtain better estimates of minor and trace elements in the bulk moon. To understand further lunar basalt petrogenesis, we propose to continue our collaboration with Drs. L.A. Taylor and C.R. Neal and study via EPMA, INAA, min-pet, radiogenic methods Apollo 11 and Apollo 12 mare basalts, and also basalts extracted from Apollo 11 and 12 breccias.

b. Accomplishments over the past year include the INAA of 28 Apollo 11 and 12 mare basalts, 31 moldavite tektites (lunar impact analogs), 3 MAC88105 lunar meteorites, and micro-diamond separates. Publications include 3 manuscripts and 9 L.P.S. XXIII two-page abstracts.

c. We will use INAA to determine ~32 major, minor, and trace elements (REE included) in individual lunar glasses, basaltic fragments, meteorites and terrestrial lunar analogs. EPMA and min-pet measurements will be done by our collaborators on the same lunar samples or aliquants.

d. Representative publications include: "Paired lunar meteorites MAC88104 and MAC88105: a new "FAN" of lunar petrology" Geochim. Cosmochim. Acta 55, 3037-3049 (1991) by C.R. Neal, L.A. Taylor, R.A. Schmitt, Y.-G. Liu, and J.O. Eckert; "Petrogenesis of the western highlands of the moon: evidence from a diverse group of whitlockite-rich rocks from the Fra-Mauro Formation" Proc. 22nd Lunar & Planet. Sci. Conf. (in press, 1992) by G.A. Synder, L.A. Taylor, Y.-G. Liu, and R.A. Schmitt.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Derek W.G. Sears
Dept. of Chemistry and Biochemistry
The University of Arkansas,
Fayetteville, AR 72701.
(501) 575 5204

CO-INVESTIGATOR: Dr. Paul Benoit

ABSTRACT: Chemical and Physical Studies of Extraterrestrial Material

a. **Objectives and Justification** We wish to explore the origin and history of a variety of extraterrestrial materials using thermoluminescence (TL), cathodoluminescence (CL), instrumental neutron activation analysis (INAA) and electron microprobe analysis (EMPA). The studies will help clarify our understanding of conditions in the early solar system.

b. **Prior Year.** We have (1) proposed a new classification scheme for chondrules in ordinary chondrites; (2) analyzed the especially significant group A chondrules from Semarkona by INAA and EMPA; (3) proposed a petrologic type scheme for eucrites, showed that the metamorphic temperatures for the 'unequilibrated eucrites' were <800°C and that the unusual shocked eucrite LEW85503 had experienced >1000°C; (4) showed that there is a relationship between the thermal properties of H5 chondrites produced by the 8 Ma break-up and time of fall on earth; (5) completed our first induced TL measurements on lunar whole-rocks and drill core samples; (6) assigned petrologic types to 12 new Antarctic and 39 Saharan type 3 ordinary chondrites; (7) confirmed the EL3 classification of three new Antarctic meteorites.

c. **Proposed Work.** We propose to (1) extend our INAA, petrologic and O isotopic studies of chondrules to Krymka and other primitive chondrites; (2) perform bulk analysis of type 3 enstatite chondrites and phases in them; (3) write up our induced TL studies of splits from the Elephant Moraine howardite (EET87513), the shocked eucrite (LEW85300) and Vaca Muerta; explore the metamorphic history of (4) CV chondrites and (5) type 3 ordinary chondrites using induced TL; (6) investigate the details of the break-up of the H chondrite parent body; (7) investigate the thermal history of lunar breccias.

d. **Publications** (1) Benoit & Sears, (1992) The breakup of a meteorite parent body and the delivery of meteorites to Earth. *Science* (in press). (2) Sears, Lu Jie, Benoit, DeHart & Lofgren (1992) A compositional classification scheme for meteoritic chondrules. *Nature* (in press). (3) DeHart, Lofgren, Lu Jie, Benoit & Sears (1992) CL and phase composition studies of chondrules. *Geochim. Cosmochim. Acta* (in press). (4) Batchelor & Sears (1991) *Geochim. Cosmochim. Acta* 55, 3831-3844. (5) Batchelor & Sears (1991) Nature 349, 516-519

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Derek W.G. Sears
Department of Chemistry and Biochemistry
University of Arkansas
Fayetteville, AR 72701
(501)-575-5204

CO-INVESTIGATOR: Paul H. Benoit

PROPOSAL TITLE: Natural thermoluminescence levels in Antarctic meteorites and related studies

ABSTRACT

a. Our objectives are to measure the natural thermoluminescence (TL) levels in as many Antarctic meteorites as possible, to make the data rapidly available to the community, and to investigate pairing, orbital distribution, terrestrial age, meteorites with unusual thermal and radiation histories, locate meteorites which are mineralogically unusual, and accumulation mechanisms and ice movement patterns. We also conduct similar studies on other types of extraterrestrial material, including non-Antarctic meteorites and lunar samples, in order to establish a database for comparison with the Antarctic meteorite data.

b. In the past year, we have (1) published data on 103 Antarctic meteorites and have almost completed measurements on an additional 25. (2) Conducted a systematic study of meteorite finds from the Prairie States, Roosevelt County, and Libya which shows good agreement between TL levels, TL theory and ^{14}C terrestrial ages. (3) Begun TL studies of modern falls, with particular interest in fine details in the recent radiation exposure histories of meteorites, and published a study of natural TL and orbits. (4) Begun studies of the variation of natural TL with depth in meteorites and other extraterrestrial materials.

c. We propose to (1) continue systematic measurement of the natural TL levels of all suitable Antarctic samples as part of their preliminary screening; (2) carry out further studies on pairing, terrestrial age, and ice movements at Elephant Moraine and several other sites based on such data; (3) carry out a detailed compilation of literature pairing data for Antarctic meteorites; (4) measure the TL of additional non-Antarctic meteorites in order to provide a larger comparison database for interpretation of such data from Antarctic meteorites and to study the recent radiation histories of modern falls (5) continue investigations into the TL depth profiles in meteorites; (6) continue collaborative studies with Cassidy's group on TL production systematics in meteorites with low ^{26}Al and other cosmogenic nuclides.

d. (1) P.H. Benoit, H. Sears, D.W.G. Sears,and J. Roth (1991,1992) *Antarctic Meteorite Newsletter*, 14(2), 14(3), 15(1).

(2) P.H. Benoit, D.W.G. Sears, and S.W.S. McKeever (1991) The natural thermoluminescence of meteorites - II. Meteorite orbits and orbital evolution. *Icarus* 94, 311-325.

(3) D.W.G. Sears, P.H. Benoit, H. Sears, J.D. Batchelor, and S. Symes (1991) The natural thermoluminescence of meteorites: III. Lunar and basaltic meteorites. *Geochim. Cosmochim. Acta* 55, 3167-3180.

(4) P.H. Benoit, H. Sears, and D.W.G. Sears (1992) The natural thermoluminescence of meteorites IV: Ordinary chondrites at the Lewis Cliff ice field. *J. Geophys. Res.* (in press).

(5) P.H. Benoit, H. Sears, and D.W.G. Sears (1992) The natural thermoluminescence of meteorites - V: Ordinary chondrites at the Allan Hills vicinity. *J. Geophys. Res.* (submitted).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. John W. Shervais
Department of Geological Sciences
University of South Carolina
Columbia, SC, 29208
(803) 777-4500

CO-INVESTIGATORS: Dr. S.K. Vetter

PROPOSAL TITLE: Basaltic Volcanism and Ancient 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. The objective of this proposal is to decipher the trace element characteristics and origin of the alkali and Mg suite parent magmas. These suites comprise most of the western highlands province, thus understanding their origin is crucial to understanding the origin of ancient planetary crusts and the chemical differentiation of terrestrial planets.

b. Last year we completed our investigation of KREEP basalt clasts in lunar breccia 15205, and began systematic major element analyses of Apollo 14 mare and highland samples which have already been analyzed for trace elements by INAA.

c. During the next grant cycle I will concentrate on trace element analysis of primocryst cores by SIMS, using the UNM/SNL Cameca IMS 4f ion probe. This will allow direct calculation of trace element concentrations in Mg suite and alkali suite parent magmas, and correlation of these concentrations with the major element characteristics of the magmas as inferred from electron microprobe studies of the same phases. We will also continue to analyze Apollo 14 samples for major element composition using fused bead EMPA; both new and previously analyzed (INAA) samples will be studied. New samples will be analyzed for trace elements by INAA before fused bead EMPA.

d. Shervais, J.W. and Vetter, S.K. (1992) Major element chemistry of apollo 14 mare basalt clasts and highland plutonic clasts from lunar breccia 14321: comparison with neutron activation results, LPS XXIII, LPI.
Vetter, S.K. and Shervais, J.W. (1992) Whole rock major element chemistry of kreep basalt clasts in lunar breccia 15205: implications for the petrogenesis of volcanic kreep basalts, LPS XXIII, LPI.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address, Telephone Number)

Haraldur Sigurdsson
Graduate School of Oceanography,
University of Rhode Island,
Narragansett, R.I. 02882-1197
401-792-6596

Co-INVESTIGATORS:
(Name Only)

Richard Turco, Steven Carey, Steven D'Hondt, Juan-Manuel Espindola

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

---

a. We propose to study the consequences of bolide impact on evaporite sediment terrane, the resulting degassing of sulfurous gases to the atmosphere, sulfuric acid aerosol formation and atmospheric and environmental effects. We also propose a study of the geochemical and sedimentologic features of the impact glass spherule deposit at the Cretaceous/Tertiary boundary in Haiti, in order to determine its mode of transport and deposition, and to model the dispersal of glass spherules from the impact site as ballistic ejecta and in thermal plumes. Geochemical evidence from high-sulfur impact glass spherules at the Cretaceous/Tertiary boundary shows that the bolide impact occurred on evaporite terrane, resulting in major emission of sulfur to the atmosphere. The resulting sulfuric acid aerosol and possible acid rain may have been key factors in the global extinction events associated with the bolide impact. The severity of the extinctions may thus be largely a function of the unusual geology of the target terrane.

b. New proposal.

c. During the first year we propose to determine experimentally the processes of degassing of anhydrite and gypsum sediments and the speciation of sulfur gases emitted. Calculation of sulfuric acid aerosol formation rates and distributions of the aerosols generated by massive sulfur injection associated with the impact will be done, on basis of the experimental data. Characteristics of the sulfur-rich glass spherules and other impact glass spherules in the Haiti deposit will be determined in terms of their sedimentology, in order to establish their transport and depositional processes. Modelling of ballistic trajectories and dispersal of impact glass ejecta will be performed in the first year also.

d.

Sigurdsson, H., S. D'Hondt, M.A. Arthur, T.J. Bralower, J.C.Zachos, M. Fossen & J.E.T. Channell, 1991a: Glass from the Cretaceous-Tertiary Boundary in Haiti. *Nature*. 349, 482-487.

Sigurdsson, H., Ph. Bonté, L. Turpin, M. Chaussidon, N. Metrich, M. Steinberg, Ph. Pradel & S. D'Hondt, 1991b: Geochemical Constraints on Source Region of Cretaceous/Tertiary Impact Glasses. *Nature*, 353, 839-842.

Sigurdsson, H., S. D'Hondt and S. Carey, 1992: The impact of the Cretaceous/Tertiary bolide on evaporite terrane and generation of major sulfuric acid aerosol. Earth Planet. Sci. Lett. (in press).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ian M. Steele
Department of the Geophysical Sciences
The University of Chicago
5734 S. Ellis Ave., Chicago IL 60637
(312)-702-8109

CO-INVESTIGATORS: Joseph V. Smith

TITLE: Mineralogy and Chemistry of Planets and Meteorites.

ABSTRACT:
(a) Mg-rich olivine should record a record of the conditions during which it formed and of subsequent process prior to incorporation into the meteorite body. Detailed chemical, isotopic, redox state, and textural analysis of the original forsterite and of the altered rims should provide evidence of these processes. Forsterite is emphasized as it is abundant in all extraterrestrial material, an early forming phase in any process, relatively resistant to alteration, and has a simple composition and structure. Data to date are consistent with growth under turbulent conditions culminating in modification of the grain rims mainly by diffusion in an Fe-rich environment prior to incorporation in the present meteorite.
(b) Chemical zoning at edges of isolated euhedral forsterites correlates with crystallographic direction and is consistent with diffusion modification of olivine. Sensitive measurements indicate that the Fe/Mn of minor element rich forsterite is near 140 compared to 80 in Allende suggesting a different process of formation. The Fe/Mn ratio should be a critical test of the equivalence of chondrule and isolated olivine as proposed in the literature. The crystal structure of stanfieldite is that of the synthetic analog although there is a possibility of cation ordering in the Fe rich mesosiderite stanfieldite. Olivine compositions of Antarctic micrometeorites resemble those of C2 olivine and not C3-UOC olivine.
(c) Zoning at the rims of forsterite grains will be compared with similar zoning for grains within chondrules and with the unaffected interior compositions. The specific intent is to verify that trends are similar and thus possibly due to the same process. Crystallographic control will be maintained as diffusion is possibly the main cause of zoning and should be a function of direction. Elemental ratios, especially Fe/Mn, will be measured by ion probe and compared for forsterites to evaluate their proposed origin from preexisting chondrules. Phosphate crystallography will continue with emphasis on merrilite-whitlockite differences based on crystal structure. Absorption spectroscopy will be used to measure the Cr+2/Cr+3 ratio in forsterite grains as an indicator of redox state during formation.
(d) Steele, I.M. (1992) Olivine in Antarctic micrometeorites: comparison with other extraterrestrial olivine. Geochim. Cosmochim. Acta, accepted. Steele,I.M., Olsen,E. and and Pluth,J.J. (1991) Occurrence and crystal structure of Ca-free beusite in the El Sampal IIIA meteorite. Amer. Mineral. 76, 1985-1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:
(Name, Address, Telephone Number)

Edward Stolper
Caltech, 170-25, Pasadena, California 91125
(818) 356-6504

Co-INVESTIGATORS:
(Name Only)

PROPOSAL TITLE:

Experimental studies of phase equilibria of meteorites and planetary interiors

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 principles of phase equilibria and the methodology of experimental petrology will be used to understand the petrology and geochemistry of Ca-Al-rich inclusions (CAIs) and tektites and the differentiation of terrestrial planets. Stable isotope geochemistry will be used to understand the deuterium to hydrogen (D/H) ratios of volatile-bearing reservoirs of the parent bodies of shergottite, nakhlite and chassignite meteorites.

b. (1) Activity coefficients of MgO, Al_2O_3 and SiO_2 in CAI melts were determined and partial pressures of gaseous Mg, Al and SiO over these melts at solar oxygen fugacities were calculated. (2) The activity-composition relationships of aluminous spinels at 1400°C were determined. (3) The free energy of formation of forsterite was determined. (4) The stability of hibonite in CAI compositions was studied experimentally and used to constrain models for the origin of CAIs containing this phase. (5) The crystallography and crystal chemistry of a new Ca-, Al-, Ti-silicate were determined. (6) Trace element abundances of trace elements in a Type B1 inclusion were determined and used to constrain the thermal history of this class of CAIs. (7) The D-H ratio of H_2O released upon heating of the Nakhla meteorite was measured. (8) The D-H ratio of a kaersutite grain in Chassigny was determined.

c. Our new technique for measuring the thermodynamic properties of oxides will be extended to include (1) determination of the mixing properties of aluminous enstatite, with application to terrestrial and extra-terrrestrial geothermometry and geobarometry; (2) study of the thermodynamics of trace elements, especially REE, in meteoritic minerals and melts; (3) determination of the free energy of formation of zircon; and (4) study of Fe-bearing systems. Stable isotope investigation of water-bearing components in SNC meteorites will be continued and correlated with detailed petrographic investigations, with the goal of distinguishing the characteristics of magmatic volatile reservoirs from those interacting with the atmosphere.

d. Crystal chemical effects on the partitioning of trace elements between mineral and melt: An experimental study of melilite with applications to refractory inclusions from carbonaceous chondrites, Geochim. Cosmochim. Acta, 54, 1755-1774 (1990). Hydrogen and carbon isotopic composition of volatiles in Nakhla: Implications for weathering on Mars. Workshop on the Martian Surface and Atmosphere Through Time (MSATT), September 23-25, 1991, Boulder, Colorado, p. 152-153 (1991). Experimental determination of oxide activities in synthetic CAI and POI melts, LPS XXIII, 215-216 (1992).

Proposal Summary

Principal Investigator: Stephen R. Sutton
Department of the Geophysical Sciences, The University of Chicago
312-702-8109
Co-Investigators: Joseph V. Smith and Sasa Bajt, The University of Chicago
Proposal Title: Development of an X-ray Fluorescence and X-ray Absorption Spectroscopy Facility at the National Synchrotron Light Source for Research on NASA-supported Project

Abstract

(A) Overall objectives and justification of the work; (B) Statement of accomplishments of prior year (C) Listing of what will be done this year (D) Relevant recent publications

(A) The aim is to develop and operate a national facility for microanalytical research on planetary materials at the National Synchrotron Light Source (NSLS), Brookhaven National Laboratory. The X-ray Microprobe (XRM) offers trace element analysis with part-per-million sensitivity for minute extraterrestrial particles (e.g., stratospheric micrometeorites) and 5 μm spots in meteorites and lunar rocks. X-ray Absorption Spectroscopy (XAS) techniques will be developed to allow studies of the oxidations states, bonding and coordination of minor elements in individual sub-millimeter crystals. Technical advice and support will be given to all NASA-supported investigators as part of this national facility. Micrometeorite results will provide chemical evidence on the origins of comets and asteroids, and the nature of the zodiacal cloud. Trace element partitioning results on meteorites and lunar rocks and glasses will give detailed information on cosmochemical fractionation and igneous differentiation. X-ray absorption spectroscopy results will provide insights on the oxidation states of the Moon, Mars and other solar system bodies (B) Microprobe upgrades included beamline installation of a silicon crystal monochromator and testing of a wavelength dispersive spectrometer. Micrometeorite analyses revealed (1) a correlation between Zn depletion and magnetite abundance in chondritic stratospheric particles, (2) elemental loss trends in Antarctic particles with varying degrees of atmospheric entry melting, and (3) evidence for a new class of chondritic material in the stratospheric collection. XAS on lunar olivine showed evidence for reduced Cr. Interiors of lunar volcanic glasses exhibited higher Zn contents than mare basalts. Reversed zoning was documented in Zagami pyroxene cores. (C) Use of the monochromator with an existing focussing mirror and crystal spectrometer will extend the work listed in (A) to greater sensitivity. A systematic XRM, analytical electron microscope, and noble gas study of stratospheric particles and laboratory-heated meteorite matrix fragments will attempt to calibrate the Zn depletion thermometer, identify carriers of trace element signatures and determine the source(s) of igneous particles. XAS studies of olivine grown under controlled fO_2 will be used to further calibrate the oxidation state technique. Trace element and XAS analyses on plagioclase crystals from the Earth, Moon, Mars and asteroids will establish the oxidation and chemical states of these bodies. Analytical techniques will be developed for high atomic number elements (e.g., rare earths) based on K-excitation by wiggler radiation. (D) Sutton, S. R., Jones, K. W., Gordon, B., Rivers, M., and Smith, J. V. (1991) Reduced Chromium in Individual Lunar Olivine Grains: X-ray Absorption Near Edge Structure (XANES). Geochim. Cosmochim. Acta, submitted. Treiman, A. H. and Sutton, S. R. (1992) Pyroxenes in the Zagami shergottite: Chemical zoning by synchrotron x-ray (SXRF) microprobe and electron microprobe and implications for petrogenesis. Geochim. Cosmochim. Acta, in press. Flynn, G. J. and Sutton, S. R. (1992) Trace Elements in Chondritic Stratospheric Particles: Zinc Depletion as a Possible Indicator of Atmospheric Entry Heating. Proc. 22nd Lunar Planet. Sci. Conf., 171-184. Flynn, G. J., and Sutton, S. R. (1992) Element abundances in stratospheric cosmic dust: indications of a new chemical type of chondritic material. Lunar Planet. Sci. XXIII, 373-4.

PROPOSAL SUMMARY

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CO-INVESTIGATOR: Suzanne Baldwin

TITLE: Noble gas studies of early solar system history

ABSTRACT:

a. Isotopic analysis of the noble gases in meteoritic samples will be used to place constraints on the early history and evolution of the meteorite parent bodies. Emphasis will be placed on understanding the I-Xe system, specifically including searches for the carrier phase(s) of radiogenic Xe, diffusion studies of the system, and comparisons with the Rb-Sr system and sulfur and oxygen isotopes. In addition, noble gas-based chronometers will be used to study the formation ages, regolith history and indigenous noble gases of meteorites from the eucrite parent body.

b. During a previous grant which is just concluding we have completed a significant fraction of an experiment on release of radiogenic ^{129}Xe from the meteorite Bjurböle. We have also nearly completed theoretical work which indicates that a Xe component in howardites, which seems to represent surface-correlated excess fission Xe, could be implanted through interaction of an asteroidal atmosphere with the solar wind.

c. Projects which should be completed by the end of the first year of this grant include 1) stepwise heating analyses of eucrite association meteorites, to search for surface-implanted noble gases (in gas-rich samples) and trapped primordial xenon (in low-cosmic-ray-exposure-age eucrites) and to determine Pu/LREE and Pu/U ratios in various cumulate and non-cumulate eucrites, 2) an ion microprobe search for radiogenic Xe in sites in Semarkona chondrules suggested by I-Xe experiments, and 3) analyses of the I-Xe system in a naturally shocked sample, in metal grains extracted from ordinary chondrites, and in olivine-rich achondrites.

d. Swindle et al. (1991) Iodine-xenon studies of petrographically and chemically characterized Chainpur chondrules. Geochim. Cosmochim. Acta 55, 3723-3734.

Burkland and Swindle (1992) Studies of the diffusion properties of the I-Xe system in Bjurbole (abstr.). Lunar Planet. Sci. XXIII, 185-186.

Swindle and Burkland (1991) Noble gases in the Monticello howardite (abstr.). Meteoritics 26, 399.

Swindle (1991) Meteorite evidence for noble gases in ancient asteroidal atmospheres (abstr.). In The International Conference on Asteroids, Comets, Meteors 1991, p. 214.

PROPOSAL SUMMARY

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TITLE: **Chronology and Isotopic Tracer Investigation of Extra-Terrestrial materials.**

ABSTRACT

a. Continuing research is proposed for a study of the age and evolutionary history of meteorites and lunar samples using U-Th-Pb, Sm-Nd, and Rb-Sr systems. The analytical techniques employed include high precision isotope measurements of Pb, Sr, Nd, Hf, and isotope dilution for U, Th, Pb, Rb, Sr, Sm. Nd, Lu, Hf, and REE abundances.

b. During past year, We performed studies of: (1) U-Th-Pb systematics of lunar dunite 72415 from four separates for U/Pb value for the early Moon. The results indicate derivation from high mu source (>500), similar to those for troctolite 76535 and norite 78235. (2) Dating of Antarctic meteorite Asuka 31 for its history and origin. The Pb-Pb, U-Pb, and Th-Pb ages are concordant at 3940 Ma,whereas Sm-Nd and Rb-Sr data indicate a slightly younger age of 3830 ± 89 Ma and 3830 ± 34 Ma, respectively. The most important results of this study is that the Pb data are less radiogenic, and show a low mu of 7. The low mu value indicates that Asuka-31 originated from partial melting of early cumulates enriched with Pb-rich sulfides. (3) U, Th, Pb partitioning in minerals of high- and low-temperature peridotites from the South African kimberlites. It is commonly accepted that CPX is the controlling mineral of the distribution of these elements and for the Pb isotopic evolution in the mantle. The results of our determination of peridotite minerals showed surprisingly, that U is concentrated in garnet more than in CPX and Mu value for garnet is over 300 and Th/U value is less than 1.

c. We propose the following studies for the next years: (1) U-Th-Pb systematics study of early-formed highland rocks, anorthosites 60025 and 15415, and noritic clasts from 67445, (2) determination of partition coefficients of U, Th, and Pb between ultramafic minerals from kimberlite xenoliths and U-Th-Pb systematics of diamonds in order to gain a better understanding of the Pb isotopic evolution in planetary bodies, (3) Dating of lunar meteorites, Yamato-793169. using U-Th-Pb, Sm-Nd, Rb-Sr methods. (4) Dating of urelites Goalpara using U-Th-Pb Sm-Nd, and Rb-Sr isotopic systematics.

Publication: (1) Pemo, W.R. and Tatsumoto, M. (1992) U-Th-Pb, Rb-Sr, and Sm-Nd isotopic systematics of lunar troctolitic cumulate 76535: Implications on the age and origin of this early lunar, deep-seated cumulate. Proc. Lunar Planet. Sci. Conf., vol. 22, 381-397. (2) Misawa, K., Tatsumoto, M., and Yanai, K. (1991) U-Th-Pb isotopic systematics of lunar meteorite Asuka-31. Proc. Antarctic meteorite Symposium 17 (in press). (3) Premo, W.R. and Izett, G.A. (1992) Isotopic signatures of tektites from the K-T boundary on Haiti. Meteoritics (in review). (4) Premo, W.R. (1992) Nd-Sr isotopic signature of the Pierre Shale: Target material at the Manson impact site and source of the Haitian tektites (K-T boundary) ? Lunar Planet. Sci. XXIII, 1099-1100. (5) Premo, W. R and Tatsumoto, M. (1992) Acid leaching of apatite: Implications for U-Th-Pb systematics of lunar highland plutonic rocks. Lunar Planet Sci. XXIII, 1101-1102. (6) Premo, W. R. and Tatsumoto, M. (1992) U-Pb isotopes in dunite 72415. Lunar Planet Sci. XXIII, 1103-1104. (7) Tatsumoto, M., Nakamura, Y., Premo, W.R., and Boyd, F.R., (1992) Elemental distribution of U, Th, and Pb in peridotite xenoliths: Implications for the Pb isotopic evolution of the Moon. Luna(1) Premo, W. R. and Tatsumoto, M. (1992) U-Th-Pb, Rb-Sr, and Sm-Nd isotopic systematics of lunar troctolitic r Planet. Sci. XXIII, 1409-1410. (8) Misawa, K., Tatsumoto, M., and Yanai, K. (1992) U-Th-Pb, Sm-Nd, and Rb-Sr systematics of lunar meteorite, Asuka-31. Lunar Planet. Sci. XXIII, 917-918.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Hugh P. Taylor, Jr.
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Co-INVESTIGATORS: Dr. Samuel Epstein
(Name Only)

PROPOSAL TITLE: Application of Stable Isotope Measurements to the Study of the Origin of Meteorites

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. Solvent extractions and HCl-HF or oxidation residues that we have prepared from meteorites contain important information regarding the origin of the solar system. For example, D/H analyses of organic molecules in these extracts and residues, and $^{30}Si/^{29}Si/^{28}Si$ analyses of oxide and carbon grains in these residues, all indicate the presence of presolar material and the mixing history of this material into the solar nebula. Our objective is to do further kinds of isotopic and chemical studies on these materials in order to better understand the chemical and isotope fractionation processes that affect H, C, O, N, and Si in meteorites, lunar samples, and in the interstellar media prior to its incorporation into the solar system. In that way we hope to delineate some aspects of the chemical history of the cosmos.

b. We have separated fractions from meteorites by solvent extraction, acid dissolution, and oxidation, and analyzed these for H, C, N, Si, and O isotopes by a variety of techniques. The highly anomalous $^{13}C/^{12}C$ and $^{30}Si/^{29}Si/^{28}Si$ ratios observed in the SiC obtained from these residues provided information regarding the origin and history of the SiC after its formation in the stars. The $^{13}C/^{12}C$ and D/H of separated amino acids and hydrocarbons signify the importance of preserved interstellar materials in the formation of these compounds. Our initial research on the volatiles evolved by heating SNC meteorites clearly indicated non-terrestrial isotopic compositions that may have significance with respect to geological processes on Mars.

c. The combination of our new Finnigan MAT 252 mass spectrometer and our newly developed on-line laser fluorination apparatus has microanalytical capabilities, and it should dramatically enhance our ability to apply stable isotope geochemical studies to meteorites, particularly of the pre-solar, interstellar materials in HF-HCl treated residues from certain meteorites. We intend to analyze $^{18}O/^{17}O/^{16}O$ relationships in a wide variety of materials from meteorites, particularly chromite and spinel in the HCl-HF residues. We will continue to analyze δD and $\delta^{13}C$ in solvent-extracted concentrates of different amino acids, carboxylic acids, and hydrocarbons from a variety of meteorites to determine the role of pre-solar and solar material in their formation. The SNC meteorites (which may have come from Mars) will continue to be studied to obtain possible information regarding the Martian hydrosphere. We plan to initiate some new studies of non-mass-dependent isotopic fractionation during ozone formation using a variety of ^{16}O, ^{17}O and ^{18}O compositions, and extend these studies to other reactions such as the production of NO_2. We will continue to study isotope effects due to shock-induced devolatilization of terrestrial rocks and meteorites. We also plan to continue our efforts to determine the oxygen isotopic compositions of organic matter and H_2O in meteorites.

d. See enclosed Krishnamurthy *et al.* (1992), Pizzarello *et al.* (1991) and Stone *et al.* (1991b).

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: **Lawrence A. Taylor**

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CO-INVESTIGATORS: **Dr. Gregory A. Snyder**
Dr. Eric A. Jerde

PETROGENESIS OF THE LUNAR CRUST AND MANTLE

ABSTRACT:

a) The formation and evolution of the lunar crust and mantle are of primary importance to planetary science. Petrologic and geochemical studies of the rocks can provide us tremendous insight into the interactions of the mantle and various components of the crust. It is data such as these that are requisite to our understanding of the Moon and terrestrial planets.

b) The last year has seen us make considerable progress in our understanding of the petrogenesis of high-Ti mare basalts. Chemical, petrographic, and radiogenic isotopic studies of Apollo 17 high-Ti basalts have led to the delineation of complex source formation and melting processes (including alkali metasomatism). Radiogenic isotopic studies of the Apollo 11 high-Ti basalts indicate that the source for all low-K high-Ti basalts is an ilmenite-bearing layer of the lunar mantle formed late in the evolution of the LMO. These studies have led us to attempt source modelling of these high-Ti basalts from an initially molten LMO through the formation of cumulate source regions containing entrained plagioclase and trapped liquid. Our understanding of Silicate Liquid Immiscibility (SLI) and the dissemination of the post-SLI REEP-frac component have received further support in our ongoing studies. We have begun a comprehensive study of Apollo 12 basalts with the hope of unravelling outstanding petrogenetic problems, and to expand our knowledge of the basalts through breccia pull-apart studies. Finally, we have completed the first draft of the Apollo 17 Sample Information Catalog of Mare Stations, which was several years in the making.

c) We propose the continuation of our studies of high-Ti basalts by mapping of Apollo 11 breccias in search of more mare basalts (especially type Ds). We will expand our modelling of mare basalt sources to low-Ti mare basalts. Radiogenic isotopic studies of alkalic rocks from Apollo 14 have indicated that the western highlands "alkalic event" is **not** coeval with crystallization of the last dregs of the LMO. Our study of the western highlands "alkalic event" will continue with modelling of post-LMO magma generation using compiled data and our own radiogenic isotopic studies. We will begin forays into Apollo 12 and 16 breccias in search of mare basalts. Continuing SIMS analysis of whitlockite-apatite pairs is also proposed.

Snyder, G.A., Taylor, L.A., Liu, Y.-G., Schmitt, R.A., 1992, Petrogenesis of the western highlands of the Moon: Evidence from a diverse group of whitlockite-rich rocks from the Fra Mauro Formation. Proc. Lunar Planet. Sci. 22, 399-416.

Paces, J.B., Nakai, S., Neal, C.R., Taylor, L.A., Halliday, A.N., and Lee, D.-C., 1991, A strontium and neodymium isotopic study of Apollo 17 high-Ti mare basalts: Resolution of ages, evolution of magmas, and origins of source heterogeneities. *Geochim. Cosmochim. Acta* 55, 2025-2043.

PROPOSAL SUMMARY

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Co-INVESTIGATORS:
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PROPOSAL TITLE: Meteoritic Sulfur Isotopic Analysis

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. Our overall proposal is to continue our analysis program of sulfur isotopes in meteoritic material. Our analysis includes all stable isotopes, $\delta^{33}S$, $\delta^{34}S$ and $\delta^{36}S$. Our previous analysis has demonstrated that there are interesting questions in nucleosynthesis, cosmic-ray spallation processes, nebular chemistry and planetary processes which may be addressed by sulfur isotopic analysis. We shall perform the appropriate meteoritic isotopic analysis to investigate these events.

(b). We developed the techniques for analysis of sulfur isotopes in iron meteorites; both inclusions and dissolved in metal. Excess ^{33}S and ^{36}S from spallation reactions was detected and the implications for cosmic-ray spallation reaction theories published. Acid residues, organic components, sulfates and sulfides were separated from carbonaceous chondrites and measured for sulfur isotopes. Sulfide minerals and acid residues were separated from a large number of enstatite and unequilibrated ordinary chondrites and measured for all sulfur isotope ratios. Chondrules were size separated from Allende and analyzed. Whole chondrules were separated from Dhajala Chainpur and Bjurbole and also analyzed for their isotopic composition

(c). We shall continue our meteoritic sulfur analysis program. We have acquired a new mass spectrometer which is dedicated to sulfur. Our analytical techniques will be further miniaturized to permit high precision analysis on samples smaller than 100 micrograms. Our search for nucleosynthetic anomalies in, e.g. CaS, TiS, iron meteorites, and acid residues will continue. Analysis of meteoritic classes as yet not analyzed will be done to resolve the observed class systematics. Chondrules from carbonaceous and ordinary chondrites (size separated and rim vs interior) will be separated and analyzed. We shall separate, identify and perform concomitant sulfur isotopic analysis on organic compounds. We shall measure, from accelerator irradiations, ^{33}S, ^{36}S yields from iron spallation by high energy protons.

(d). Gao, X. and M.H. Thiemens (1991). Sulfur isotopic analysis of the Orgueil meteorite. Lunar and Planet. Sci. XXII, 427-428.

Gao, X. and M.H. Thiemens (1991). Systematic study of sulfur isotopic composition in iron meteorites. Geochim. Cosmochim. Acta 55, 2671-2679.

Gao, X. and M.H. Thiemens (1992). Sulfur chemical and isotopic distributions in carbonaceous chondrites. Submitted to Geochim. Cosmochim. Acta.

Gao, X. and M.H. Thiemens (1992). Sulfur isotopic variations in enstatite and ordinary chondrites. Submitted to Geochim. Cosmochim. Acta.

PROPOSAL SUMMARY

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Co-INVESTIGATORS: RL Brodzinski, JC Evans
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PROPOSAL TITLE: Measure and Interpret Antarctic Meteorite Aluminum-26 for Terrestrial Age Dating and Temporal Variations in the Galactic Cosmic Ray Flux

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 measure the activity of ^{26}Al in Antarctic meteorites and ^{26}Al and other radionuclides in fresh fall meteorites. The data will be used for terrestrial age dating and determination of exposure history to galactic and solar cosmic rays. The measurement of ^{26}Al activities in Antarctic meteorites is a part of the characterization of the Antarctic meteorite collection, as recommended by the Meteorite Working Group.

b. ^{26}Al activities have been measured in 61 Antarctic meteorites in the past year, bringing the total number of analyzed specimens to 670 (including 11 Yamato specimens and Adelie Land). Eleven radionuclides, including ^{26}Al, ^{22}Na, ^{60}Co, ^{56}Co, and ^{54}Mn were measured in the Noblesville H chondrite, which fell on 31 August 1991. We have continued our work to identify meteorites with unusual ^{26}Al activities (high ^{26}Al activities may indicate strange orbits or SCR exposure; low ^{26}Al activities point to long terrestrial residence times or short cosmic ray exposures). For the Antarctic meteorites, comparison of ^{26}Al activity distributions in L and H chondrites show distinct differences. The mean ^{26}Al activity of Antarctic L chondrites indicates an average terrestrial age of ~140 kyr. In contrast, the mean ^{26}Al activity of Antarctic H chondrites is similar to that of modern H chondrite falls, suggesting that Antarctic H chondrites fell relatively recently — within the past 50 kyr. Several Antarctic specimens show unusually high activities: ALHA 83101 (L6) has 117±6 dpm/kg — the highest activity ever recorded in a chondrite and suggesting possible SCR exposure. Results for Noblesville show normal ^{26}Al (52±3 dpm/kg) but high ^{22}Na (135±14dpm/kg), suggesting an unusual exposure history in the last ~100 kyr. Other results from the ^{26}Al data include support for most pairings and the identification of new possible pairings, identification of samples with high ^{26}Al activities consistent with SCR exposure, and identification of samples with low ^{26}Al activities consistent with long terrestrial residence times or short cosmic ray exposure ages.

c. We plan to continue two related tasks: 1) characterization of Antarctic meteorites ^{26}Al assay; and 2) measurement of cosmic ray produced ^{26}Al and short-lived radionuclides in fresh fall meteorites to determine temporal variations in the galactic cosmic ray flux.

d. Wacker J.F. Meteoritics, **26**, 404 (1991).
Lipschutz M.E. *et al.*, Lunar Plan. Sci. Conf XXIII, 785 (1992).
Wacker J.F., Evans J.C., McKinley S.G., and Reeves J.H. Meteoritics, submitted.

PROPOSAL SUMMARY

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Title: Re-Os isotope investigation of meteorites.

Abstract:
a) We propose to continue our study of the ^{187}Re-^{187}Os isotopic systematics of meteorites, as a means of providing new insights to the origin and chemical evolution of the solar nebula, and the parent bodies of meteorites. The ultimate goal of this research is to place chronological and geochemical constraints on the evolution of planetary materials from the formation of primitive material in the solar nebula through agglomeration, planetary accretion and core formation.
(b) This is a progress report.
(c) Our low-blank Re and Os purification chemistries will be combined with high-precision negative thermal ionization mass spectrometry techniques to pursue 2 interrelated tasks. (i) Iron Meteorites and Chondrites. The Re-Os system is a direct method of determining chemical closure ages for irons. The "magmatic" irons are samples of planetary cores and Re-Os closure ages may provide clues about the timing of differentiation and cooling, or metamorphism in the parent asteroids. We have completed preliminary Os isotopic studies of carbonaceous and enstatite chondrites (Walker and Morgan, 1989; Morgan *et al.*, 1990), and IIAB and IIAB iron meteorites (Morgan *et al.*, 1992) using resonance ionization mass spectrometry techniques. We have also completed the first high precision Re-Os isotope study of IIA iron meteorites (Horan *et al.*, 1992). The data suggest that different iron meteorite groups may have crystallized at significantly different ages ranging from 4.56 Ga to 4.41 Ga. The high precision measurements made possible by the negative thermal ion mass spectrometry will greatly help to resolve age and other petrogenetic differences between iron groups and between irons and chondrites. We intend to continue to re-analyze a suite of the most important meteorites using the higher precision techniques. (ii) Chondrite Components. Re-Os isotopic heterogeneities in Semarkona suggest either a Re leaching event or accretion of the unequilibrated chondrites from components with isotopically distinct sources. Individual characterized components from Semarkona and Allende will be analyzed, as well as refractory inclusions from C chondrites and single particles of apparently primitive material from Al Rais and Renazzo.
(d) Morgan J.W., Walker R.J. and Grossman J.N. Rhenium-osmium isotope systematics in meteorites.I: Magmatic iron groups IIAB and IIIAB. *Earth Planet. Sci. Lett.*,in press. Appendix 1.

Horan M.F., Morgan J.W., Grossman J.N., Walker R.J. (1992) Rhenium-osmium isotopic constraints on the age of iron meteorites. *Science* 255, 1118-1121. Appendix 2.

PROPOSAL SUMMARY

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Co-Investigators: C. Alexander, G. Crozaz, T. Bernatowicz, E. Zinner

Proposal Title: SOLID STATE AND MASS SPECTROMETRIC MEASUREMENTS OF EXTRATERRESTRIAL MATERIALS

(a) Our goal is to understand the origin and evolution of the solar system by studying various materials including interstellar grains (ISGs), nebular products such as refractory inclusions, and igneous rocks from planetary objects. We use several experimental techniques including ion probe mass spectrometry, analytical electron microscopy (SEM-EDS, TEM-EDS-EELS) and optical spectroscopy (FTIR, micro-Raman) to study a variety of extraterrestrial samples including meteorites, IDPs, polar micro-meteorites, and lunar rocks. Central to our work is the measurement of isotopic anomalies, the identification of their (microscopic) carriers, and the relationships among isotopic systems.

(b) Since our last submission of a full proposal we have made substantial progress in identifying and characterizing ISGs and in relating them to plausible pre-solar astrophysical sources. We review our contributions in this field, which have focussed on reduced ISGs from C-rich stars. During the last funding period we have conducted numerous studies of refractory inclusions from primitive meteorites with the general aims of understanding the histories of these objects. This knowledge has been applied to such general questions in planetary science as whether there was a uniform mixture of live ^{26}Al in the early solar system which could have served as a heat source for planetary differentiation. We have also studied magmatic systems in highly evolved solar system bodies through measurements of trace element distributions in lunar and meteoritic minerals.

(c) We propose new research which utilizes ion-imaging to search for grains from O-rich stars. We also propose to search for new types of reduced ISGs, to expand our search for *in situ* ISGs in meteorites, and to conduct ion probe and noble gas studies to explore the nature and abundances of different interstellar phases in a variety of meteorites. We will continue to investigate the carriers of D/H enrichments and their relationship to N isotopic anomalies that we have found in IDPs. A search for ISGs in polar micrometeorites will also be made. Future work will involve, among other things, the study of very refractory inclusions, measurements of the Mn-Cr system and comparison of initial Sr and the Al-Mg systems to establish whether ^{26}Al and ^{53}Mn are useful chronometers of early solar system processes. We propose to conduct trace element (REE) studies of SNC meteorites to study magmatic evolution on another planetary-sized body, and to use the ion probe to determine the REE carriers in unequilibrated ordinary and enstatite chondrites. During the current grant we have also started a collaboration with the Zare group at Stanford to measure polycyclic hydrocarbons (PAHs) in primitive materials. The status of this work and future directions are briefly discussed.

(d) ref: Alexander *et al.* (1991) *Nature* **348**, 715; Bernatowicz *et al.* (1991) *Ap. J. Let.* **373**, L73; Kovalenko *et al.* (1992) *Anal. Chem.*, in press; Maurette *et al.* (1991) *Nature* **351**, 44; Podosek *et al.* (1991) *Geochim. Cosmochim. Acta* **55**, 1083; Virag *et al.* (1992) *Geochim. Cosmochim. Acta*, in press; Wadhwa and Crozaz (1992) *L.P.S.C.* **XXIII**, 1483.

PROPOSAL SUMMARY

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Dr. Andrew J. Gratz

PROPOSAL TITLE: **Pristine Igneous Rocks and the Genesis of Early Planetary Crusts**

ABSTRACT:

a. *Objectives.* We study the nature and early histories of planetary crusts, with special emphasis on the ancient Moon. Most of the accessible lunar crust consists of materials hybridized by impact-mixing. Rare pristine (unmixed) samples reflect the original genetic diversity of the early crust. Other areas of study include: lunar meteorites, and analogous Apollo breccias; petrology of igneous meteorites in general; impact breccias, especially metal-rich Apollo samples and polymict eucrites; primordial "magma ocean" differentiation; effects of regolith/megaregolith insulation on thermal evolution and geochronologic records of small planetary bodies; and planetary bulk compositions and origins.

b. *Selected accomplishments of the past year.* We: (1) developed the first study of possible inheritance of impactor silicate differentiation through lunar origin by giant impact, and found that the giant impact model tends to imply a peculiar, fractionated refractory-lithophile element pattern for the Moon's bulk composition; (2) further investigated numerous extraordinary lunar rocks, including several lunar meteorites, and an Apollo 14 rock (14286, 4.4 g) consisting mostly of FeNi-metal; (3) studied the fourth polymict ureilite, EET87720, and in developing a new model for ureilite genesis, found that explosive volcanism, driven by oxidation of graphite entrained in basaltic magmas, may have been a common phenomenon on moderately large C-rich asteroids in the early solar system.

c. *Plans for this year.* We will acquire new data for lunar meteorites and pristine rocks, and examine implications for the history of the lunar crust. We will complete our study of the unique "spinifex" textured, rapidly-cooled Apollo 12 lava sample 12024,15. Large lunar metal samples will be studied, as constraints on processes within large lunar impact melts. Polymict eucrites will be analyzed to constrain brecciation processes on their parent asteroid. We will investigate sundry igneous meteorites, especially angrites, ureilites, geochemically unusual eucrites, and the LEW88516 shergottite. Modeling studies will address differentiation of silicate magmaspheres, and cooling of the early lunar crust beneath its insulating megaregolith. We will develop constraints for lunar bulk composition and origin.

d. *Some recent publications.* (1) Warren & Kallemeyn (1991) The MacAlpine Hills lunar meteorite, and implications of the lunar meteorites collectively for the composition and origin of the Moon, *Geochimica.* (2) Warren (1992) Inheritance of silicate differentiation during lunar origin by giant impact: *Earth Planet. Sci. Lett.*, submitted. (3) Warren & Kallemeyn (1992) Explosive volcanism and the graphite - oxygen fugacity buffer on the parent asteroids of the ureilite meteorites: *Icarus*, submitted.

PROPOSAL SUMMARY

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PROPOSAL TITLE: Meteorite Magnetism

ABSTRACT:
Introduction:
The main thrust of the meteorite magnetism research over the past year has been to experimentally evaluate the bulk magnetism records in class 5 and 6 meteorites, to critically assess the meteorite magnetism research that has been completed by all researchers, to assess what we know about shock magnetization, and to continue investigation of the REM values.

Several slabs of meteorites (Plainview H5, Shaw L6, Allende C3V) have been diced into (at least 100) small cubical specimens at most several millimeters on edge. The Plainview set has been prepared and is being evaluated. This effort will be the main thrust of continued research.

The Goddard research and all meteorite magnetism research that has been critically reviewed will be presented in a review paper titled Magnetization in Primitive Solar System Materials. This paper will be submitted to Reviews of Geophysics.

Summary of the Years Work:

Chondrite meteorites magnetic records provide plentiful evidence for the existence of magnetic fields at many different stages in the history of the meteorites. The available magnetic record reveals that most meteorites when examined in bulk, exhibit records which suggest a direction of magnetization stable during demagnetization out to alternating fields sufficient to demagnetize any earth induced magnetic viscosity, or temperatures (during thermal demagnetization) which would be experienced in a terrestrial context. Other meteorites exhibit well defined excursions, mostly along great circle paths suggesting a well organized multicomponent source of the record. These are a few meteorites that exhibit chaotic records. All of the above can most appropriately be applied to the description of the magnetic records in petrographic class 5 and 6 meteorites belonging to groups H, L, and LL.

There is responsible evidence indicating that component parts of all meteorite groups and all classes within each group exhibit stable to unstable demagnetization behavior. Components from a bulk meteorite might also exhibit widely scattered directions while the bulk sample is nicely behaved. Some of the problems relate to the choice of demagnetization technique. Thermal and alternating demagnetization experiments are very different techniques when applied to meteorites.

Magnetic hysteresis loop and thermomagnetic analysis for example, provide evidence that a group of chondrites from a given meteorite (Bjurbole, Chainpur Allende for example) have different proportions of the same magnetic phases which contribute proportionately to the NRM record.

PROPOSAL SUMMARY

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Title: GEOCHEMICAL AND ISOTOPIC INVESTIGATIONS OF LUNAR AND PLANETARY MATERIALS AND INTERPLANETARY DUST

ABSTRACT (Single--spaced, type within box below. Paragraphs numbered a--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.):

The concentration and isotopic composition of Os,Re,Ir,Pt,Pd,W,Mo,U,Th,Sr,Ca,Pb,Gd,Sm,Nd,Ba,Zr,Ag, K,Ti,Cr,Fe,Ni,Zn,Mg,Sn,Te,Cd and Tl will be determined on selected lunar rocks, mineral separates, microrock samples ($\sim 20 \times 10^{-6}$g) and meteorites to the highest precision currently achievable. Samples will be jointly studied with colleagues doing petrographic phase equilibrium and chemical investigations. The principal purposes will be to: 1)clarify the techniques and systematics used to elicit chronological information;2)develop a more complete knowledge of the lunar and planetary time scales;3)determine the nature of differentiation processes involved in the generation of lunar magmatic rocks;4) determine the composition of initial Pb, Sr and Os as a function of age;5)understand the stages of meteorite evolution;6)develop methods for analysis of cometary dust and gases;7)pursue evidence for the correlation of shortlived nuclides and exotic nucleosynthetic components in the early solar system; 8) study petrology and mineralogy of extraterrestrial materials including opaque assemblages in order to understand the processes of condensation and planetary metamorphism; 9)pursue evidence of intrinsic isotopic heterogeneity within coexisting minerals in both coarse- and fine-grained refractory inlcusions; 10)address constraints provided by kinetic isotope fractionation effects, including their study by controlled experiments; 11)study the chronology of major impact events and the use of PGE as tracers for impactors on the moon and the earth. Basic methods will be measurement of:A)internal isochrons by Rb-Sr, U-Th-Pb, Sm-Nd, Re-Os, using mineral separates;B)total rock isochrons on related rock types;C)isochrons using extinct nuclides;D)correlated isotopic anomalies;E)the chemical and isotopic characteristics of early solar system condensates and evaporative residues; and F) the chemical isotopic characteristics of pre-solar dust grains. We will improve techniques of micro-manipulation, mass spectrometry (both PTIMS and NTIMS), and SEM for analysis of small samples (10^8-10^{11} atoms) in order to analyze lunar and meteoritic samples and interplanetary and cometary dust particles. J. H. Chen and G. J. Wasserburg (1990) The isotope composition of Ag in iron meteorites and the presence of ^{107}Pd in protoplanets, GCA, 54, 1729-1743. A. Prinzhofer, D. A. Papanastassiou and G. J. Wasserburg (1992) Sm-Nd evolution of meteorites, GCA, 56,797-815. J. Völkening and D. A. Papanastassiou (1990) Zinc isotope anomalies, Ap. J. (Lett.), 358, L29-L32. J. D. Blum, D. A. Papanastassiou, C. Koeberl and G. J. Wasserburg (1992) Nd and Sr isotopic study of Australasian tektites, GCA 56, 483-492. R. A. Creaser, D. A. Papanastassiou and G. J. Wasserburg (1991) Isotopic analysis of Os, Re, and Ir by negative thermal ion mass spectrometry, GCA, 55, 397-401. B.W. Stewart, D. A. Papanastassiou and G.J. Wasserburg (1992) Sm-Nd chronology and petrochemistry of mesosiderites, LPSC XXIII, 1365-1366. J. H. Chen, G. J. Wasserburg and D. A. Papanastassiou (1992) Th and U abundances in meteorites, LPSC XXIII, 223-224. R. A. Creaser, D. A. Papanastassiou and G. J. Wasserburg (1992) Re-Os isotope study of iron meteorites using negative thermal ion mass spectrometry, LPSC XXIII, 263-264.

Proposal Summary

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Proposal Title: DEVELOPMENT AND APPLICATION OF THE ION MICROPROBE FOR ANALYSIS OF EXTRATERRESTRIAL 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 or your recent publications relevant to the proposed work.)

The major research effort will be the continued investigation of the isotopic composition of primitive components in unequilibrated meteorites, including pre-solar SiC and refractory oxide grains, and a search for extinct nuclides in different meteorite classes. The time scales for formation and differentiation of solid bodies in the early solar system will be studied using the short-lived parent-daughter systems ^{26}Al-^{26}Mg($7x10^5$y) and ^{53}Mn-^{53}Cr ($3.7x10^6$y). The Mg isotopic studies will focus on: (1) A search for the interstellar carrier grains of ^{26}Al; (2) the distribution of $^{26}Mg^*$ in high Al-Mg phases in carbonaceous, ordinary and enstatite chondrites; (3) the relationship between CAI metamorphism and Al-Mg systematics. The search for $^{53}Cr^*$ will focus on pallasites, mesosiderites, angrites and IIIAB iron meteorites. A major effort will be devoted to understanding the timescale and nature of Cr re-distribution. The isotopic compositions of C, N, O, Mg, Si, Ca and Ti in pre-solar SiC and oxide grains will be measured to assess the nature and number of the stellar sources. The distribution of pre-solar SiC in meteorites of different metamorphic grade will be determined and compared to that of pre-solar diamond. The distribution of trace elements within zoned crystals and among coexisting phases will be measured in natural and synthetic chondrules, basaltic fragments and differentiated meteorites. Crystal/liquid partition coefficients will be determined and used to constrain thermal histories. Laboratory studies will investigate chemical and isotopic variations produced by distillation and sputtering. Diffusion studies of Mg, Ca, Ba, Sr, Mn, Cr, Si, O and REE will be carried out in an effort to unravel mechanisms of solid and liquid state transport that play a major role in the origin and metamorphism of meteoritic and planetary materials. These laboratory studies will explore possible processes that may have been active in the early solar system. This research is planned in concert with the complementary program using thermal ionization mass spectrometry outlined in a companion proposal. J. Stone, I.D. Hutcheon, S. Epstein & G.J. Wasserburg (1991) Correlated Si isotope anomalies and large ^{13}C enrichments in a family of exotic SiC, EPSL 107, 570-581; Y.J. Sheng, I.D. Hutcheon and G.J. Wasserburg (1990) Origin of plagioclase-olivine inclusions in carbonaceous chondrites, GCA 55, 581-599; J. Stone, I. D. Hutcheon, S. Epstein and G.J. Wasserburg (1991) Silicon, carbon and nitrogen isotopic studies of silicon carbide in carbonaceous and enstatite chondrites, Stable Isotope Geochemistry: A Tribute to Samuel Epstein, 487-504; A.K. Kennedy, R. Hutchison, I.D. Hutcheon and S.O. Agrell (1992) A unique high Mn/Fe diabase fragment in the Parnallee (LL3) ordinary chondrite: nebular mixture or planetary differentiate from a previously unrecognized planetary body?, EPSL, in press; Y. J. Sheng, G.J. Wasserburg and I.D. Hutcheon (1992) Self-diffusion of Mg in spinel and in equilibrium melts: constraints on flash heating of silicates, GCA, in press.

Proposal Summary

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Proposal Title: **DIFFERENTIATED METEORITES AND THE COMPONENTS OF CHONDRITES**

Abstract:

a. Our studies have five main thrusts: 1) compositional-petrographic studies of chondrules to aid in understanding their origin; 2) investigation of nebular components by the analysis of chondrules and small fragments from highly unequilibrated chondrites; 3) investigation of shock-produced phases and textures in ordinary chondrites that can survive annealing; 4) petrographic, chemical and isotopic studies of pristine igneous clasts from mesosiderites; and 5) analysis of iron meteorites and interpretation of the data in terms of nebular and planetary fractionation processes.

b. Accomplishments during the past year include: 1) elucidation of inferred nebular components of the EH formation location based on analysis of small chunks of EH3 Qingzhen; 2) description of the variety of petrographic assemblages containing metallic Cu in ordinary chondrites and their implications for chondrite thermal histories; 3) discovery of igneous mesosiderite clasts that have the most extreme positive Eu anomalies among solar system rocks; 4) investigation of the formation of the first known occurrences of pyrophanite and baddeleyite in chondrites.

c. Proposed research areas include: 1) petrographic study of the surprisingly common aberrant grains found in equilibrated chondrites to determine whether they are exotic clasts of the products of shock differentiation; 2) the separation, petrographic characterization, multielement and O-isotope analysis of a set of chondrules and matrix material from the ALH85151 and LEW85332 chondrites; 3) petrographic investigation of shock-produced phases and textures in ordinary chondrites that can survive annealing; 4) a comprehensive study of compositional relationships among the ungrouped iron meteorites in order to assess the number of parent bodies that produced them.

d. Recent publications: A.E. Rubin and D.W. Mittlefehldt, Geochim. Cosmochim. Acta **56**, 827-840 (1992); A.E. Rubin, Amer. Mineral. **76**, 1356-1362 (1991); J.T. Wasson and X. Ouyang Geochim. Cosmochim. Acta **54**, 3175-3183 (1990).

PROPOSAL SUMMARY

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PROPOSAL TITLE: Mineralogic and Petrologic Studies of Meteorites and Lunar Samples

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.)

PURPOSE: To infer the properties and evolution of the solar nebula from the petrographic and geochemical properties of chondrules, CAI's, and matrix in primitive chondritic meteorites; from this to attempt to understand the origin of the planets.

LAST YEAR: We carried out studies of equilibrium and kinetic mineral-forming processes in the solar nebula. Hashimoto published a major paper on the effect of enhanced levels of nebular H_2O on the volatility of the various cationic elements. We calculated the equilibrium "condensation sequences" of minerals for systems having various fractionated (non-cosmic) bulk compositions. We began studies of the Mezö-Madaras chondrite, and the genetic implications of its merrihueite- and free-silica-bearing chondrules.

NEXT YEAR: We will carry out petrographic studies and thermodynamic analyses of a number of particularly interesting meteorites that Visiting Scientist M. Petaev brought with him from Russia. We will expand and conclude our study of Mezö-Madaras, and model nebular environments and processes that can explain the volatile-enriched character of the precursor material for many of its chondrules. I will be involved in several collaborations with astrophysicists who study star-forming processes, including a program on Planet Formation to be held by the Institute for Theoretical Physics, U. California Santa Barbara.

PAPERS: Hashimoto, A. (1991) The effect of H_2O gas on volatilities of planet-forming major elements -- I. Experimental determination of thermodynamic properties of Ca-, Al- and Si-hydroxide gas molecules, and its application to the solar nebula. *Geochim. Cosmochim. Acta 56*, 511-532. Wood, J. A. and Pellas, P. (1991) What heated the parent meteorite planets? In *The Sun in Time* (eds. C. P. Sonett, M. S. Giampapa, M. S. Matthews), pp. 740-760. Univ. Arizona Press, Tucson. Kring, D. A. (1991) High temperature rims around chondrules in primitive chondrites: evidence for fluctuating conditions in the solar nebula. *Earth Planet. Sci. Lett. 105*, 65-80.

PROPOSAL SUMMARY

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PROPOSAL TITLE: Analyses at High Spatial Resolution of Organic Molecules in Extraterrestrial Samples: Two-Step Laser Mass Spectrometry

ABSTRACT:

We have developed a microprobe two-step laser mass spectrometer (μ-L^2MS) capable of detecting attomole (10^{-18} mole) amounts of organic material with a spatial resolution of 40 μm. The improved microprobe instrument has been used to analyze an assortment of samples, and notable developments have been made on the following:

- o samples of limited size (collected particulates)
- o samples of fine spatial heterogeneity (freshly-cleaved meteorite surfaces)
- o samples containing a high mass distribution of organic material (the Allende meteorite)

We propose to continue analyzing ordinary and carbonaceous chondrites, interplanetary dust particles, chondrule rims, and impact craters from the trailing edge panels of the long duration exposure facility (LDEF) for polycyclic aromatic hydrocarbons (PAHs). we aim not only to confirm whether organic species are present within our detection limits, but also to perform experiments to understand and further characterize the organic contents of the samples. This includes observing trends, if such exist, in PAH distributions and the degree of alkylation, as well as isotope and isomer ratio measurements. Working with Professor Peter R. Buseck, Arizona State University, we intend to analyze the Allende meteorite, to characterize its high mass distribution, and to perform an organic spatial map to be coordinated with a complementary mineralogical analysis. We also intend to analyze the chondrule rims of the Bjurbole meteorite for the presence of PAHs. With Professor R. M. Walker and Dr. Conel M. O'D. Alexander at Washington University in St. Louis we plan to study particles of interplanetary dust and the impact sites on the LDEF panels.

PROPOSAL SUMMARY

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TITLE: Laboratory Studies of Interplanetary Dust

(a) Interplanetary dust particles (IDPs) are thought to have been derived both from cometary and asteroidal sources. This task provides for the detailed examination of the mineralogy, microstructures, bulk and mineral compositions of IDPs. The aim of this research is the evaluation of hypothesized sources of this particulate material, and elucidation of its physico-chemical history.
(b) We have characterized the mineralogical assemblages of hydrated and anhydrous chondritic interplanetary dust particles, permitting comparisons to be made with other primitive materials [1-4], and discovered and characterized trends in olivine and pyroxene compositions which permit unequilibrated chondritic IDPs to be distinguished from processed ones, and for comparisons to expected cometary dust to be made [5]. We have taken a leading role in interplanetary dust impact feature surveys of the Long Duration Exposure Facility (LDEF), and are characterizing these samples [6].
c. Additional IDPs of all types will be identified from the stratospheric collections and LDEF surfaces to increase the IDP information database. All particles will be partially thin-sectioned, with the resulting thin slices being characterized in JSC's SEM and STEM laboratories. We will arrange for the collection of trace element analyses and isotopic analyses of some particles. We will further develop our analytical techniques for light element analyses, and for solar flare track analysis.
d. [1] Zolensky, *Microbeam Analysis - 1991*; [2] Zolensky and Lindstrom, *Proc. Lunar and Planetary Science Conf. 22*, 1992; [3] Zolensky et al., submitted to Geochimica et Cosmochimica Acta; [4] Ming et al., *Lunar and Planetary Science XXIII*; [5] Zolensky and Barrett *Microbeam Analysis - 1992*, in press; [6] Bernhard et al., *Proceedings of the Second LDEF Post-Retrieval Symposium*, in press.

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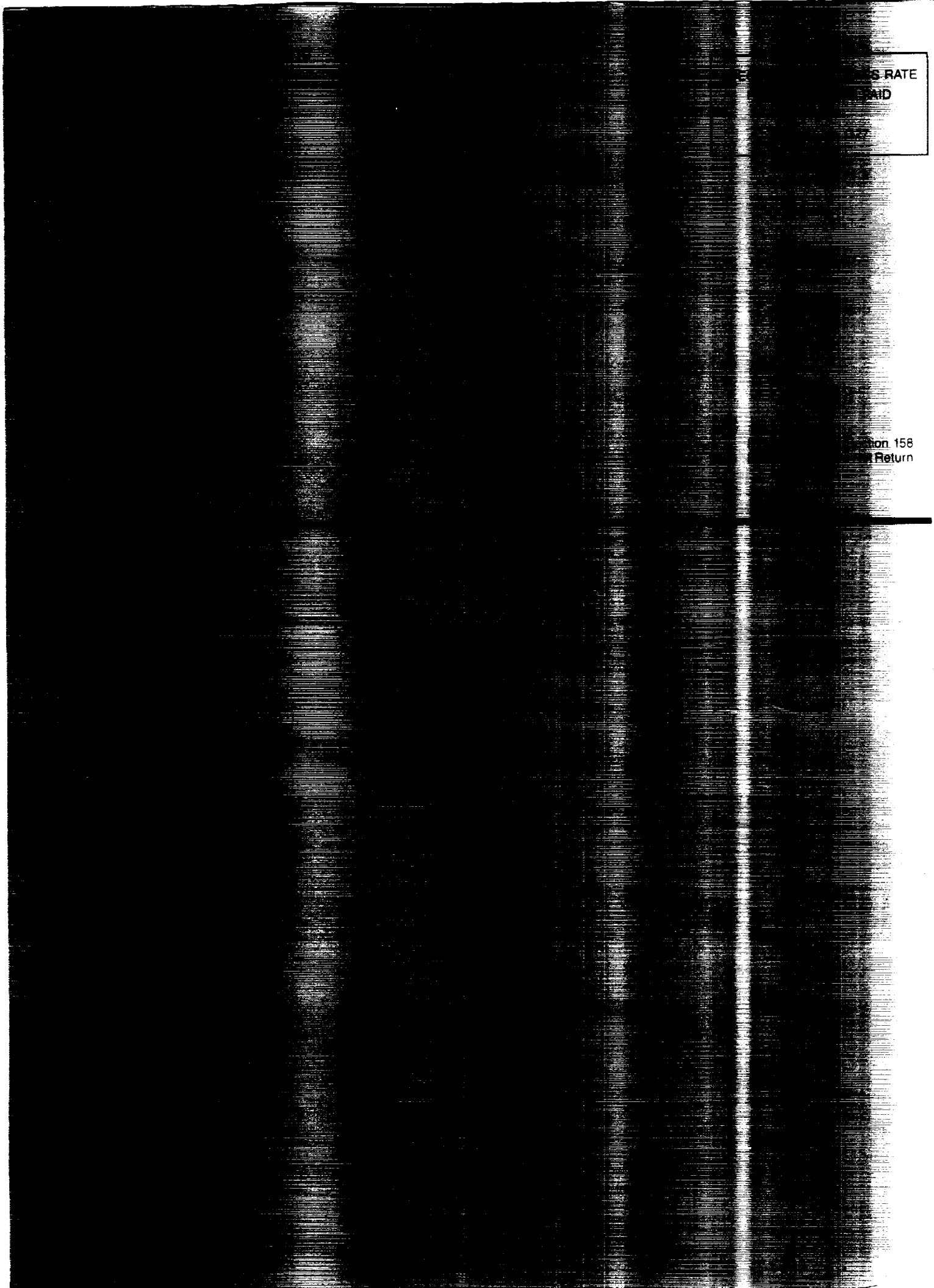
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