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Recent field and geochemical research (1) has questioned the claim for the earliest traces of life on Earth (2) in a banded quartz-pyroxene dominated rock from Akilia Island, southern West Greenland. This rock, once considered a banded iron formation (BIF), has now been interpreted as a highly deformed ultramafic igneous rock that has undergone pervasive silica addition. We present oxygen isotope analysis by laser fluorination/mass spectrometry on quartz in a suite of samples from the banded rock on Akilia, as well as similar rocks on Ingnerssuartut Island (ca. 10 km south of Akilia). All studied rock samples show $\delta^{18}O$ values consistently around $+12\ ^o/_{oo}$ relative to SMOW, which is significantly lower than $\delta^{18}O$ values of quartz from BIFs of the related amphibolite-facies Isua Supracrustal Belt, ca. 150 km northeast of Akilia. Instead, the data fall in the $\delta^{18}O$ range of granites and pegmatites. Typical low-grade metamorphic BIFs have quartz $\delta^{18}O$ of ca. $+20\ ^o/_{oo}$ and magnetite $\delta^{18}O$ of ca. $+3\ ^o/_{oo}$. If one assumes closed-system conditions, isotope mass balance shows that the observed low values for quartz can only be obtained by isotope exchange between quartz and magnetite during metamorphism if an original BIF consisted of at least 50-80 wt % magnetite. This is not consistent with the observed mineralogy; magnetite is a minor mineral phase in the Akilia quartz-pyroxene rock, and some of the layers in the succession are nearly pure quartzites. It is possible, however, that open-system isotope exchange occurred between quartz of an original chert/BIF and a low $\delta^{18}O$ metamorphic fluid that equilibrated with surrounding igneous rocks. In order to explain the observed low $\delta^{18}O$ values, a pervasive fluid infiltration and high fluid/rock ratio is required, for a sufficiently long time to allow complete recrystallization of the original quartz grains. Quartz from our Akilia samples does not show any variation in $\delta^{18}O$, suggesting that if it was ever part of a chert/BIF, then pervasive fluid infiltration would have been required for the entire outcrop. Such fluids would dissolve graphite during recrystallization if not carbon-saturated, and would exchange $\delta^{13}C$ if carbon saturated. Either way the preservation of carbonaceous inclusions in apatite crystals, that were previously interpreted as biogenic in origin, appears highly unlikely. It could be argued that we have sampled only those parts of the outcrop that were most intensely infiltrated with silica, and our $\delta^{18}O$ values would simply reflect metasomatic quartz, not the original chert/BIF. However, we obtained $\delta^{18}O$ values from the exact same location in which the isotopically light carbon was discovered. We conclude that the observed mineralogy and quartz $\delta^{18}O$ do not favor a BIF protolith. The apatite-graphite associations in the Akilia quartz-pyroxene rock must have formed during or after the last main metamorphic event, and thus are at least younger than ca. 2800 Ma. The graphite inclusions may be metasomatic in origin or may be derived from the introduction of organic carbon during metamorphism. (1) Fedo, C. M., Whitehouse, M. (2002) Science, 296, 1448-1452. (2) Mojzsis, S. J., et al. (1996) Nature, 384, 55-59.

P71C-0475 0830h POSTER

Graphite as a Biomarker in Rocks of the 3.8 Ga Isua Supracrustal Belt

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Recent petrographic and isotopic studies of graphite and apatite in supracrustal rocks from the 3.8 Ga Isua belt (ISB) in southern West Greenland [1, 2] have shown inconsistencies in interpreting traces of life in the earliest terrestrial sediment record. Isotopically light graphitic carbon, suggestive of a bioorganic origin, has been previously reported from the carbonate-rich Isua rocks [3, 4] that at the time were recognized as sedimentary deposits. However, these carbonate-rich rocks, that provided the basis for original biologic interpretations, have been shown to have a metasomatic origin [5] not sedimentary as previously believed. This protolith reinterpretation has highlighted the need for assessment of graphite genesis and related isotopic systematics when using graphite as an ancient biomarker. We have, for this purpose, studied graphite in a suite of samples from the ISB including metacarbonates, turbidites, cherts and banded iron formations (BIFs).

Graphite is relatively abundant (0.1-2 wt. %) in metacarbonate samples, while the abundances of reduced carbon in metasedimentary BIFs and metacherts are below 100 ppm. Petrographic analyses show that graphite in metacarbonates typically associates with Fe-bearing carbonate and magnetite. This mineral association indicates graphite formation in Isua metacarbonates by thermal-metamorphic reduction of carbonate ion, in which the carbonate ion is reduced to form graphite and ferrous iron is oxidized to form magnetite. Carbon isotopic compositions of graphite ($\delta^{13}C$ ca. -2 per mil) and associated Fe-carbonate ($\delta^{13}C$ ca. -6 per mil) indicate isotopic equilibrium between these two phases at ca. 500 C, consistent with the metamorphic history of the ISB. Stepped-combustion experiments undertaken on Isua BIFs and metacherts reveal that these sediments contain virtually no graphite, and the small amount of reduced carbon found there represents recent organic contamination. Our stepped-combustion-mass-spectrometry data demonstrate that previous isotopic results on graphite deficient Isua rocks obtained by single step combustion are unreliable.

The proposed biologic significance of graphite occurring as inclusions in apatite [4] in Isua rocks is not supported by our findings because such graphite-apatite association can only be found in biologically irrelevant metacarbonate rocks. The isotopic systematics of the epigenetic processes responsible for formation of isotopically light graphite enclosed in apatite crystals [4] will be discussed, integrating new ion microprobe isotope data on graphite in apatite and other mineral phases occurring in Isua metacarbonates.

References: [1] van Zuilen, M., Lepland, A. & Arrhenius, G., 2002. Reassessing the evidence for the earliest traces of life. Nature 418: 627-630. [2] Lepland, A., Arrhenius, G. & Cornell, D. in press. Apatite in early Archean Isua supracrustal rocks, southern West Greenland: its origin, association with graphite and potential as a biomarker. Precam. Res. [3] Schidlowski, M., 1988. A 3,800-million-year isotopic record of life from carbon in sedimentary rocks. Nature 333: 313-318. [4] Mojzsis, S.J., Arrhenius, G., McKeegan, K.D., Harrison, T.M., Nutman, A.P. and Friend, C.R.L., 1996. Evidence for life on Earth before 3800 million years ago. Nature 384: 55-59. [5] Rosing, M.T., Rose, N.M., Bridgwater, D. and Thomsen, H.S., 1996. Earliest part of Earth's stratigraphic record: a reappraisal of the >3.7 Ga Isua (Greenland) supracrustal sequence. Geol. 24: 43-46.

P72A MCC: Hall D Sunday 1330h

Closing the Loop: Remote Analysis of Terrestrial and Planetary Surfaces II Posters *(joint with V)*

Presiding: **L K Fenton,** California Institute of Technology**; S W Ruff,** Arizona State University

P72A-0476 1330h POSTER

Reduction of Spectral Contrast Between Laboratory and Remote Spectral Observations

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A significant challenge in "Closing the Loop" is the apparent reduction in spectral contrast observed in remotely acquired data compared to laboratory data. Laboratory measurements of many geologic materials (minerals, rocks, soils) show well defined absorption or emission features linked to the fundamental chemistry and structure of the constituents, forming the basis of remote material identification. High spectral resolution observations of natural surfaces exhibit diagnostic absorption features permitting material identification. However, the strength of the absorption features is attenuated relative to laboratory measurements. While this does not affect the identification of materials which have well defined, strong absorptions, it can affect identification of materials that exhibit weak absorptions. Furthermore, models or analytical approaches to quantify the amount of material present will under estimate the true amounts due to this reduction in spectral contrast. A central question is what are the causes of the reduction in spectral contrast and can they be accommodated? Here I assess three possible causes: particle size, texture, and unaccounted for components. Many laboratory measurements are of well characterized materials of relatively large particle size. Natural surfaces contain a wide range of particle sizes. Theory predicts and many studies have shown that contrast is reduced for small particle sizes. Also, where a range of particle sizes exists, the small particle sizes influence the measured signal greater than their mass fraction in the system. Texture (solid vs. particulate, rough vs smooth) is well known to affect spectral contrast. This is particularly important for thermal emission measurements where cavities behave as small blackbodies, reducing spectral contrast. Smooth surfaces for vis-near infrared wavelengths have much reduced contrast while contrast in increased at thermal emission wavelengths. Unaccounted for constituents probably play the largest role in reducing spectral contrast. Natural surface contain a number of weathering products which are poorly known, and equally poorly crystalline. The lunar example provides guidance for this where the lunar soils show weakened contrast relative to rocks from which they were derived. Detailed detective work revealed that this was due to agglutinates, free iron metal, and very fine grained shocked plagioclase. An assessment of the relative importance of these spectral reduction processes will be presented and possible effects on the goal of "Closing the Loop" will be discussed.

P72A-0477 1330h POSTER

Application of the machine learning method in an inverse scattering problem

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In the past few years and in the next decade, several ground penetrating radars have been or will be used to explore geological composition of subsurface layers, for example, with the aim to discover watter or ice subsurface reservoirs. This paper is focused on the fundamental physical and mathematical theory behind these measurements and numerical analysis of a gradient inverse scattering method for the determination of the geometrical and dierectrical properties of the subsurface layers from received radar signal bacscattered by the studied media.

We consider a model of an ellipse-shaped seam surrounded by several layers with different conductivity and a numerically generated backscattered signal (eventually with imposed artifical noise). We discuss several convergence methods (Newton's method, gradient and conjugate gradient methods, Levenberg-Marquardt method, false position method, simulated annealing and treshold accepting) used for the inverse analysis of the backscattered signal. To improve accurancy and efficiency of these methods we use machine learning method. Its procedures decision trees and support vector machines are analyzed with respect to their ability to recover seam's properties from the signal without additional information about the backscattering process.

P72A-0478 1330h POSTER

Development of Rule-Based Autonomous Spectral Analysis Techniques for Planetary Surfaces: Preliminary Results Using Lab Spectra

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Many different regression schemes have been used for autonomous identification of minerals from reflectance and emittance spectra. Most existing analysis procedures focus on direct examination of individual spectra or ad hoc procedures to identify specific types of minerals. These procedures are constrained by limitations of the spectral library used as a training set and are inadequate to deal with the enormous volume of data from current and planned missions. One promising alternative to regression schemes is 'expert systems' or rule-based systems, which is one of the oldest AI technologies. A simple rule-based system consists of three components: a list of facts, a set of rules, and a 'production rule interpreter'. The rule-based approach has several advantages over other classification schemes, including the ability to take advantage of the knowledge of human experts, simple problem diagnosis methods, and a trace facility to explain reasoning. Because of these advantages development of a rule-based system for autonomous spectral identification on planetary surfaces is underway.

The objectives of this project include characterization of spectral bands for selected minerals in laboratory and field spectra and development of algorithms for automated spectral identification of key minerals in visible/NIR and mid-IR spectral ranges. A variety of spectral issues complicate the identification of minerals regardless of whether a human user or an automated system is involved in the processing. These include pure minerals versus mixtures and natural samples, the grain size and texture of minerals, and cation substitutions in the mineral structure.

The advantage of the rule-based system is that it is not based on spectral libraries, but on spectral features. Preliminary efforts so far have enabled the autonomous identification of a few minerals based on the presence of multiple spectral features at wavelengths within a defined range using only a band center. Work currently underway includes specifying a band width as well as band center and appears promising for identification of a broader number of minerals.

P72A-0479 1330h POSTER

Automated Remote Sensing with Near Infrared Reflectance Spectra: Carbonate Recognition

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Reflectance spectroscopy is now a standard tool for studying the mineral composition of rock and soil samples and for remote sensing of terrestrial and extraterrestrial surfaces. We describe research on automated methods of mineral identification from reflectance spectra and give evidence that a simple algorithm, adapted from a well-known search procedure for Bayes nets, identifies the most frequently occurring classes of carbonates with reliability equal to or greater than that of human experts. We compare the reliability of the procedure to the reliability of several other automated methods adapted to the same purpose. Evidence is given that the procedure can be applied to some other mineral classes as well. Since the procedure is fast with low memory requirements, it is suitable for on-board scientific analysis by orbiters or surface rovers.

URL: http://www.phil.cmu.edu/projects/rockspec

P72A-0480 1330h POSTER

Mapping Playa Evaporite Minerals, White Sands, New Mexico Using Landsat ETM+

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Evaporite minerals are the main source of several industrial and agricultural minerals important to the U.S. and world economy. Landsat ETM+ data covering the White Sands, New Mexico have been used in this study. The White Sands Dune Field, Lake Lucero, and Alkali Flat have been chosen as target sites. The study aims to determine the number of evaporite mineral endmembers that can be detected and mapped using Landsat ETM+. Furthermore, the study also aims to determine the spatial distribution of fractional abundances of evaporite mineral endmembers assuming a linear mixing model. The Minimum Noise Fraction (MNF) transform and Principal Component Analysis (PCA) were employed to determine a reduced set of noise-free spectral bands. The Pixel Purity Index (PPI) and n-D Visualization (nDV) were conducted on the reduced set of spectral bands to identify spectrally pure evaporite mineral endmembers in the image. Mineral maps of the spatial distribution and relative abundance of evaporite minerals were performed using two different algorithms: Spectral Angle Mapper (SAM) and Linear Spectral Unmixing (LSU). Four evaporite mineral endmembers have been identified using Spectral Angle Mapper. These minerals are gypsum, halite, calcite, and thenardite. The results of Linear Spectral Unmixing showed that the most common and abundant evaporite mineral in the White Sands is gypsum. The results of Spectral Angle Mapper (SAM) and Linear Spectral Unmixing (LSU) are validated by collecting field samples from different locations within the White Sands. A good match has been determined between results of Landsat ETM+ data and field and laboratory work. Mapping of playa evaporite minerals is of potential importance for the goal of saline soil characterization, regional groundwater hydrology and quality, and mineral resource development.

P72A-0481 1330h POSTER

Surface-Temperature and Emissivity Recovery using the Spaceborne Multispectral Thermal Imager (MTI) Sensor

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Determining surface-temperature (T) and emissivity spectra (ϵ) is significant to many aspects of Earth and planetary sciences, and has motivated the design and utilization of terrestrial remote-sensing instruments. However, as the amount of radiation emitted from a surface is dependant on both its T and ϵ, their estimation from remotely sensed data remains an underdetermined problem, requiring additional assumptions in order to constrain the inherent extra degree of freedom. A simple algorithm, based on the normalized emissivity method, enables the retrieval of terrestrial surface temperatures (260-330K) and emissivities to within $\pm$1K, and $\pm$0.02 respectively, with data from the Multispectral Thermal Imager (MTI) thermal bands. Using the normalized emissivity method, the extra degree of freedom in determining T and ϵ from remotely sensed data is reduced by assigning a maximum ϵ value to each band, and assuming that the true emissivity in one of the bands is within an acceptable range from the assumed ϵ. Using Planck's function and the assumed emissivities, apparent temperatures are calculated for each band. The maximum apparent temperature is then taken as the estimated surface-temperature, which is subsequently used to estimate emissivities in the other bands.

Designed as a research and demonstration satellite, MTI offers five thermal bands: two in the mid-infrared wavelengths (MIR: 3-5 μm), and three in the thermal infrared wavelengths (TIR: 8-12 μm). Each of these bands has a unique dL/dT (where L is emitted radiance, and T is temperature), which is defined by Planck's function. The MTI T/ϵ separation algorithm utilizes the fact that dL/dT in the MIR bands is significantly higher than in the TIR bands. Consequently, T estimates using the MIR bands are less sensitive to errors in emissivity assumptions, and can be used in some cases to improve T recovery. However, this also implies that MIR emissivities, in atmosphere-free numerical simulations, are recovered to within $\pm$0.04, as opposed to $\pm$0.02 ϵ recovery in the TIR bands in similar simulations. Night-time validation of the MTI T/ϵ separation algorithm at Mauna Loa Caldera in Hawaii suggests that the algorithm performs within similar error thresholds in real conditions. Day-time implementation of the algorithm requires significant correction for reflected solar irradiance in the 3.87-μm MIR band, but only minor correction in the other 4.97-μm MIR band. Emissivity recovery in the MIR range may enable improved surface-composition and particle-size estimations.

P72A-0482 1330h POSTER

Mineralogical Ground Truth for AVIRIS Hyperspectral Observations of Cinder Cones on the Summit of Mauna Kea Volcano

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Palagonitiztion has been suggested as an import surface weathering process on Mars based on comparisons of spacecraft and telescopic remote sensing and laboratory data for phyllosilicate-poor palagonitic tephra. Palagonite (a poorly ordered material) is found in close association with products of local hydrothermal alteration in the summit region of Mauna Kea Volcano (Hawaii). We are investigating the mineralogical and chemical composition of these basaltic hydrothermal alteration products as a guide to specific hydrothermal alteration products that might be present on Mars. Using a variety of analytical techniques (including reflectance and Moessbauer spectroscopy, major element analysis, and X-ray diffraction), we have identified and characterized the spectra signatures of hematite, kaolinite, smectite, jarosite, and alunite as well-crystalline hydrothermal alteration products. The close spatial association of both poorly-crystalline palagonite and well-crystalline hydrothermal minerals on Mauna Kea, AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) coverage of the same area, and the ground-truth laboratory data provide a way to quantify the remote-sensing detectability of hydrothermal alteration products in the presence of unaltered and other altered materials. The AVIRIS observations of Mauna Kea are a good analogue for CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) measurements of Mars because both are visible-infrared hyperspectral mapping instruments. CRISM measurements are part of the Mars Reconnaisance Orbitor 2005 mission.

P72A-0483 1330h POSTER

Field and Radar Remote Sensing Analyses of Compound Flow Fields

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This research is part of an ongoing field and remote sensing analysis of surface units within the 1969-1974 Mauna Ulu flow field (Kilauea Volcano, Hawai'i). The current study examines the complex unit-scale topography produced by primary lava emplacement and secondary modification, as well as the utility of radar data for distinguishing flow regimes and post-emplacement changes within the flow field.

Study sites were selected to represent the range of surfaces present within the flow field and described in terms of adjacent flow units, topographic characteristics, and a semi-quantitative assessment of fracturing and inflation. Topographic characterization included a qualitative description of the exposure surface at the cm- to m-scale as well as a measurement of the maximum relief displayed over a 1-m horizontal distance within the unit. Each pahoehoe unit was also characterized in terms of the degree of fracturing and apparent inflation that had occurred at the scale of toes (small-scale), small lobes and channels (intermediate-scale), and large lobes and tumuli (large-scale). The average maximum relief measured at the selected sites increases from sheets (29 cm) and networks of toes with glassy surfaces (32 cm), to disrupted, remobilized units (55 cm) and 'a'a (56 cm), to viscous, late-stage toe networks (72 cm). All of the selected pahoehoe sites display surface fractures at small- to intermediate-scales, and pahoehoe sheets may additionally display large-scale fracturing. Fractures appear to be predominantly associated with flow inflation (at small, intermediate, and large scales) and cooling (at the small scale).

Two AIRSAR flight lines that were acquired October 11-12, 2000 are examined in the current analyses. The lowest mean backscatter coefficient of the units sampled in this study is associated with tube-fed pahoehoe sheets, followed successively by tube-fed networks of toes with glassy surfaces, late-stage tube-fed toes, remobilized tube-fed pahoehoe, surface-fed pahoehoe, medial 'a'a, and finally distal 'a'a. An apparent correlation observed in the field between small-scale (mm to cm) and larger-scale (dm to m) roughness is supported by the radar analysis. Because individual pahoehoe units are typically too small to resolve in the radar data, the AIRSAR data alone has not been useful for identifying primary emplacement morphologies and secondary modification of the units. However, radar may be used for constraining the range of surfaces

present within a flow field, and may be used with morphologic information to provide reasonable interpretations for emplacement of units that are larger than the pixel size. Furthermore, radar data may be used to constrain the extent of inflation within the flow field if independent information about primary morphologies is available, such as from visible-wavelength remote sensing data.

P72A-0484 1330h POSTER

Determining Crystal Abundance in Glassy Lavas: Combining Laboratory Infrared Spectroscopy With Remote Sensing

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Variations in the surface composition of high silica glassy lavas can provide information about the emplacement history, eruptive style, and structure of flows and domes. However, traditional field mapping of these variations is commonly time consuming, incomplete and impossible for planetary and remote terrestrial environments. Thermal infrared (TIR) remote sensing can provide a more efficient and effective method for mapping this chemical variability. Both high spectral resolution laboratory data and high spatial resolution airborne thermal images were used to evaluate the abundance and composition of crystals in silicic glasses.

Image and laboratory thermal emission spectra were collected from the compositionally mixed Glass Mountain flow in northern California, which has a bulk silica content from 57% to 75%. The multispectral image data, acquired using the MODIS/ASTER (MASTER) airborne simulator, were reduced to emissivity and compared to laboratory emission spectra of 40 samples. Data were modeled using a linear deconvolution algorithm to calculate compositional abundances for two end-member suites one containing rhyolite and dacite bulk rocks and the other containing common phenocryst minerals. Crystal contents derived from the deconvolution approach of the laboratory spectra ranged from 0% in glassy obsidians to more than 48% in the most mafic samples. These modeled abundances generally agreed with values derived from a petrographic analysis, but were higher on average. One possible explanation for this bias is an increased emitted infrared signal due to the presence of microlites and nanolites.

Application of the deconvolution-model to the MASTER remote sensing data produced crystal abundance maps that highlight zones of heterogeneity. However, complications due to instrument calibration, the effects of vesicularity, and the moderate spectral resolution limit the accuracy of this approach. As techniques are improved, spectral data from spaceborne instruments, such as ASTER and THEMIS, can be used to characterize glassy lavas on Earth and other planets. Laboratory spectroscopy provides a baseline for this work.

P72A-0485 1330h POSTER

Thermal Infrared Spectra of Experimentally Shocked Albitite

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We have acquired thermal infrared (3-40 microns) hemispherical reflectance and emissivity spectra of shocked samples of a fine-grained (1-5 mm) albitite from Szklary, Poland to determine the spectral degradation effects of shocked albite as a function of increasing shock pressures (17-56 GPa). Reflectance data were acquired using a Nicolet 5SXC FTIR spectrometer at the HIGP, University of Hawaii, and emission spectra were acquired using a Nicolet Nexus 670 emission spectrometer at Arizona State University. These data complement similar previous measurements of experimentally shocked anorthosite relevant to interpreting spectra provided by the Thermal Emission Spectrometer (TES) on Mars Global Surveyor. The samples were shocked using the 25-mm barrel gun at Johnson Space Center and provided 400 mg per sample. Large (2-10 mm) chips of recovered material were separated from the samples and washed to remove clinging fines, and the residual was powdered to provide a consistent grain size (∼20 microns). Spectra were obtained of both the chips and the powder samples. Results for the chips show a progressive loss of spectral features and contrast compared to unshocked samples, while results for the powders show a reduction in the depth of the transparency feature located near 855 wavenumbers (11.7 microns) with increasing pressure. The albite structure retains its crystalline state to higher pressures than anorthosites, consistent with previous transmission spectra. Additional visible/near-infrared (0.35-2.50 microns) measurements of the powdered albitite and anorthosite samples also were acquired at the RELAB facility. These spectra show a decrease in albedo and a loss of water bands near 1.4 and 1.9 microns with increasing pressure. The broad feldspar absorption near 1.25 microns was not present in the albitite sample (possibly due to its fine original grain size) but was present in the anorthosite sample, where its band depth decreased with increasing shock pressures.

P72A-0486 1330h POSTER

Effects of Palagonitic and Basaltic Dust Coatings on Visible, Near-IR, Thermal Emission and Moessbauer Spectra of Rocks and Minerals: Implications for Mineralogical Remote Sensing of Mars

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Dust coatings on the surface of Mars complicate and, if sufficiently thick, mask the detection of the mineralogical signatures of the underling material from remote sensing instrumentation aboard orbiters, landers and rovers. An air-fall method for depositing fine-grained material (<50 microns) was developed to uniformly coat rock (basalt, andesite, kaolinite and quartz claystone, schistose hematite) and mineral (olivine, pyroxmangite, siderite) substrates to thicknesses up to ∼2000 microns. Dust analogs used to date include, palagonite from the summit region of Mauna Kea Volcano (Hawaii) and crushed basaltic material from Mulcahy Lake (Canada). The method allows for the determination of spectral effects resulting from various thicknesses of dust accumulation with numerous experiment techniques (visible, near-IR, thermal emission and backscatter Moessbauer spectroscopy). Results demonstrate that infinite optical thickness in the visible wavelengths (350-700 nanometers) is on the order of 10-35 and 10-55 microns for palagonitic and basaltic dust coatings, respectively. Band features for all the substrates were complete diminished in the near-IR (700-2100 nanometers) with coatings of ∼300 microns for both dust analogs. In the thermal emission spectra (2000-200 wavenumbers) the emissivity spectrum of the substrate was obscured with dust thicknesses of 150-250 microns. Palagonitic dust coatings ∼2000 microns thick (∼25 mg/cm^2) were not sufficient to mask the substrate material from the 14.4 kev gamma-rays used in the Moessbauer experiments.

P72A-0487 1330h POSTER

Silica-Coated Basalt on Mars: A New Interpretation of Dark-Region Thermal-Emission Spectra

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Results from the Thermal Emission Spectrometer (TES) show that Martian dark regions are composed of two distinct components. One is accepted to be basalt. The other is controversial, having been interpreted as andesite/basaltic andesite and as chemically weathered basalt. This second component, referred to here as S2, occurs most prominently in the northern plains, but it is also seen in the southern highlands, generally in higher concentrations at higher latitudes. The apparent latitudinal dependence of S2 suggests that its occurrence may be linked to water or near-surface ground ice.

In the andesite hypothesis, the TES S2 spectrum has been linearly deconvolved to plagioclase feldspar, high-silica glass, and pyroxene near the TES detection limit. We accept this mineralogical interpretation of S2, but propose that the high-silica glass component can be interpreted as amorphous silica. We have performed x-ray diffraction and thermal-emission measurements on several samples of non-crystalline and microcrystalline opal. The thermal-emission spectra of silica glass and amorphous, opaline silica are highly similar in shape and the location of absorption features are identical. A good match to the S2 spectrum has been produced by linear deconvolution, using TES-derived basalt and opal as endmembers (rms = 0.340, 1300-300 cm^{-1}). Adding constituents such as alumina will shift the opal absorption features to lower wavenumbers, which is predicted to produce better deconvolution results.

We propose that S2 may be basalt coated by amorphous silica. This hypothesis is similar to the weathered-basalt model in that it requires some degree of aqueous chemical processing. However, silica coatings occur on the exterior of rocks, formed by sedimentary deposition of silica. When weathering rinds form, chemical components are dissolved from a rock. Consequently, weathering rinds tend to be mechanically weak and would be highly susceptible to wind abrasion, especially under Martian eolian conditions. Conversely, silica coatings are resilient and have been found to form on active dune sands on Earth. Additionally, the near-infrared evidence for clay minerals on Mars is lacking. While a viable hypothesis for S2, glass-rich basaltic andesite lacks a model to explain its widespread occurrence. Alternative explanations of S2 should be explored, and silica rock coating is a practicable geologic model.

P72A-0488 1330h POSTER

Experimental Constraints on the Interpretation of Martian Reflectance Spectra

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Experiments to determine the crystallization sequence of the Mars PathFinder (MPF) rock composition have been carried out to explore the possible mineral assemblages present in this SiO2-rich (57.4 wt.%) Martian igneous rock. Recent MGS thermal emission spectrometer observations (Bandfield et al., 2000) have suggested the presence of large volumes of andesitic lava covering the northern hemisphere of Mars, but this interpretation has been called into question. Experimentally produced mineral assemblages can be used to infer spectral characteristics that would exist in lavas similar in composition to the MPF rock. The inferred spectra could then be used to examine remotely sensed data to further constrain the identity of surface rock types on Mars.

We performed a series of 1 atmoshpere experiments at the QFM oxygen buffer using the calculated soil free MPF composition reported by Wanke et al.(2001). Experiments were performed over a temperature range of 1200 to 1000°C and experimental durations were 10 days. The liquidus of the MPF composition is approx. 1075°C where plagioclase (An 94) and quartz become the saturating phases. At 1050°C, augite (Wo= 30; mg#= 43) joins the sequence. Fe-Ti oxides have joined the crystallization assemblage at 1000°C. Therefore, the potential mineralogy for a lava with the MPF composition would be SiO2(57 wt.%),FeO (18 wt.%) rich glass, plagioclase, quartz, augite and Fe-Ti oxides.

Cloutis and Gaffey (1991) developed a band I and II minima contoured pyroxene quadralateral in order to predict pyroxene composition based on reflectance spectra. Using the quadralateral in reverse, the augite produced in our experimental series should have band I and II minima at 0.97 and 2.15 microns respectively. No band I minima was observed in the IMP spectra taken at the Pathfinder Site near 1 micron as would be expected if pyroxene was present in the rocks at the pathfinder landing site (McSween et al., 1999). The 1 micron minima commonly associated with pyroxene has been observed from both telescopic and orbiter imaging (Mustard and Sunshine, 1995). The absence of the 1 micron minima in the IMP spectra could be due to masking phases, possibly the Fe-Ti oxides produced in our experiments at 1000°C.

P72A-0489 1330h POSTER

Integrating THEMIS Imagery, MOC High-Resolution Images, and TES-Derived Thermal Inertia Data to Evaluate the Dust Thickness, Distribution, and Origin in the Tharsis Region and Arabia Terra, Mars

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The Tharsis region and Arabia Terra, Mars are characterized as having a low albedo (0.26 to 0.35), low thermal inertia (26 to 148 J/m2Ks1/2), and low rock abundance. These regions are interpreted to be covered in a blanket of unconsolidated dust with an average particle size less than about 40 microns. Areas of low thermal inertia and high albedo are inferred to be regions of active dust accumulation and low wind velocities implying that the dust thickness is increasing. An understanding of the dust quantity on these surfaces and recent changes in dust thickness is critical to identify the erosional and depositional history of this deposit and to understand how recent geologic processes have affected the transport of fine-particulate material.

The thickness of the dust deposits in the Tharsis region is currently estimated to be between 10 cm and several meters, with a reduction of thickness away from the center. Arabia Terra has a similar dust deposit and initial investigation suggests that the thickness of dust in this region is also variable. This study uses Mars Global Surveyor Thermal Emission Spectrometer (TES) thermal inertia information, Mars Orbiter Camera (MOC) high-angle images, and Mars Odyssey Thermal Emission Imaging System (THEMIS) infrared and visible data to quantitatively evaluate the distribution of dust and the variation in thickness of this deposit in Tharsis Montes and Arabia Terra, Mars. Thermal inertia will be used to calculate a minimum thickness of dust required to produce the thermal signature observed. MOC images will be analyzed via depth to diameter ratios of area craters and visual characteristics to assess the variation in dust mantling. These thermal and visual characteristics will be utilized to assess the behavior of this surface cover, verify if this deposit possesses similar characteristics in both regions, and determine if these deposits have fluctuated in recent history.

P72A-0490 1330h POSTER

Identification of a Spectrally and Thermophysically Unique Region in Northern Amazonis Planitia, Mars: Surface Analysis using TES and THEMIS Data

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An intermediate-albedo (0.23-0.24) region located in northeastern Amazonis Planitia (approximately 900 km2 in area, centered at 40N, 150W) has been discovered to have a unique combination of certain spectral and thermophysical properties. The range of thermal inertia values for this region is 40-150 J/m2Ks1/2. On Mars, these values are usually indicative of a thick deposit of very fine-grained material (<63 microns) [1]. However, unlike typical dust deposits on Mars, this region exhibits moderate spectral contrast, with surface emissivity values ranging from 0.94-0.97 near 1030 cm-1. These emissivity values are uncharacteristic of fine-grained material [e.g., 2]. The modal mineralogy obtained by linear deconvolution of selected emissivity spectra from at least four different orbits over this region is not different than that reported for the Acidalia Planitia andesitic surface [3], within the mineral abundance detection limit estimated for TES [4]. However, the atmospherically-corrected surface spectral shape is distinct from the surface spectra common to Acidalia Planitia [3], Syrtis Major [3, 4], Sinus Meridiani [5] and Nili Fossae [6]. A spectral index was developed that describes the shape of a concave-down portion of the surface spectrum near 900 cm-1. A global 4 pixel-per-degree map of this index shows that the spectral character is unique to this region on Mars. MOC and THEMIS visible images available for this area show a uniform geomorphology consisting of parallel sinuous features trending NW-SE. Finally, THEMIS IR images show a sharp temperature contact that corresponds with the boundary of this area in the spectral index map. There are likely to be other explanations for reconciling the low thermal inertia with high spectral feature depth, however a favored hypothesis for this anomalous surface is that it is composed of a consolidated but highly porous material. This and other interpretations for this region will be discussed.

References: [1] Kieffer et al. 1977, JGR, 82, 4249-4291; [2] Moersch and Christensen, 1995, JGR, 100, 7465-7477; [3] Bandfield et al. 2000, Science, 287, 1626-1630; [4] Christensen et al. 2000, JGR, 105, 9609-9621; [5] Christensen et al. 2000, JGR, 105, 9623-9642; [6] Hamilton et al. 2001, LPSC XXXII Abstracts, abstract 2184

P72A-0491 1330h POSTER

Sedimentary history in Proctor Crater on Mars from TES thermal inertia measurements

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The thermal inertia of Martian dunes has been studied in detail since the first thermal models were produced for Mars. In particular, the dunefield within Proctor Crater, located in the southern highlands in Noachis Terra, has been used as a basis for comparison between different models. Here, the sedimentary environment of the interior of Proctor Crater is described in detail using recently derived thermal inertias from the Thermal Emission Spectrometer (TES) [*Jakosky et al.,* 2000; *Mellon et al.,* 2000].

The warmest and clearest TES tracks produce an average thermal inertia of 277 ± 17 J m^{-2} s$^{-0.5}$ K^{-1}, consistent with a grain size estimate of 740 ± 170 μm. This estimate is in the range of coarse sand (*e.g.,* 500-1000 μm), as expected for Martian dune sands. Furthermore, each TES track crossing the dunefield shows a steady decrease in thermal inertia to the south. This trend comes from differential cooling rates of the dune surfaces reflected in nighttime surface temperatures, rather than being an artifact produced by changes in albedo, air pressure, or elevation. This shift could be produced by a number of different processes, such as a spatial variation in mean grain size or dune cementation, or by a gradual shift in the percentage of interdune flats relative to dunes. Possible sources of this trend are discussed.

The remainder of the crater floor shows an interesting patchwork of varying thermal inertias. Where small bright duneforms predominate (distinct from the large dark dunes that comprise the dunefield), effective thermal inertias are consistent with grains in the range of medium to coarse sand, the lowest values on the floor of Proctor Crater. However, the bright duneforms are probably not composed of loose sand grains, because in areas these bright duneforms appear partly degraded, suggesting some amount of cohesion. They are interpreted to be either stabilized dunes covered by some amount of dust that artificially lowers their thermal inertia, or granule ripples.

Other places of the floor of Proctor Crater have thermal inertias consistent with gravel or indurated fine material. The lack of dust devil tracks and bright duneforms in these areas suggests that this is a windswept terrain, where all loose material has been deflated by the wind and the surface has been scoured, perhaps exposing a lower layer of material in Proctor Crater. A similarly high thermal inertia in a large deep deflationary pit on the crater floor suggests that such indurated terrains could comprise several sedimentary layers in the crater, now only revealed by erosive wind action.

The thermal inertia of the floor of Proctor Crater indicates a terrain dominated by aeolian processes. Sand and dust deposition as well as deflation and abrasion have worked together to form and modify the surface of the crater floor. Additionally, for the first time, the change in thermal inertia across a Martian dunefield is investigated in order to understand its sedimentary history.

Jakosky, B. M., et al., *JGR, 105,* 9643-9652, 2000.; Mellon, M. T., et al., *Icarus, 148,* 437-455, 2000.

P72A-0492 1330h POSTER

Hematite and Etched Terrain Distribution in Terra Meridiani, Mars

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Analyses of TES-based bolometric albedo, thermal inertia, and spectral emissivity-derived hematite index for the Hematite region in Terra Meridiani (centered at 1.5 deg S and 3.0 deg W) indicate the terrain to be homogenous at resolutions of 3 km per pixel. In contrast, MOC NA frames with a maximum resolution of 1.5 meters per pixel show that though the Hematite region is composed primarily of smooth, dark, pervasive dune-forms, there are also exposures of a ubiquitous bright material. This high albedo etched unit is interpreted to be a resistant substrate that extends beyond the borders of the overlying hematite-bearing plains. In order to quantify the relative superficial abundance of bright substrate and dark plains, we conduct high-resolution mapping of the hematite-bearing unit using MOC NA frames processed to ISIS level 2 (map projected with units proportional to radiance on sensor). As an illustrative example, MOC NA E03-01763 exhibits the etched unit in three typical settings: young crater rims, older craters which have lost much of their topographic signature but retain bright rims, and intercrater plains underlying dark, motley dunes. By area, 9.1% of the frame consists of bright material distributed uniformly across the scene. In general, MOC frames from the Hematite unit exhibit bright materials with an areal coverage ranging from 3% to 12%. This analysis demonstrates that the Mars Exploration Rover will be able to perform in-situ analyses of both the dark, hematite-bearing plains and the bright substrate over the course of the primary 90 sol mission.

P72A-0493 1330h POSTER

Formation of Martian Crystalline Hematite: New Information From Comparisons of Laboratory and TES Infrared Spectra

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The Thermal Emission Spectrometer (TES) instrument aboard Mars Global Surveyor discovered several isolated deposits of gray, crystalline hematite in Sinus Meridiani, Aram Chaos, and Valles Marineris. Comparison of the average Sinus Meridiani hematite spectrum measured by TES to laboratory emissivity spectra for a variety of naturally occurring hematites shows small but potentially important differences. In particular, the emissivity minimum at 300 cm^{-1} in the Sinus Meridiani spectrum is displaced 10-25 cm^{-1} to lower wavenumbers compared to pure hematite samples. In addition, the shape of the band in the TES data is thinner than the broad band seen in natural hematites. These differences may imply that the natural variability of hematite spectra has not been fully characterized, especially with respect to the reaction pathway and crystal morphology.

Here, we describe the thermal infrared spectral characteristics of several series of synthetic hematite samples derived by direct precipitation, dehydroxylation of fine-grained goethite and the oxidation of magnetite. The temperature of hematite formation, as well as the nature of the hematite precursor has distinct effects on the shape and position of the major absorption bands in the hematite infrared spectrum. Therefore, the shapes and positions of these features may be diagnostic of the hematite formation process. Comparison with TES spectra show that the best match to martian coarse-grained hematite is a synthetic sample derived by the dehydroxylation of goethite at 300°C. Spectra of goethite-precursor samples dehydroxylated at higher temperatures provide increasingly poor fits with increasing dehydroxylation temperature. In addition, spectra of samples derived by direct precipitation and high-temperature thermal oxidation of magnetite are poor fits to the martian coarse-grained hematite.

One of the main sites under consideration for NASAs 2003 MER missions is the hematite-rich region of Sinus Meridiani. The presence of the Mini-TES instrument on the rover will provide a unique opportunity to build upon TES measurements made from orbit around Mars. Of great importance will be the ability of Mini-TES to record surface spectral features in the 525-875 cm^{-1} region which cannot be done with TES due to the 667 cm^{-1} CO_2 fundamental absorption. The shape and position of the martian hematite absorption at 540 cm^{-1} will be visible for the first time, providing additional spectral information for comparison with laboratory data.

P72A-0494 1330h POSTER

The Single Scattering Albedo of Martian Atmospheric Dust in the 290-500 nm Region

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Despite multiple previous investigations, the detailed wavelength-dependence of Martian atmospheric dust absorption at ultraviolet (UV) and near-UV wavelengths is not particularly well-known. Several efforts have made some progress (e.g., Pang and Ajello, Icarus, 30, 63, 1977; Clancy et al., JGR, 100, 5251, 1995; Wolff et al., JGR, 104, 9027, 1999), but observational or instrumental constraints have severely limited the amount of detail retrievable. Ideally, one would observe an isolated dust signature with moderate spectral resolution and adequate spectral coverage. In essence, one would like to obtain data of a large-scale, optically-thick dust storm with a well-calibrated spacecraft-based spectrometer. Such a set of data has very recently been obtained, albeit somewhat fortuitously. Using the Hubble Space Telescope and the Space Telescope Imaging Spectrograph (STIS) instrument to perform high resolution imaging spectroscopy of Mars during the 2001 opposition, the combination of an electronics failure and an unusually early onset of a global dust storm, we have observations of Martian atmospheric dust with a minimal-to-undetectable surface contribution.

Our 2001 observations utilized the G430L grating to cover 289 to 590 nm at 0.27 nm/channel. The STIS 0.2 arcec slit was pushbroom-scanned across the 13-16 arcsec diameter planet in 70 adjacent steps, yielding a 3-dimensional image cube in 1024 wavelengths and at 20x80 km spatial resolution per spectrum. This was done during four visits on 2001 August 9, 10, 14, and September 4 (L_S=211° to 227°).

We will present the derived dust absorption spectra (i.e., single scattering albedo) which has resulted from our multiple-scattering, radiative transfer analyses of the STIS data. Our results will be compared to analogous efforts of Goguen et al. (personal communication, 2002) using nearly-contemporaneous observations in the 230-300 nm range (STIS/G230L). In addition, in order to better constrain the dust properties (e.g., size, shape) and subsequently isolate the single scattering albedo, our work includes retrievals from Mars Global Surveyor Thermal Emission Spectrometer observations (both the thermal infrared and solar-band channel).

P72B MCC: Hall D Sunday 1330h

Outer Planet Satellite Interiors I Posters *(joint with GP, T, V)*

Presiding: **E P Turtle,** University of Arizona**; W B Moore,** University of California, Los Angeles

P72B-0495 1330h POSTER

Formation of Regular Satellites in a Two-component, Extended Gaseous Subnebula: Predictions for the Cassini Mission

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It has long been hypothesized that the regular satellites of giant planets accreted in a planetary subnebula, but the properties of that subnebula have remained poorly understood. Unfortunately, reliable hydrodynamical planetary collapse calculations with sufficient resolution to characterize the large surface density range of the extended circumplanetary disk are lacking. Hence at present it is still useful to be guided by "minimum mass" models. Since satellite migration is likely, the question remains how to distribute the mass of solids within the disk. We argue that the subnebula accretion disk for Jupiter and Saturn should be divided into two components: the first extending outside (but perhaps close to) the centrifugal radius located at $\sim R_H/48$, and the second from there out to the location of the innermost irregular satellites at $\sim R_H/5$, where R_H is the Hill radius of the primary. Though such lengthscales have been mentioned in the literature before, their meaning has not been clarified. We will discuss heuristic estimates for both the location of the transition region between the inner and outer disks, and the radial extent of the circumplanetary disk.

Given such subnebulae, it is possible to compare the satellite systems of Jupiter and Saturn to see how the findings made by the Galileo spacecraft might apply to future observations by Cassini. Measurements of Callisto's gravity by the Galileo spacecraft indicate that the distribution of mass is less centrally condensed in Callisto than in Ganymede. In light of the similarities in sizes and densities between these two satellites and Titan it is fair to ask whether Titan can be expected to be more like Ganymede or more like Callisto in its degree of differentiation. Though measured in planetary radii Titan is located between Callisto and Ganymede, in terms of Hill radii of the primary the association is much closer to Ganymede. This leads us to conclude that (unlike Callisto) Titan formed in the inner disk in $< 10^5$ years. This timescale is too short for the heat generated by accretion to be radiated away, so we expect that Titan is fully differentiated. In this regard it may be more like Ganymede. On the other hand, both Callisto and Titan are likely to have received significant amounts of volatile-rich materials from the extended portion of the disk in the late stages of their accretion. Not surprisingly, then, Titan's surface is expected to be volatile rich. In particular, we argue that the composition of Titan's surface may be quite similar to that of the bright, trailing side of Iapetus (which itself is too volatile-rich to have been formed by solids accreted directly from heliocentric orbit). Indeed, late impacts with Iapetus-like or Hyperion-like objects that migrated due to gas drag into Titan's feeding zone may be responsible for the formation of Titan's thick atmosphere.

P72B-0496 1330h POSTER

Ammonia and the Interior of Titan

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Titan's surface will be very different from those of the Galileans, not just because of interactions with the atmosphere, but because the internal evolution will have been unique. The incorporation of ammonia in the ices making up Titan will make the evolution of Titan's interior structure very different.

The presence of ammonia was previously only hinted at by formation models and the remarkably thick nitrogen atmosphere. However, recent radar observations showing Iapetus' bright face to be surprisingly radar-dark also point to incorporation of ammonia in the ices of the Saturnian satellites, explaining Titan's radar-darkness too.

Ammonia will have several effects. As is well-known, its freezing-point depression to 176K makes a liquid layer ('internal ocean') more likely. A significant difference compared with the Galileans is that the greater expansivity of ammonia solutions compared with pure water causes the adiabat to be steeper, and thus a greater temperature difference prevails across the liquid layer. This in turn leads to a higher Carnot efficiency for the mantle heat engine - by an order of magnitude compared with Callisto - suggesting endogenic activity may be more manifest on Titan than on its Galilean cousins.

The replenishment of methane in Titan's atmosphere against photolysis requires either surface lakes, or volcanic replenishment. If plausible methane contents of water-ammonia cryolavas are assumed, the heat flux associated with volcanism can be easily accommodated by the expected radiogenic heat production in the rocky core.

URL: http://www.lpl.arizona.edu/~rlorenz

P72B-0497 1330h POSTER

Aqueous Seams in the Small Moons of Saturn and Uranus

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Eight small moons of Saturn and Uranus have a size and mass sufficient to have formed, and possibly maintained, an aqueous seam between a radiogenic rocky core and an insulating icy mantle. Analysis of thermal conduction in a composite sphere indicates that, at radiogenic rates typical of chondritic meteorites, four of these moons could maintain thin oceans even without tidal or other uncharacterized internal heating. If the radiogenic rate of rocky outer-planetary material is characteristic of the returned Lunar samples, which is about double the chondritic rate, aqueous seams may have formed in all eight moons as well as in Triton and Pluto, and could be maintained to the present day. Trans-Neptunian Objects with radii greater than 910 km are also candidates for thin oceans, the minimum radius reduced to 720 km if Lunar radiogenic rates are assumed. The assumption of differentiation of rock and ice in smaller bodies is supported by the high radiogenic rates during the formation of the Solar System. The melting point of icy materials was easily exceeded, leading to their outward flow and the corresponding concentration of radiogenic material in the core. Bodies with a density of about 1750 kg/m3 have the best proportion of ice and rock that balances the insulating value of the former with the heat production of the latter. Lower density bodies with higher water content such as Rhea may be more easily differentiated and therefore more likely to form and maintain an ocean. The presence of low-viscosity seams can be a major influence on the character and dissipation of tidal energy.

P72B-0498 1330h POSTER

Effects of Early Water-Rock Chemical Interactions on Interior Structures, Physical Properties, and Heat Balances of Galilean Satellites

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The layered internal structures of Io, Europa, and Ganymede, together with the presence of water in Europa, Ganymede, and Callisto imply that melting of accreted ice and large-scale water-rock type interaction accompanied differentiation of the satellites. Assuming that the original rocky material of the Galilean satellites was olivine rich (i.e., ultramafic), these interactions were analogous to processes which occur during aqueous alteration of terrestrial peridotites (serpentinization) and parent bodies of chondrites. Major chemical changes during this early aqueous alteration of Galilean satellites would have involved production of serpentine, magnetite, and hydrogen at the expense of olivine and water. Physical changes would have included rock volume increase owing to production of phyllosilicates, release and consumption of heat during chemical reactions, and changes in electromagnetic properties caused by formation of magnetite and/or secondary native metals in partially altered rocks. On Io, early water-limited serpentinization could have led to formation of magnetite followed by dehydration of hydrous phases driven by release of radioactive and tidal heat. Aqueous processes on Europa and Ganymede could have been less water-limited and likely led to profound alteration and oxidation of rocks. Magnetite formed through water-rock processes in the Ganymede's mantle may contribute to its permanent magnetic field. Callisto may have experienced an incomplete aqueous alteration allowing primarily and secondary native metals to survive oxidation. Volume change during serpentinization of satellites, and later release of water during deserpentization, can affect tectonic processes, including redistribution of ice and liquid water, disruptions of outer icy shells, and resurfacing. Release of chemical energy of serpentinization reactions would have contributed to the heat balances of the early Galilean satellites.

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P72B-0499 1330h POSTER

Io's Heat Flow Derived from Global Heat Balance Constraints

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The magnitude of Io's heat flow is of great importance for constraining tidal heating mechanisms and for understanding its interior structure. Most previous estimates of the heat flow have concentrated on the emission from the discrete hot spots and have thus been lower limits, as they did not account for low-temperature emission from the regions between the hot spots, due either to very old cooling lava flows or conduction through the crust. Improved heat flow estimates, considering emission from the entire surface, can be obtained by comparing Io's total thermal radiation, in all directions and at all wavelengths, with the total amount of sunlight that it absorbs. Io's thermal radiation as a function of solar phase angle can be constrained by ground-based observations and by Voyager