Linda T. Elkins-Tanton, E. M. Parmentier, and P. C. Hess, "Magma ocean fractional crystallization and cumulate overturn in terrestrial planets: implications for Mars," in revision for *Meteoritics and Planetary Science.*

P31A-07 0930h

Martian Mantle Analogues - Properties of Fe-Rich Silicate Melts

Marcel Potuzak[1] (498921804221; potuzak@min.uni-muenchen.de)

Philippe Courtial[1]

Donald B. Dingwell[1]

[1]University of Munich, Earth and Environmental Sciences, Theresienstrasse 41/III, MUNICH 80333, Germany

Data from Mars missions have revealed that the planet has a very active igneous history and that it may still be volcanically active. To improve and understand the hypotheses regarding the formation and evolution of Mars a model for its interior must be developed. This requires a knowledge of the physico-chemical properties of Martian magmas that control their dynamics. Two different simple Fe-bearing systems have been studied to date: (i) anorthite-diopside eutectic composition (AnDi) with variable amount of Fe (up to 30 wt%) as a basalt analogue and (ii) sodium disilicate (NS2 up to 10 wt% Fe). In addition, the compositional range has been extended to include the more complex SNC meteorite composition (more relevant to Mars). The high-T viscosities (1594-1200°C) have been measured using the concentric cylinder method in air. The low-T viscosities (817-711°C) have been measured using the micropenetration method in an Ar atmosphere for samples that could be quenched to glasses. High-T density measurements (1026-1567°C) have been performed on investigated Fe-bearing melts using the Pt-based double-bob Archimedean method. The oxidation state of Fe has been determined on quenched glasses at regular T steps by wet chemistry method. Differential scanning calorimetry (DSC) measurements have been performed on glassy samples at heating and cooling rates of 5, 10, 15 and 20 K/min in order to define the glass transition temperature (Tg). Isothermal viscosity decreases from 0.15 to 0.22 log Pa.s (high-T) and from 0.8 to 1.2 log Pa.s (low-T) with the addition of each 5 wt% Fe into the AnDi eutectic system. The viscosity of all these melt compositions shows non-Arrhenian behaviour across the whole T-range investigated. The density of the melts increases by about 0.05 g.cm^{-3} with each addition of 5 wt% of Fe. Fe^{3+} content decreases with increasing T (i.e., about 10% between 1300-1600°C). The DSC measurements suggest that the Tg decreases about 19°C with the addition of each 5 wt% Fe at a given cooling/heating rate. Low viscosities, which result from the high Fe content of Martian magmas, promote highly fluid lava behaviour, with implications for lava runout distances, eruptive styles and the landforms produced.

P31A-08 0945h

Investigation of the Cooling Capacity of Plate Tectonics and Flood Volcanism in the Evolution of Earth, Mars and Venus

Peter van Thienen[1] (++31-30-2535141; thienen@geo.uu.nl)

Nico J. Vlaar[1] (vlaar@geo.uu.nl)

Arie P. van den Berg[1] (++31-30-2535072; berg@geo.uu.nl)

[1]Department of Theoretical Geophysics, Utrecht University, P.O. Box 80021, Utrecht 3508 TA, Netherlands

The cooling of the terrestrial planets from their presumed hot initial states to the present situation has required the operation of one or more efficient cooling mechanisms. In the recent history of the Earth, plate tectonics has been responsible for most of the planetary cooling. The high internal temperature of the early Earth, however, prevented the operation of plate tectonics because of the greater inherent buoyancy of thicker oceanic lithosphere (basaltic crust and depleted mantle) produced from a hotter mantle. A similar argument is valid for Venus, and also for Mars. An alternative cooling mechanism may therefore have been required during a part of the planetary histories. Starting from the notion that all heat output of planets is through their surfaces, we have constructed two parametric models to evaluate the cooling characteristics of two cooling mechanisms: plate tectonics and basalt extrusion / flood volcanism. We have applied these models to the Earth, Mars and Venus for present-day and presumed early thermal conditions. Our model results show that for a steadily (exponentially) cooling Earth, plate tectonics is capable of removing all the required heat at a rate comparable to or even lower than its current rate of operation during its entire history, contrary to earlier speculations. The extrusion mechanism may have been an important cooling agent in the early Earth, but requires global eruption rates two orders of magnitude greater than those of known Phanerozoic flood basalt provinces. This may not be a problem, since geological observations indicate that flood volcanism was both stronger and more ubiquitous in the early Earth. Because of its smaller size, Mars is capable of cooling conductively through its lithosphere at significant rates. As a result may have cooled without an additional cooling mechanism during its entire history. Venus, on the other hand, has required the operation of an additional cooling agent for probably every cooling phase of its possibly episodic history, with rates of activity comparable to those of the Earth.

P31B MCC: Level 2 Wednesday 0830h

Applications of Planetary Radars I Posters *(joint with G)*

Presiding: **K Larsen,** Jet Propulsion Laboratory, California Institute of Technology**; K Williams,** Center for Earth and Planetary Studies, Smithsonian Institution

P31B-1055 0830h POSTER

A new concept for seismology on Venus using orbiting radar instead of landers

Philippe Lognonne[1] (+33-145114251; lognonne@ipgp.jussieu.fr)

Raphael Garcia[1] (+33-145114152; garcia@ipgp.jussieu.fr)

Giovanni Occhipinti[1] (+33-145114272; occhip@ipgp.jussieu.fr)

Barbara Romanowicz[2] (+1-510642-3977; barbara@seismo.berkeley.edu)

W. Bruce Banerdt[3] (+1-818354-5413; bruce.banerdt@jpl.nasa.gov)

[1]Departement de Geophysique Spatiale et Planetaire Institut de Physique du Globe de Paris, 4 Avenue de Neptune, Saint Maur des Fosse 94107, France

[2]UC Berkeley Seismological Laboratory, 215 McCone Hall #4760, Berkeley, CA 94720-4760, United States

[3]Jet Propulsion Laboratory, Mail Stop 183-501 4800 Oak Grove Drive, Pasadena, CA 91109, United States

Magellan images of Venus show extensive faulting and fracturing, suggesting movement of the planet's crust and the current possibility of frequent Venus quakes. The high surface temperature and pressure of the planet is, however, such that a long lived network would be extremely challenging and probably financially prohibitive. We propose therefore to use the strong coupling between the atmosphere and the solid planet for detecting surface waves generated by quakes on Venus. After a quake, the surface of a planet is vibrating horizontally and vertically. By continuity, the atmosphere at the surface must move with a vertical velocity equal to the surface vertical velocity, and this vibration is then propagated upward. Its kinetic energy is conserved as long as the atmospheric viscosity does not produce significant attenuation. Due to the exponential decay of density with altitude, the amplitude of the wave increases exponentially and produces significant perturbations of the electron density in the ionosphere. Such signals are now commonly observed on the Earth for large quakes, both with ground Doppler HF sounders and space-based GPS satellites. We show that the dense atmosphere of Venus amplifies this effect by a factor of about 100 compared to the Earth. Moreover, the structure of the ionosphere makes radar observations of these signals from above easier than on Earth. We present simulations and estimates of the detection threshold of this new strategy for Venus seismology. A general concept of the experiment is then proposed.

P31B-1056 0830h POSTER

Investigating Impact Crater Related Surficial Deposits on Venus With Arecibo Multi-Polarization Radar Images

Lynn M. Carter[1] ((607)-255-3317; lcarter@astro.cornell.edu)

Donald B. Campbell[1] (campbell@astro.cornell.edu)

Bruce A. Campbell[2] (campbellb@nasm.si.edu)

Jean-Luc Margot[3] (margot@gps.caltech.edu)

[1]Cornell University, Space Sciences Building Cornell University, Ithaca, NY 14853, United States

[2]Smithsonian Institution, Center for Earth and Planetary Studies Smithsonian Institution, Washington DC 20560, United States

[3]California Institute of Technology, Department of Geological and Planetary Sciences California Institute of Technology, Pasadena, CA 91125, United States

Magellan spacecraft images of Venus revealed several different types of impact crater related deposits on Venus. Examples include the hundreds of kilometers in length parabolic-shaped deposits and the smaller (tens of km) dark halos. Wind streaks are associated with some of these features, confirming the presence of mantling material. These areas on Venus may look significantly different at optical wavelengths, since radar can penetrate several wavelengths into the surface and reveal underlying terrain. Linear polarization analysis can be used to investigate whether there is a surficial deposit in a given region. A circularly polarized wave can be decomposed into two orthogonal linear-polarized waves of equal magnitude. If a circularly polarized radar signal penetrates into a surface that is smooth at wavelength scales, and is scattered by embedded rocks or a sub-surface layer, the received echo will have a linear-polarized component. This linear polarization is produced because the "horizontal" and "vertical" components of the incident circular wave have different transmission coefficients into and out of the surface layer. If there is no sub-surface reflection, there will be no linear polarization. We used the 13-cm wavelength Arecibo radar system to observe Venus during two inferior conjunctions. We transmitted a circularly polarized wave and received both of the reflected circular polarizations. From these data, delay-Doppler images in all four Stokes polarization parameters were created, and a map of the degree of linear polarization was formed. Our data reveals linear polarization associated with impact craters, volcanic dome fields, and areas of wind streaks. In particular, we note significant linear polarization from areas near 44 craters, including 5 of the craters with parabolic deposits. The linear polarization signature is usually associated with the diffuse, featureless radar-bright areas near the crater. In addition, the craters that show a linearly polarized echo component often have dark halos or bright floors, and thus are likely be younger in age. This technique can be used for other objects as well, including possibly determining whether there is regolith covering the polar ice deposits on Mercury and searching for regolith on asteroids.

P31B-1057 0830h POSTER

Eastern Sahara Paleohydrology from JERS-1 Radar Data: Potential Analog to Mars

Philippe Paillou[1] (Philippe.Paillou@obs.u-bordeaux1.fr)

Tom G Farr[2] (818-354-9057; tom.farr@jpl.nasa.gov)

Ake Rosenqvist[3] (ake.rosenqvist@nasda.go.jp)

[1]Astronomical Observatory of Bordeaux, 2 rue de l'Observatoire, Floirac BP 89, 332, France

[2]Jet Propulsion Laboratory, California Institute of Technology, MS 300-233, Pasadena, CA 91109, United States

[3]NASDA/EORC, Roppongi First Building, 13F, Tokyo 106-0032, Japan

The recent geological and hydrological history of the eastern Sahara is still mainly hidden under large regions of wind-blown sand. The subsurface geology is generally invisible to optical remote sensing techniques (LANDSAT, SPOT), but radar images obtained from the Shuttle Imaging Radar missions were able to penetrate the superficial sand layer to reveal parts of the paleohydrological networks. However, the incomplete geographic coverage of the SIR missions did not allow regional-scale mapping of the hidden hydrological and tectonic structures of the eastern Sahara, and scientific interpretations of available data remain partial and incomplete. Nevertheless, complete L-band radar coverage of the eastern Sahara exists and can be exploited: it was obtained by JERS-1, a Japanese satellite for Earth observation that was operated by NASDA from 1992 to 1998. We have produced the first radar mosaic of the eastern Sahara covering Egypt, Sudan, Libya and Chad, from existing archives of JERS-1 L-band radar images, at a final resolution of 50 meters. Such a data set will help in discovering unknown subsurface structures (river channels, former lakes, faults, impact craters, etc.) and will contribute to answering several key questions about the recent climatic, geological, and hydrological history of the eastern Sahara. As the eastern Sahara represents a good terrestrial analog to Mars, our work may also be applied to the exploration of Mars. Much of the surface of Mars has been

intensely reworked by aeolian processes, and key evidence about the history of the Martian environment (paleo lakes and rivers) appears to be hidden beneath a widespread layer of wind-blown dust. Our results show that a Mars radar mapping mission, as the one proposed in the MEEM project, would allow imaging of the near subsurface geomorphology inaccessible to any other kind of sensor. It would provide unique data to address the origin of many enigmatic features related to the history of climate and water on Mars.

P31B-1058 0830h POSTER

Echo Source Discrimination in Airborne Radar Sounding Data From the Dry Valleys, Antarctica, for Mars Analog Studies

John W. Holt[1] (512-471-0487; jack@ig.utexas.edu)

Donald D. Blankenship[1]

Matthew E. Peters[1]

Scott D. Kempf[1]

Benjamin J. Williams[1]

[1]University of Texas Institute for Geophysics, The John A. and Katherine G. Jackson School of Geosciences, University of Texas at Austin, 4412 Spicewood Springs Rd., Bldg. 600, Austin, TX 78759, United States

The identification of features on Mars exhibiting morphologies consistent with ice/rock mixtures, near-surface ice bodies and near-surface liquid water, and the importance of such features to the search for water on Mars highlights the need for appropriate terrestrial analogs in order to prepare for upcoming radar missions targeting these and other water-related features. Climatic, hydrological, and geological conditions in the McMurdo Dry Valleys of Antarctica are analogous in many ways to those on Mars, and a number of ice-related features in the Dry Valleys may have direct morphologic and compositional counterparts on Mars. We have collected roughly 1,000 line-km of airborne radar sounding data in the Dry Valleys for Mars analog studies. A crucial first step in the data analysis process is the discrimination of echo sources in the radar data. The goal is to identify all returns from the surface of surrounding topography in order to positively identify subsurface echoes. This process will also be critical for radar data that will be collected in areas of Mars exhibiting significant topography, so that subsurface echoes are identified unambiguously. Using a Twin Otter airborne platform, data were collected in three separate flights during the austral summers of 1999-2000 and 2001-2002 using multiple systems, including a chirped 52.5 - 67.5 MHz coherent radar operating at 750 W and 8 kW peak power (with multiple receivers) and 1 - 2 microsecond pulse width, and a 60 MHz pulsed, incoherent radar operating at 8 kW peak power with 60 ns and 250 ns pulse width. The chirped, coherent data are suitable for the implementation of advanced pulse compression algorithms and SAR focusing. Flight elevation was nominally 500 m above the surface. Targets included permafrost, subsurface ice bodies, rock/ice glaciers, ice-covered saline lakes, and glacial deposits in Taylor and Beacon Valleys. A laser altimeter (fixed relative to the aircraft frame) was also used during both seasons. Post-processing of the positioning data yields accuracies of 0.10 m for samples at 15 m intervals. Precise positioning was accomplished through the use of two carrier-phase GPS receivers on the aircraft and two at McMurdo Station. Surface and shallow subsurface properties are being supplied by glacial geomorphologists conducting ground-based studies in Taylor and Beacon Valleys. Two techniques are being used in parallel to discriminate subsurface echoes from surface echoes due to surrounding topography. In the first method, surface returns are simulated using aircraft position data, the modeled radar antenna pattern, and surface topography from a digital elevation model (DEM) recently acquired by the USGS and NASA in the Dry Valleys with 2-meter postings. These predicted surface returns are then compared with the actual data to reveal side echoes. The second method identifies all echoes in the radar data and maps them into possible correlative surface features to the sides of the aircraft through range estimation. This uses the measured time delay of the echo and known surface topography. We map the echoes onto the DEM (and optical imagery) at the appropriate range in order to identify candidate surface return sources. The two methods should identify all echoes that are not from the subsurface. The comparison of different radar configurations and parallel tracks where they are available will also be utilized to identify the source of any ambiguous echoes.

P31B-1059 0830h POSTER

GPR Measurements at Planetary Analog Sites in Northern Arizona

Kevin K. Williams[1] (williamsk@nasm.si.edu)

John A. Grant[1]

Alan E. Schutz[2]

[1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, United States

[2]Geophysical Survey Systems, Inc., 13 Klein Drive, North Salem, NH 03073, United States

Ground penetrating radar (GPR) operating at frequencies generally between 100-1000 MHz can penetrate up to 10-20 m to reveal information regarding the dielectric properties of the subsurface. This information provides insight into subsurface geologic structure and setting. The ability to remotely sense the subsurface structure of an area without drilling or excavating has proven economical and, in some cases, invaluable in civil engineering and geological applications on Earth. In recognition of the benefits of a GPR on potential future rovers and landed missions to the Moon, Mars, or other solar system body, fieldwork has been conducted to assess GPR data of volcanic, cratered, and other analog settings in northern Arizona. Measurements were made at Sunset Crater, Meteor Crater, and the 2002 FIDO rover test site near Cameron, AZ. At each site, data were collected using commercial GPR antennas at 400 MHz, 500 MHz, and 1.5 GHz as well as a 600 MHz prototype planetary GPR antenna. For comparison, shallow seismic data were also collected along some of the GPR tracks, In these Mars analog terrains, GPR data reveal subsurface interfaces that are useful for understanding the geologic history at those sites. Interfaces in the data collected at Sunset Crater help delineate several episodes of cinder deposition that mantle the surface of a lava flow. At Meteor Crater, the thickness of distal portions of the ejecta blanket can be estimated where the GPR penetrated through to the pre-impact surface. At the FIDO site, data indicate local fluvial systems are incised into coherent bedrock rather than older channel fill, thereby highlighting the stripped nature of the setting. GPR data collected in these three different geologic settings demonstrate the ability of ground penetrating radar to provide information about subsurface geology through non-invasive techniques. The ability to remotely sense the shallow subsurface is especially desirable for Mars rover missions planned for the next decade because direct sampling via drilling to depths up to 20 m may not be possible.

P31B-1060 0830h POSTER

A Comprehensive Approach in Understanding the Martian Geoelectrical and Geomagnetic Context for the Interpretation of Futur Radar Sounding Data.

Essam Heggy[1] (heggy@lpi.usra.edu)

Stephen Clifford[1] (Clifford@lpi.usra.edu)

Jean-Jacques Berthelier[2] (jjb@cetp.ipsl.fr)

Cynthia Dinwiddie[3] (cdinwiddie@cnwra.swri.edu)

Philippe Paillou[4] (paillou@obs.u-bordeaux1.fr)

[1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, Tx 77058, United States

[2]Centre d'Etude Terrestre et Planetaire, 10-12, Av. de l'Europe, Velizy 78140, France

[3]SouthWest Research Institute, 6220 Culebra Road, San Antonio, Tx 78238, United States

[4]Bordeaux Astronomical Observatory, 2 rue de l'Observatoire, Floirac 33270, France

Low frequency sounding radars on Mars can probes the subsurface layers to varying depths depending on the sounding geometry and the geoelectrical and geomagnetic properties of the soil at the sounded sites. Hence a good knowledge of the electric and magnetic properties of the rocks and sediments constituting the investigated media is crucial for any future data analysis and interpretation. We have undertaken a comprehensive investigation of the potential electrical and magnetic losses that may be encountered on Mars based on three steps: The first is the laboratory characterization of Mars-like volcanic and sedimentary materials in the low frequency band of 1-30 MHz, which covers the frequency range of the MARSIS experiment onboard the Mars Express orbiter (ESA-2003), the SHARAD shallow sounder that will be flown in 2005 (NASA-ASI) and possible ground penetrating radars that may be flown as part of future rover and geophysical network missions. The electromagnetic properties of these analog Mars materials will be presented as a function of various important geophysical parameters, such as porosity, bulk density and temperature. The second step is the integration of these measurements into a series of frequency dependent geoelectrical models representing the distribution and state of subsurface water under variety of geologic conditions, with the intent of identifying those locations on Mars that offer the best opportunity for an unambiguous detection of subsurface liquid water. We then use the Finite Difference Time Domain method to simulate the radar wave propagation across those models and hence getting a possible preview of the backscattered echo corresponding to different geological context and radar characteristics. These simulations will be compared with the data returned by MARSIS and SHARAD in an effort to better understand the nature and characteristics of the subsurface Martian environment. Finally, these analyses will be supplemented by field investigations of simple terrestrial analogue sites using 2-30 MHz GPR instruments. Recent soundings conducted in the West Egyptian Desert by a 2 MHz GPR demonstrated the ability of this technique to detect the Nubian Aquifer at a depth around 900 m beneath thick layer of marine sedimentary quaternary and tertiary structures constituted mainly of dry porous dolomite, illinite, limestone and sandstone, given a reasonable knowledge of the local geoelectrical properties of the crust. In this talk we will summarize our efforts date and discuss their implications for the interpretation of data from future Mars radar sounding investigations.

P31B-1061 0830h POSTER

Backscattering simulations from the Martian surface and subsurface in the case of the MARSIS radar sounder.

Romain Garmier[1] (+49-5556-979 440; garmier@linmpi.mpg.de)

tor hagfors[1] (hagfors@linmpi.mpg.de)

[1]garmier, MPAE, Max Planck strasse 2, Katlenburg-Lindau 37191, Germany

In December 2003, the Mars Express spacecraft will be inserted into orbit around Mars. One of the scientific instruments is a radar sounder named MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding). Its main objective is to detect the presence of water, liquid or solid, in the upper crust of Mars down a depth of 5 km. MARSIS is a nadir looking radar with four operative modes of bandwidth 1 MHz and central frequency 1.8 MHz, 3 MHz, 4 MHz and 5 MHz. The maximum penetration depth is obtained for the lowest altitude (250 km) and with the lowest frequency. Unfortunately the clutter from the off-nadir direction may dwarf the subsurface echo return. To characterize the clutter and the subsurface return level according to the surface roughness and the subsurface geology (layering and composition), we simulate the backscattering of a pulse from the surface and the subsurface to the antenna. The Martian surface consists of a random rough surface described statistically by 3 parameters: the RMS height, the correlation length and the Hurst exponent. Each parameter may be adjusted according to the requirements of the simulations. The subsurface is composed of different geological layers with a complex permittivity which is function of the composition and the depth of the material (Maxwell Garnet model). Each layer is divided in sub-layers with constant permitivities. Different subsurface models (2 layers, 3 layers) with different compositions (porous basalt, andesite, basalt + water...) were used. The interface between two layers is not flat. The backscattered field from the surface is analytically computed using the scalar Kirchhoff approximation whereas the subsurface return consists of simple transmission and reflection through the different sub-layers along the nadir direction (i.e. we did not consider the 3D volume scattering because it is too expensive in term of computation) . The signal reaching the radar is then compressed by the matched filter and we also investigate the clutter reduction by Doppler filtering. We present map of power returns in function of the nadir point position of the radar through the surface and the time delay for the signal to reach the antenna.

P31B-1062 0830h POSTER

Terrestrial Radar Observations of Gusev Crater, Mars

Kristopher W. Larsen[1] (818-354-9429; kris@shannon.jpl.nasa.gov)

Albert F.C. Haldemann[1] (albert@shannon.jpl.nasa.gov)

Raymond F. Jurgens[1] (jurgens@shannon.jpl.nasa.gov)

Martin A Slade[1] (marty@shannon.jpl.nasa.gov)

[1]Jet Propulsion Laboratory, California Inst. of Tech. 4800 Oak Grove Dr., Pasadena, CA 91109, United States

The Mars Exploration Rover, Spirit, was launched on June 10, 2003, and is scheduled to land on the floor of Gusev Crater in January 2004. The close opposition of Mars in the summer of 2003 provided a final opportunity to observe the Gusev Crater landing site using Earth-based radar telescopes prior to the Rover's arrival. Similar observations of the Terra Meridiani site in 2001 demonstrated the capabilities of delay-Doppler radar interferometry in mapping the radar properties of planetary surfaces. The 2003 observation suite includes

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data from four nights in which the observation's subradar track was within five degrees of latitude of the planned landing site. High resolution, approximately five kilometers per pixel, radar imaging of the landing site indicates a site that will be of low risk to the rover and provides testable predictions of the local surface roughness that the rover will encounter.

P31B-1063 0830h POSTER

Surface Penetrating Radar Simulations for Jupiters Icy Moons

Thorsten Markus[1] (301-614-5882; Thorsten.Markus@nasa.gov); Prasad Gogineni[2] (gogineni@ittc.ku.edu); James L Green[3] (James.L.Green@nasa.gov); Bodo W Reinisch[4] (bodo_reinisch@uml.edu); Paul Song[4] (paul_song@uml.edu); Shing Fung[3] (fung@mail630.gsfc.nasa.gov); Robert F Benson[5] (Robert.F.Benson@nasa.gov); William L Taylor[3] (taylor@mail630.gsfc.nasa.gov); John F Cooper[3] (jfcooper@pop600.gsfc.nasa.gov); Leonard Garcia[3] (garcia@mail630.gsfc.nasa.gov); Dennis L Gallagher[6] (Dennis.L.Gallagher@nasa.gov)

[1]NASA/GSFC, Code 975, Greenbelt,, MD 220771, United States

[2]ITTC, University of Kansas, Lawrence, Lawrence, KS 66045, United States

[3]NASA/GSFC, Code 630, Greenbelt, MD 20771, United States

[4]Ctr. f. Atmospheric Research, Univ. of Mass., Lowell, Lowell, MA 01854, United States

[5]NASA/GSFC, Code 692, Greenbelt, MD 20771, United States

[6]NASA NASA, Marshall Space Flight Center, Huntsville, AL 35812, United States

The icy moons of Jupiter (Europa, Callisto, and Ganymede) are of similar overall composition but show different surface features as a result of different subsurface processes. Furthermore, each of these moons could have a liquid ocean of water buried underneath the icy crust, but their depth can only be speculated. For Europa, estimates put the thickness of the ice shell anywhere between 2-30 km, with a few models predicting up to 100 km. Much of the uncertainties are due to the largely unknown temperature gradients and levels of water impurities across different surface layers. One of the most important geological processes is the possible transportation of heat by ice convection. If the ice is convecting, then an upper limit of about 20 km is set for the depth of the ocean underneath. Convection leads to a sharp increase in temperature followed by a thick region of nearly constant temperature. If ice is not convecting, then an exponentially increasing temperature profile is expected. The crust is thought to be a mixture of ice and rock, and although the exact percentage of rock is not known, it is expected to be low. Additionally, the ice crust could contain salt, similar to sea ice on Earth. The exact amount of salt and how that amount changes with depth is also unknown. In preparation for the Jupiter Icy Moons Orbiter (JIMO) mission, we performed simulations for a surface-penetrating radar investigating signatures for different possible surface and sub-surface structures of these moons in order to estimate the applicability of using radar with a frequency range between 1 and 50 MHz. This includes simulations of power requirements, attenuation losses, layer resolutions for scenarios with and without the presence of a liquid ocean underneath the ice, cases of convecting and non-convecting ice, different impurities within the ice, and different surface roughnesses.

P31C MCC: 2008 Wednesday 1020h

Faulting and Fault-Related Processes on Planetary Surfaces I *(joint with T)*

Presiding: **D A Ferrill,** Southwest Research Institute**; R A Schultz,** University of Nevada, Reno**; R T Pappalardo,** University of Colorado, Boulder

P31C-01 1020h

The Mechanics of Pseudotachylite Formation in Impacts

H. Jay Melosh (520 621 2806; jmelosh@lpl.arizona.edu)

Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721, United States

Geologist James Shand first recognized pseudotachylites near the Vredefort structure in 1916. They appear to be black, glassy veins that often contain broken fragments of country rock. The veins range from millimeters thick to masses many meters in extent. Since this discovery they have puzzled several generations of geologists. Pseudotachylites are evidently due to rapid melting of rock in place and seem to be associated with environments, such as faulting, landslides and impacts, where rock is put into rapid motion. I examine the basic constraints controlling the formation of pseudotachylites in the rapidly sheared rocks in the vicinity of a large meteorite impact. The prevailing opinion among many geologists is that pseudotachylites are formed by friction melting of rock. The principal mystery of pseudotachylite formation is not that friction can cause melting, but that it seems to form thick masses of it. Yet such thick masses ought to preclude melting by reducing the friction between sliding rock masses. I propose that a solution to this conundrum is that the melt produced by sliding on narrow shear zones is extruded into the adjacent country rock, thus keeping the sliding surfaces narrow while thick masses of melt accumulate in pockets opened by slip on faults oriented at large angles to the sliding plane.

P31C-02 1035h

Earth Versus Mars: dike-induced topography resolved by MOLA

Cheryl L. Goudy[1] (775-784-6464; cgoudy@mines.unr.edu)

Richard A. Schultz[1] (schultz@mines.unr.edu)

[1]University of Nevada, Reno, Mackay School of Mines/ 172, Reno, NV 89557

Graben on Mars have often been interpreted to result from dike intrusion. On Earth field observations, geodetic data, and numerical models show that dike intrusion and normal faulting typically result in graben subsidence. Topography across the Krafla rift zone in Iceland has been successfully fit to the combined effects of subsurface dike inflation plus slip along two inward-dipping, dike-induced normal faults. Topographic profiles of graben in the Tharsis and Elysium regions on Mars show similar morphometric features. This morphologic similarity suggests a similar process at depth. Quantitative mechanical models of dike-induced graben topography on Mars have been elusive. We have now developed a boundary element model capable of predicting the topography of graben that have evolved through the combined processes of dike intrusion and related normal faulting. By analogy with the Krafla rift zone example and the previous model results, we calculate the amount of surface displacement expected on Earth for a vertical dike with a height of 4.5 km (dike top depth = 1.5 km, and dike bottom depth = 6.0 km), accompanied by two faults 6.0 km apart dipping toward the graben center at 55 degrees with a down-dip length of 6.0 km. The horizontal stress gradient is equal to the vertical lithostatic gradient (principal stress ratio = 1.0) for Earth assuming magmatic density of 2200 kg/m^3 and crustal density of 2600 kg/m^3, and the shear modulus is 24 GPa. We find that if gravity is the main factor affecting graben-related topography, Martian graben would produce topographic displacements that are 25% less than that of a terrestrial counterpart. Our models predict approximately 4 m and 3 m of maximum vertical displacement on Earth and Mars, respectively. Larger dikes suggested for Mars could produce uplifts of 10's of m. This relief is within the vertical precision of the MOLA data and will provide a direct test of the volcanic hypothesis of Martian graben.

P31C-03 1050h

Topographic and Structural Analysis of Devana Chasma, Venus: A Propagating Rift System

Walter S. Kiefer[1] ((281) 486-2110; kiefer@lpi.usra.edu)

Laura C. Swafford[2]

[1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058, United States

[2]Dept. of Geology, Michigan State University, East Lansing, MI 48824, United States

Devana Chasma is a rift system on Venus that formed due to extensional stresses from the Beta Regio and Phoebe Regio mantle plumes. Devana has often been compared to the East African Rift system on Earth. Here, we focus on the portion of Devana in the lowland plains between Beta and Phoebe, 20 North - 4 South, a distance of 2500 km. Over this region, Devana is typically 150 to 250 km wide. Recent gravity modeling (Kiefer and Peterson, Geophys. Res. Lett., Jan. 2003) demonstrated that most of this segment of the rift is presently underlain by hot, low density mantle material. The rift has a 600 km lateral offset near 8 North latitude, where the gravity results show no evidence for hot mantle. This lead Kiefer and Peterson to propose that Devana is actually two propagating rifts, one propagating southward from Beta Regio and the other propagating northward from Phoebe Regio. As a test of this hypothesis, we have examined the detailed structural geology of this section of the rift using topographic profiles and radar imagery from the Magellan mission. We constructed a series of topographic transects spaced at approximately 50 km intervals along the rift and measured the average flank height and the maximum rift depth. We measured the total vertical offset along faulted surfaces and converted this to horizontal extension assuming a characteristic normal fault dip of 60 degrees. Plots of these quantities as a function of distance along the rift reveals several characteristic zones. Average flank height has maximum values near the edges of Beta Regio (3.5 km) and Phoebe Regio (2.75 km) and decreases rapidly as the rift crosses the intervening plains. This is consistent with the rift forming due to thermal anomalies centered at Beta and Phoebe. The virtual absence of elevated rift flanks in the offset region near 8 North is consistent with the absence of hot mantle in this region, as inferred from the gravity model. The horizontal extension decreases strongly with increasing distance from Beta Regio (20 - 10 N), whereas the horizontal displacement shows little trend with distance from Phoebe Regio (4 S - 7 N). The horizontal extension has a minimum in the offset region (8 N), consistent with the observed decrease in fault density in this region. Both the flank height and horizontal extension results appear to be consistent with the propagating rift model. The maximum depth along the rift is typically between -1 and -3 km, with no strong trend along the rift.

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Wrinkles on the Crust of Venus

George E. McGill (413-545-0140; gmcgill@geo.umass.edu)

Department of Geosciences,, University of Massachusetts,, Amherst,, MA 01003, United States

Wrinkle ridges are very abundant on the plains of Venus, and thus they constitute an important source of kinematic information. Wrinkle ridges generally are inferred to be related to thrust or reverse faults. We can address some of the kinematic issues with a set of questions: Can the presence of wrinkle ridges be used to define stratigraphic material units? Can the formation of wrinkle ridges be used as a rough time line? Can wrinkle ridges define kinematics by determining temporal sequences of stress states? Intersection relationships of wrinkle ridge sets with each other and with other structures, and the ages of wrinkle ridge sets relative to the impact crater population provide the data needed. The area studied includes the 20 quadrangles bounded by 60 west and 90 east longitude, 50 north and south latitude, slightly less than one-third of the total surface area of Venus, and it includes 314 impact craters, slightly less than one-third of the total global population. Throughout most of the area studied wrinkle ridges occur as 2 or more sets with different orientations. Wrinkle ridges can be used to define a stratigraphic material unit only if it can be shown that wrinkle ridge formation was coeval with the processes forming the material unit. Relationships with older fracture fabrics and with the impact crater population effectively rule out formation of wrinkle ridges coeval with material emplacement. In the area studied, east-west trending wrinkle ridges appear to be the oldest set, and these probably formed quickly enough to define a regional time line. If one can unequivocally determine the relative ages of wrinkle ridge sets, the temporal sequence of stress states in the plains can be determined. Commonly, the earliest structures to form after plains emplacement are radar-bright lineaments inferred to be fractures or small faults. East-west wrinkle ridges formed after these lineaments, and after formation of a small but significant fraction of the impact crater population. A larger fraction of the impact crater population formed before wrinkle ridges with other orientations, and these commonly terminate at intersections with east-west wrinkle ridges. Thus at least a regional scale north-south contraction of plains materials was followed by rotation of the maximum contraction direction into various other directions, depending on locality.

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Fine-scale Fractures on the Surface of 433 Eros: Implications for Structural Control and Tectonic Resurfacing of Craters

Louise Prockter[1] (240-228-6769; Louise.Prockter@jhuapl.edu)

Olivier Barnouin-Jha[1] (Olivier.Barnouin-Jha@jhuapl.edu)