of crustal fault systems required to underpin the grand challenge of earthquake prediction; new understanding and predictive capabilities of geological processes such as tectonics and mineralisation.

URL: http://www.quakes.uq.edu.au/ACESS

U42B-12 1655h

A Virtual Earth Simulator to Simulate Rupture Propagation on Earthquake Faults

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The particle-based Lattice Solid Model was developed to provide a basis to study the non-linear dynamics of earthquakes and the physics of rocks. A new approach, termed LSMearth, has been developed that allows different microphysics of earthquakes to be easily studied. The model - which runs in 2D or 3D is implemented using an object-oriented approach and enables the effect of different microphysics on macroscopic behaviour to be studied. The application provides a virtual laboratory where all measurable quantities can be visualized and where the simulation, running on a remote super-computer, can be controlled from any personal computer. Simulations are run in parallel using a message passing approached based on MPI.

Unlike laboratory experiments which are limited in scale and where direct observations of the contacts occurring between grains of rock in the gouge layer is not possible, the numerical simulations allow the study of the nucleation process as well as the propagation of the shear rupture in experiments performed with bare surfaces or a gouge layer. Because the size of a shear rupture zone is approximately one order of magnitude larger than the nucleation region size, large-scale numerical simulations are here executed to analyse both shear rupture and the nucleation process and to study the scaling of the size and the duration of the nucleation with the size of the eventual earthquake. Using such large-scale experiments, the model provides a means to improve our understanding of the nucleation process and to gain insights into the mechanisms that control the growth of the nucleation zone.

U42C MC: 134 Thursday 1730h

The Future of Climate Change Research; Presentation by Ari Patrinos; Associate Director, Health Environmental Research, U.S. Department of Energy

Presiding: **M K McNutt,** Monterey Bay Aquarium Research Institute

U42C-01 1730h

The Future of Climate Change Research

Aristides Patrinos

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There is no abstract for this presentation.

U51A MC: 134 Friday 0830h

Origin and Early Evolution of the Earth I

Presiding: **K Righter,** University of Arizona**; D C Rubie,** University of Bayreuth

U51A-01 0830h INVITED

Habitability of Terrestrial Planets in the Early Solar System

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The Protoearth, Mars, Venus, and the Moon-forming impactor were potentially habitable in the early solar system. The interiors of larger asteroids had habitable circulating water. To see when the inner solar system became continuously habitable, one needs to consider the most dangerous events and the safest refugia from them. Early geochemical and accretionary processes set the subsequent silicate planet reservoirs and hence hydrospheric and atmospheric masses. The moon-forming impact made the Moon and the Earth sterile bodies. Following the impact, the Earth passed through a rock-vapor atmosphere on the scale of 1000s of years and an internally heated steam greenhouse on the scale of 2 m.y. Minerals bearing the principle volatiles (water, Cl, and CO2) were stable at the Earths surface by the time it cooled to 800K. The mass of reactable shallow material was insufficient to contain the available water and CO2. Habitable conditions were established after CO2 could be deeply subducted into the mantle. Vast quantities of H2 were vented during accretion and after the moon-forming impact and eventually lost to space. It is unknown whether significant amounts of this gas were present when the Earths surface cooled into the habitable range. The moon remained sterile because its interior is essentially devoid of water. The mantle of the Earth, in contrast, cannot hold the available water, leaving the excess to form oceans. Nitrogen may behave similarly with the excess going into the air. Impacts of large asteroids (and comets) were an ever-present danger on otherwise habitable planets. The safest niche on planets was kilometer or deeper crustal rocks habitable by thermophiles. It is inevitable that several objects, which would have left only thermophile survivors, struck the Earth. Such events were so infrequent that the conditions of such a bottleneck should not be confused with conditions for the origin of life. An alternative refugium involves ejection of life within rock fragments and return of such fragments to the surface of the home planet or transfer to another habitable planet. Mars and the larger asteroids were habitable first and provide likely sources of seed and also testable places to look for preserved evidence. Extant terrestrial life appears to have passed through thermophile bottlenecks. There are subtle hints of space transfer. The need of extant life for Ni may be a vestige of life on a young planet covered with ultramafic rocks.

U51A-02 0850h INVITED

An impact origin of the Earth-Moon system

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In the leading hypothesis for lunar origin, the Moon forms from debris ejected as a result of the collision of a roughly Mars-sized impactor with early Earth (Hartmann & Davis 1975; Cameron & Ward 1976). The likelihood of giant impact events has been substantiated by over a decade of planetary accretion simulations (e.g., Wetherill 1985, 1992; Agnor et al. 1999; Chambers 2001). The most recent simulations predict a median accretion time of 50 million years for an Earth analogue to reach 90% of its final mass (Chambers 2001), in good agreement with lunar and terrestrial formation times derived from Hf-W systematics (e.g., review by Halliday et al. 2000).

Simulations of potential lunar forming impacts using a method known as smooth particle hydrodynamics, or SPH, can now achieve resolutions sufficient to study the production of bound debris necessary to yield the Moon. A wide variety of works have found that off-center, low-velocity collisions yield material in bound orbit from which a satellite may then accumulate. However, identifying impacts capable of producing the Earth-Moon system has proven difficult (Cameron 1997, 2000, 2001; Cameron & Canup 1998, Canup et al. 2001). Previous works (Cameron 1997, 2000, 2001) identified only two types of impacts capable of producing the Moon. The first involved an impact by an object with about 3 times the mass of Mars, and about twice the angular momentum of the Earth-Moon system; the second involved an the impact of an object with about twice the mass of Mars with an Earth that was only about half formed. Both scenarios are more restrictive and problematic than that originally envisioned, since they require that the Earth-Moon system's mass or angular momentum be significantly modified after the Moon-forming event by either multiple large impacts, or selective subsequent accretion of material onto only the Earth and not the Moon.

Recent scaling trends identified in the SPH simulation results (Canup et al. 2001) implied that a smaller, Mars-mass impactor would be better able to simultaneously account for the Earth-Moon system mass and angular momentum (Canup & Asphaug 2001). This smaller scale impact had not been considered viable since early low-resolution SPH simulations found that it placed too much iron into orbit to yield an appropriately iron-poor Moon (Benz et al. 1986). However, recent work using high-resolution simulations (Canup & Asphaug 2001) found that impacts by an object with 10 to 12% of the Earth's mass produce orbiting debris that is less than 3% iron by mass, and that contains sufficient mass and angular momentum to yield the Moon outside the Earth's Roche limit. This type of impact leaves the Earth-Moon system with approximately its final mass and angular momentum, and implies that the Moon formed near the very end of Earth's accretional history.

U51A-03 0905h INVITED

Review of Early Intense Bombardment and Associated Problems

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Since pre-Apollo years of the 1960s, it has been recognized that cratering on the moon must have been much more intense, averaged over the first few hundred My, than the average after 3500 My ago. This phenomenon is known as the "early intense bombardment." Initial interpretation of Apollo data raised the possibility that much of this cratering occurred in a single episode, or "spike" on the flux vs time curve, at about 3950 My ago, with a width of about 150 My. In some interpretations this was the primary source of all early cratering, known as a "catastrophic terminal bombardment." In one model Ryder has suggested that there was very little cratering before this. In other models, this is a spike superimposed on a declining flux, and there may have been various spikes.

A host of problems remain.

(1) Do we really have adequate dates for the lunar basins? The predominant opinion seems to be that virtually all visible basin were created in a burst within about 300 My. Confirming these dates would resolve the existence of the proposed catastrophe, which would then be constrained to involve numerous 50 and 100-km scale bodies hitting the moon.

(2) How does intense cratering work to remove earlier samples of igneous crustal rocks and impact melts? The original suggestion of the catastrophe was in order to explain the paucity of pre 4000-My rocks in the lunar sample. Cumulative impacts tend to destroy early rocks whether or not they are concentrated in a catastrophe. In some models, the extended declining impact, due to megaregolith production, tends to destroy impact melts because they concentrate at the surface, while dredging up (and yet also pulverizing) crustal igneous samples from deep-seated reservoirs.

(3) How severe is the absence of pre-4000 My impact melts? Their absence has been used as an argument for the existence of a cataclysm at 3950 My ago. But the details of item (2) need to be combined with actual distributions of impact melt ages and igneous rock ages to refine these discussions.

(4) Do lunar meteorites show the same age distributions and properties as the front side Apollo samples? This may be a test of the hypothesis that Imbrium debris have contaminated the front side.

(5) Do asteroids show the same age distributions as the lunar samples? Available models of a cataclysm at 3950 My ago suggest the impactors came from the outer solar system and therefore they should have affected the asteroid belt as well.

(6) What is the significance of the "Genesis Rock," ALHA 84001, among the first 20 specimens from Mars given that astronauts were trained to look for lunar "Genesis Rocks" and couldn't find them? Mars should have been affected by the cataclysm, according to available models. Hartmann (2001) suggested it tells us that the Martian crust was not destroyed by plate tectonics as on Earth, and parts of the primordial Mars crust were exposed by erosion to provide the meteorite source. Hence Mars may be the only planet where we can access a primordial crust. The erosion must have happened after a putative cataclysm at 3950 My ago.

(7) In short, did a cataclysmic spike at 3950 My ago, how big was it in terms of forming most lunar basins and other features, and how much of the total lunar cratering was concentrated in it?

U51A-04 0920h INVITED

The Formation of a Water-Rich Earth

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It is now generally accepted that in the inner solar system the process of runaway growth ended with the formation of many "planetary embryos" of lunar to martian mass (1,2). The terrestrial planets then formed on a longer time-scale (from several tens to a hundred million years), by the high-velocity mutual collisions of these embryos (3,4,5).

The radial extent of the primordial population of planetary embryos is not known. In principle, a system of embryos originally within 2 AU from the Sun