Barbara Thompson[2]

Eric Sundquist[3]

Ed Sarachik[4]

[1]Brown University, Dept of Earth Sciences, United States

[2]NASA Goddard Space Flight Center, Dept of Earth Sciences, United States

[3]USGS-Woods Hole, Dept of Earth Sciences, United States

[4]University of Washington, Dept of Earth Sciences, United States

Four presentations given on the topics of Comparative Planetology, Solar Variability, Carbon Cycle, and Climate Modeling.

U12A MC: Hall D Monday 1330h

Milankovitch and Climate: Twenty-five Years Later II

Presiding: **T J Crowley,** Duke University**; W Prell,** Brown University

U12A-0001 1330h POSTER

Did Climate Friction Really Change the Earth Obliquity ?

Benjamin LEVRARD[1] ((33) 1 40 51 21 32; blevrard@bdl.fr)

Jacques LASKAR[1] ((33) 1 40 51 21 24; laskar@bdl.fr)

[1]ASD/IMC, Observatoire de Paris, 77 av Denfert-Rochereau, Paris 75014, France

The lagged response of continental ice sheets to climate changes of the Earth resulting from obliquity variations and viscoelastic response of the Earth may induce a secular trend in the obliquity (Bills, 1994; Rubincam, 1995; Ito et al, 1995; D.M Williams et al., 1998) although the amplitude of this phenomena called climate friction is still very controversial.

(Ito et al, 1995) predicted a positive drift of $0.04^\circ/Ma$ with Late Pleistocene glacial conditions, while D.M Williams et al.(1998) proposed a large decrease of 30° during 100 Ma around the Late Precambrian-Cambrian (ca. 550 Ma) boundary, favoured by the presence of hypothetical huge extented ice cap on a South polar supercontinent, and thus arguing in favor of G.E Williams' high obliquity scenario (1993) as an explanation of low-latitude Precambrian glaciations.

However, these models have considered obliquity as the only ice-age driver, while ice sheets are also probably driven by others Milankovitch periods from eccentricity or climatic precession, or they have used extreme palaeogeographic continental and glacial distributions.

We have revisited the 'climate friction' scenario for the Earth, and show that the absolute value of the secular drift of the Earth's obliquity should not have exceed $0.01^\circ/Ma$ for the Late Pleistocene and $0.05^\circ/Ma$ for each Neoproterozoic glacial interval. Futhermore, we show that widespread continental glaciations from low to high-latitude during Varanger glacial interval (ca. 610-570 Ma) on Pannotia supercontinent and low-latitude Sturtian continental glaciations (ca. 750-700 Ma) on an equator-straddling Rodinia supercontinent have probably drifted the obliquity in opposite directions inducing a global invariancy of the obliquity during Neoproterozoic Era.

If the Earth suffered a global or partial ice-covered period (Snowball Earth hypothesis), the climate friction effect would be even reduced.

If we take account of possible massive and long Permo-Carboniferous glaciations (ca. 340-260 Ma), we predict that climate friction has probably not changed the Earth obliquity by more than 1 or 2° during the last 800 Ma.

U12A-0002 1330h POSTER

Re-evaluating the Orbital Theory of Pleistocene Climate

Peter Huybers (617-492-7279; phuybers@mit.edu)

Massachusetts Institute of Technology, Bldg 54 rm 17-24 77 Massachusetts Avenue, Cambridge, MA 02139, United States

The presence of orbital-like variation in the $\delta^{18}O$ record was firmly established by Hays et al in 1976. Evaluating the significance of orbital variations in forcing the climate, however, remains an open question. Relying on the numerous long and highly resolved isotopic records made available in the last 25 years, I attempt to evaluate the geographic and temporal variations in the $\delta^{18}O$ record using a minimum number of assumptions. I begin by generating a minimally tuned common time scale for 23 separate $\delta^{18}O$ records, each of which extends through the Brunhes Matuyama magnetic reversal. I then assess the plausible range of observed variability linearly and non-linearly attributable to orbital variations. I find that the phasing and magnitude of the earth's response to orbital changes varies according to both climate state and location.

URL: http://web.mit.edu/phuybers

U12A-0003 1330h POSTER

Physical Record of Milankovitch Cycles from Variations in Sea Level and Ice Sheet Extent on the Antarctic Continent 24 Ma ago

Peter J Barrett[1,2] (*1-650-735-6830; peter.barrett@vuw.ac.nz); Timothy R Naish[3]; Gary S Wilson[4]; Ross D Powell[5]; Peter N Webb[6]; Ken J Woolfe[7]; Cape Roberts Science Team

[1]Antarctic Research Centre, Victoria University of Wellington, P O Box 600, Wellington, New Zealand

[2]Department of Geological & Environmental Sciences Sciences, Stanford University, Stanford, CA 94305, United States

[3]Institute of Geological and Nuclear Sciences, P O Box 30368, Lower Hutt, New Zealand

[4]Department of Earth Sciences, University of Oxford, Parks Road, Oxford, United Kingdom

[5]Department of Geological Sciences, Northern Illinois University, DeKalb, IL, United States

[6]Department of geological Sciences, Ohio State University, Columbus, OH 43210, United States

[7]School of Earth Sciences, James Cook University, Townesville 4811, Australia

Between 1997 and 1999 the Cape Roberts Project (CRP) drilled 3 holes to recover 1500 m of Oligocene and early Miocene strata from the western margin of the Victoria Land Basin (average recovery 95%). The cores record 46 unconformity-bound glacimarine cycles, or depositional sequences, many of which include the direct evidence of grounded ice. The site lies just seaward of the Transantarctic Mountains and of the margin of the present day East Antarctic Ice Sheet, and is thus well-placed to record ice sheet and sea level changes in the distant past.

Studies of the sedimentary facies, paleoecology and seismic geometries indicate that the entire sequence accumulated in shallow coastal waters as part of a laterally extensive seaward-thickening nearshore wedge. The cycles typically begin with an erosion surface followed by glacial deposition (diamictite, sandstone), relatively ice-free open marine sedimentation (mudstone) and shoaling before the overlying unconformity (well sorted sandstone).

Three of the cycles (9, 10 & 11) from 130 to 307 mbsf at the second drill site (CRP-2A) are unusually thick (around 60 m) and have been rather well dated within the range 23.7 to 24.1 Ma. Two biostratigraphic datums and four strontium isotope ages constrain correlation of a robust magnetic polarity stratigraphy with the geomagnetic polarity time scale (GPTS). Single crystal 39Ar40Ar laser fusion ages on anorthoclase phenocrysts from tephra layers at 190 and 280 mbsf confirm and independently calibrate the integrated age model.

These time constraints make it plain that the frequency of these 3 cycles, and most likely the other thinner and less complete cycles in the CRP sequences, lies in the range of those identified by Milankovitch as derived from the earth's orbital parameters. These frequencies are also recorded for this time period in the oxygen isotope record from the western Atlantic Ocean, ODP site 929.

Our chronology for cycles 11 and 10 shows them to have been deposited entirely within the 119 ka Chron C6Cn.3n, and hence likely to be 40 ka obliquity-driven cycles, as are the cycles at this time at ODP Site 929. Cycle 9, which rests on an erosion surface, spans the uppermost part of C6Cn.2r, all of C6Cn.2n and the lowermost part of C6Cn.1r, and is 120 ka in duration. We suggest that the erosion and hiatus at the base of cycle 9 represents ice sheet expansion that is correlative with the oxygen isotope Mi1 event and that cycle 9 is correlative to the major 100 ka cycle at 23.8 Ma immediately following the Mi1 event.

We think it most likely that all of the 46 Antarctic ice sheet expansions and contractions recorded in the Cape Roberts core too place at Milankovitch frequencies. If so, this means that much more is lost in sequence-bounding unconformities from the stratigraphic record of continental margins than is preserved (in this case 46 cycles from a possible 300 or more, presuming most are of 40 ka duration). The record also indicates that the cycles of climate and sea level change now accepted for the Quaternary era should be part of our thinking at least back to earliest Oligocene times.

URL: http://www.geo.vuw.ac.nz/croberts

U12A-0004 1330h POSTER

Warming at 140 ka: Causality Problem for Milankovitch?

Jonathan Levine[1] (510-704-7510; jlevine@socrates.berkeley.edu)

Daniel B Karner[1]

Richard A Muller[1]

[1]University of California - Berkeley, Deparment of Physics, Berkeley, CA 94720, United States

Sediment cores that contain records of both temperature and global ice volume indicate a major warming at about 140 ka. This is a potential causality problem for Milankovitch theory, because summertime, high-latitude, northern hemisphere insolation is at a low point at 140 ka, and does not peak until 127 ka. Such "early warming" is observed in the North Atlantic, Equatorial Atlantic, East Pacific, and West Pacific. Thus the phenomenon is more widespread than previously appreciated. Because it is observed at sites around the world, and because the warming is of a scale similar to that of deglaciation - itself the largest amplitude climate change of the Quaternary - its failure to be explained by Milankovitch forcing is a serious shortcoming for the theory.

U12A-0005 1330h POSTER

Milankovitch Cyclicity in the Eocene Green River Formation of Colorado and Wyoming

Malka Machlus[1] (machlus@ldeo.columbia.edu)

Paul E Olsen[1] (polsen@ldeo.columbia.edu)

Nicholas Christie-Blick[1] (ncb@ldeo.columbia.edu)

Sidney R Hemming[1] (sidney@ldeo.columbia.edu)

[1]Lamont-Doherty Earth Observatory of Columbia University, 61 Rt 9W, Palisades, NY 10964-8000, United States

The Eocene Green River Formation is a classic example of cyclic lacustrine sediments. Following Bradley (1929, U.S.G.S. Prof. Paper 158-E), many descriptive studies suggested precession and eccentricity as the probable climatic forcing to produce the cyclic pattern. Here we report spectral analysis results that confirm this hypothesis. Furthermore, we have identified the presence of a surprisingly large amplitude obliquity cycle, the long-period eccentricity cycle (400 k.y.) and the long period modulators of obliquity.

Spectral analyses of data from Colorado were undertaken on an outcrop section and core data using two different proxies for lake depth. In a section measured in the west Piceance Creek basin, three lithologies (ranks) were used as a proxy for relative water depth, from relatively shallow to deep water: laminated marlstones; microlaminated, light-colored oil-shales; and microlaminated black oil shales. A multi-tapered spectrum of the 190-m-thick record in the depth domain shows significant peaks at periods of 2.1, 3.4, 12 and 39 m. These are interpreted as the precession, obliquity and eccentricity cycles. The precession cycle confirms Bradley's independent estimate of 2.4 m per 20 k.y. cycle, based on varve counts at the same location. A high-amplitude, continuous 3.4 m (obliquity) cycle exists in the evolutive spectrum of this record. A second spectral analysis of an oil-shale-yield record was made on a 530 m core near the basin depocenter. This record includes the time-equivalent of the outcrop section, spans a longer interval of time, and has a higher sedimentation rate. Peaks are found at 5, 10, 25 and 79 m. Again, the probable obliquity peak, at 10 m, is continuous along the record. Initial tuning of this record to a 39.9 k.y. cosine wave improves the resolution of the precession, short and long eccentricity cycles.

Spectral analysis of oil shale yield and sonic velocity data of cores from the Green River basin, Wyoming, gives similar results. Spectral peaks at 6, 13, 31 and 122 m appear mainly in the Tipton and the Wilkins Peak members. The correlation between oil shale yield, lithology and relative water depth was examined in the upper part of the Wilkins Peak Member and the Lower part of the Laney Member. The succession from microlaminated black oil shale to laminated micrite corresponds with documented lateral changes in facies from deep to shallow environments, thus confirming the use of these facies as relative water-depth proxies. Furthermore, the upsection record of oil shale yields correlates with these facies, with higher yields corresponding to deeper water facies. This correlation supports the use of the oil shale yield record as a proxy for short-term lake-level changes, and therefore a proxy for climate.

The spectral analysis results from both basins show the importance of the obliquity cycle in these continental records. This cycle cannot be identified by cycle-counting, and therefore was not previously recognized. Earlier published attempts at spectral analysis of short records from the Piceance Creek and Uinta basins misinterpreted the observed cycles. This is the first time both the obliquity cycle and the long-term eccentricity cycle have been identified in the Green River and Piceance Creek basins.

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U12A-0006 1330h POSTER

New Insights Into Southern Hemisphere Temperature Changes From Vostok ice Cores Using Deuterium Excess Correction Over the Last 420,000 Years

Francoise VIMEUX[1] (33 1 69 08 57 71; vimeux@lsce.saclay.cea.fr)

Kurt M CUFFEY[2] (kcuffey@socrates.berkeley.edu)

Myriam KHODRI[1] (khodri@lsce.saclay.cea.fr)

Jean JOUZEL[1] (jouzel@lsce.saclay.cea.fr)

[1]LSCE, CE Saclay Orme des Merisiers Bat.709, Gif sur Yvette 91191, France

[2]Dept of Geography and Dept of Earth and Planetary Science, 507 McCone Hall University of California, Berkeley, CA 94720-4740, United States

Isotopic composition of the ice, deuterium (delta D) and deuterium excess (d), are currently used to infer both ice sheet and vapor source region temperature changes respectively. However, modeling studies (from simple to comprehensive models) show that to improve interpretation of isotopic profiles from ice cores we need to consider other controls on both deuterium and deuterium excess. Actually, both local and source temperatures affect delta D and d. In addition, ocean isotopic composition is also of primary importance. Thus, using Rayleigh model based estimates, we propose to combine both Vostok deuterium and deuterium excess histories to reconstruct, on a common time scale, temperature variations at both location of deposition and oceanic moisture source over the last 420,000 years. We examine each of these temperature histories regarding raw isotopic profiles. We show that source temperature recorded by deuterium excess is a source temperature gradient signal between low and mid latitudes rather than a low latitude signal of temperature. We also discuss the so-deduced Southern Hemisphere meridional temperature gradient, strongly modulated by the obliquity period. We show that this temperature gradient is well correlated with logarithm of sodium and dust recorded in Vostok cores, suggesting a strong link with atmospheric meridional transport. Finally, the combination of these results with new modeling studies using both a coupled ocean-atmosphere GCM (IPSL model) and an intermediate complexity climate model (CLIMBER model) provides interesting inputs to discuss climate mechanisms involved over glacial inceptions, between southern low and high latitudes.

U12A-0007 1330h POSTER

The Importance of Precessional Signatures in the Tropical Climate

Amy C. Clement[1] ((305) 361-4846; aclement@rsmas.miami.edu)

Alex Hall[2] ((310) 206-5253; alexhall@atmos.ucla.edu)

Anthony J. Broccoli[3] ((609) 452-6671; ajb@gfdl.noaa.gov)

Charles Jackson[4] ((512) 471-0401; charles@ig.utexas.edu)

[1]Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, 4600 Rickenbacker Cswy, Miami, FL 33149-1098

[2]University of California-Los Angeles, 7955 Math Sciences Building 405 Hilgard Ave. Dep't of Atmospheric Sciences Box 951565, Los Angeles, CA 90095

[3]NOAA/Geophysical Fluid Dynamics Laboratory Princeton University, Forrestal CampusU.S. Route 1 P.O. Box 308, Princeton, NJ 08542

[4]University of Texas at Austin, 4412 Spicewood Springs Rd., Bldg. 600, Austin, TX 78759-8500

The presence of orbital frequencies in the paleoclimate record is well established. The mechanisms that link the orbital forcing with climate, however, remain poorly understood. In this paper, we focus on climate change on orbital timescales in the tropics. Experiments with an atmospheric general circulation model are used to investigate the response of the tropical climate to precessional forcing. These results are compared with the tropical response to Last Glacial Maximum forcing. We find that while the glacial forcing has a large tropical mean signal in temperature, the precessional response of the hydrological cycle and atmospheric circulation are at least as large as that of the glacial, and at times of large eccentricity may overwhelm the glacial signal. These results emphasize the different nature of changes associated with the 100 kyr cycle of glaciation and the direct response to orbital forcing. Examples are given to show how these results can offer quantitative aid in deciphering these signals in tropical paleoclimate records.

U12A-0008 1330h POSTER

Limitations and Failures of the Milankovitch Theory

Richard A Muller (510 486 7430; ramuller@lbl.gov)

University of California, 50-232 LBL, Berkeley, CA 94720, United States

Although variations of the Milankovitch theory can account for some aspects of climate change, there are serious failures that require attention. In particular, we will discuss the status of the "causality problem", the apparent fact that major shifts in climate occur prior to the Milankovitch driving force, and the spectral peak problem, in which the spectral shapes predicted by the Milankovitch theory do not match those in the spectrum and the bispectrum of the data.

The standard Milankovitch theory ascribes all climate change to the same mechanism: summer insolation in the northern hemisphere. Variations in cloud cover are ignored, even though the net forcing of clouds is (at the present time) approximately 30 Watts per square meter – substantially greater than the rms variations in insolation (18 Watts per square meter). Thus changes in cloud cover could be more important than changes in the standard Milankovitch parameters. We will discuss mechanisms that link variations in the orbital inclination of the Earth to changes in cloud cover, and how these address the causality problem, the spectral problems, and several other failures of the Milankovitch theory.

How can we reconcile the failures of the Milankovitch approach with its obvious successes (e.g. in accounting for the 23 kyr cycle in sapropels, and the atmospheric oxygen variations in the Vostok data)? The answer is that climate is multi-dimensional. Insolation certainly affects climate. But we should not make the logical mistake of therefore assuming it accounts for the 100 kyr cycle of glaciation that has dominated for the past 800 kyr.

URL: http://muller.lbl.gov

U12A-0009 1330h POSTER

Orbital Theory, Marine Isotope Stage 11, and the Holocene Problem

Jerry F McManus[1] (508 289-3328; jmcmanus@whoi.edu)

Delia W Oppo[1] (doppo@whoi.edu)

James L Cullen[2] (cullen@dgl.ssc.mass.edu)

Peter Huybers[3] (phuybers@wind.mit.edu)

[1]Woods Hole Oceanographic Institution, G&G Department, Woods Hole, MA 02543, United States

[2]Salem State College, Dept. of Geological Sciences, Salem, MA 01970, United States

[3]Massachusetts Institute of Technology, 77 Mass Ave, Cambridge, MA 02139, United States

As pointed out by Hays, Imbrie and Shackleton (1976), orbitally controlled variations in seasonal insolation provide a likely pacing for the Pleistocene ice ages. The interglacial intervals that serve as respites from the recurring glaciations are also of particular interest, since we are living within the Holocene, the most recent of these interglacial episodes. A key question is the timing of the inevitable return to glacial conditions that may be required by the orbital pacemaker. Another open question is how the climatic progression will proceed, now that mild conditions have persisted for approximately one half of an orbital (precession) cycle. Some insights to these questions may be derived from similar past intervals. Among the Pleistocene interglaciations, marine isotope stage 11 (MIS 11) may constitute the best analogue for the development and eventual demise of the Holocene, due to its comparable orbital configuration of minimal eccentricity. Detailed evidence from ODP Sites 980 and 983 in the North Atlantic indicates a markedly similar regional and global climate regime during MIS 11 and the Holocene, suggesting a consistent, if anomalous, response in excess of the presumed high northern latitude summer insolation forcing. Sea-surface temperature proxies based on planktonic foraminifera assemblages and (δ18O) indicate stable ocean warmth for an extended interval during MIS 11. A variety of age models yield a minimum duration of 30 kyr for these regional conditions, or one and a half orbital (precession) cycles. This length suggests the possibility that the climate system may skip a beat when precession cycles have diminished amplitude due to minimal eccentricity-modulation. Both planktonic and benthic (δ18O) during MIS 11 are indistinguishable from Holocene values. The simplest interpretation of these results is that regional hydrography in the North Atlantic, and global ice volume, were very similar during the two interglaciations. Only the duration of MIS 11 differs significantly from the elapsed portion of the Holocene. If the duration of the Holocene and MIS 11 is as similar as the presumed forcing and the climatic response of the two intervals, then the expected natural return to glacial conditions may be in the distant future.

U12A-0010 1330h POSTER

Paleoenvironmental Clues from Milankovitch Cyclicity and Rock-Magnetism in the Early Cretaceous Pelagic Realm of the Southern Alps, Italy

Tim Erbrecht[1,2] (erbrecht@denali.uni-trier.de)

Helmut Mayer[1,2] (mayerh@tryfan.colorado.edu)

[1]INSTAAR, University of Colorado, Boulder, CO 80309, United States

[2]Geomathematik, Universität Trier, Trier 54286, Germany

In the Southern Alps of Italy a relatively continuous record of the Valanginian to Hauterivian is preserved in the Maiolica/Biancone Formation. The focus of this study is on sedimentary-parameter variations through well exposed, tectonically undisturbed sections, their analysis as stratigraphic time series and their paleoclimatic and paleoenvironmental interpretation. Through time-series analysis characteristic Milankovitch cycles were detected. Parameters studied include carbonate content, bedding thickness, magnetic susceptibility, natural remanent magnetization, coercivity ratios, demagnetization behavior, and acquisition of isothermal remanent magnetization. Rock-magnetic parameters by themselves have little paleoclimatic or paleoenvironmental meaning. But if calibrated with the help of paleontological or isotopic climate indicators for the specific environment studied, they provide the long, continuous and areally extended records needed for useful paleoenvironmental reconstruction. Thus, the value of environmental-magnetic methods lies in the fact that they are fast, easily applicable, non-destructive, and inexpensive.

In the Biancone Formation an excellent negative correlation of magnetic susceptibility with carbonate content verifies that the susceptibility signal reflects a primary depositional feature. Susceptibility may be used as a proxy for carbonate content with high confidence in this pelagic setting. The carbonate cycles represent primary productivity cycles which can be attributed to climatically driven shifts in oceanic circulation in this Tethyan basin.

Evidence for Milankovitch cycles in the Early Cretaceous suggests that orbital forcing was as effective then as it has been during the Quaternary, although the climatic setting was quite different with warm, equable and ice-free conditions in contrast to the Quaternary ice-age climate. Orbitally forced and climatically driven environmental change was strong enough even in the Cretaceous climate state to leave a clear mark in the sensitive pelagic record, although no polar ice caps existed, which play a dominant role in climate models for the Quaternary.

U12A-0011 1330h POSTER

Stochastic forcing of Pleistocene ice sheets: Implications for the origin of Millennial–Scale Climate Oscillations

William T Hyde[1] (919 681 8228; hyde@rossby.eos.duke.edu)

Thomas J Crowley (tcrowley@nc.rr.com)

[1]Department of Earth and Ocean Sciences, Duke University, Durham, NC 27708, United States

Considerable evidence now exists for high frequency climate changes in the last ice age cycle (Daansgard–Oeschger and Bond cycles). Though large scale ice sheet flow has too long a time constant to play a significant role in these events, stochastically forced changes in the mass balance of the Pleistocene ice sheets may have resulted in significant variation in freshwater flux to the North Atlantic. In this paper we mimic the effects of "natural variability" with small ($\lesssim 0.5 W/m^2$) stochastic changes in insolation and examine the response in terms of ice volume change in an ensemble of coupled energy balance/ice sheet model runs. The total change in ice mass is comparable to a third of the volume of the current Greenland ice sheet, with meltwater discharge potentially sufficient to trigger Dansgaard-Oeschger type events. In general the Eurasian ice sheet is more sensitive. The distribution and occurrence of spectral peaks in the 1–9k band is also comparable to the geologic record, and there is some evidence that oscillations in the "Bond cycle" band may be related to harmonics of the precession cycle. Cyclical perturbations mimicking the $\approx$ 1500 year oscillation produce freshwater fluxes large enough to have a significant negative feedback on the North Atlantic thermohaline circulation. Overall, results suggest that some caution is necessary in interpreting the physical significance of sub–Milankovitch spectral peaks in paleo time series.– such peaks may simply reflect the superposition of stochastic variability on a low frequency oscillation. If so, our results suggest that orbital and millenial time scales are closely linked and the shorter time scales cannot be understood in isolation from the Milankovitch band.

U12A-0012 1330h POSTER

Role of CO2, Insolation and Antarctic ice Sheet on the Interglacial Marine Isotope Stage 11

Dominique Raynaud[1] (33 4 76824245; raynaud@glaciog.ujf-grenoble.fr); Marie-France Loutre[2]; Catherine Ritz[1]; Jean-Marc Barnola[1]; Andre Berger[2]; Jerome Chappellaz[1]; Jean Jouzel[3]; Vladimir Lipenkov[4]; Jean-Robert Petit[1]; Francoise Vimeux[3]

[1]LGGE/CNRS, Rue Moliere BP 96, St-Martin-d'Heres 38402, France

[2]Institut d'Astronomie et de Geophysique Universite Catholique de Louvain, Chemin du Cyclotron,2, Louvain la Neuve 1348, Belgium

[3]LSCE/CEA-CNRS-IRD, Orme des Merisiers CEA Saclay, Gif-sur-Yvette 91191, France

[4]AARI, Beringa Street 38, St Petersburg 199397, Russian Federation

The Marine Isotopic Stage 11 (MIS 11), around 400kyr BP ago, has been suggested as an analogue for a future climate under natural forcing because of the similar conditions of orbitally driven insolation during this interglacial period and the one covering the Holocene and the near future. There are many open questions about unusual MIS 11 climatic conditions (length of the interglacial, temperature, sea level, marine carbonate system), as recorded in different marine and continental records. The Antarctic Vostok ice core provides the only atmospheric record extending back to MIS 11 and we use it to discuss the Antarctic temperature, the atmospheric CO2 concentration and the ice sheet stability in the central part of East Antarctica during this interglacial.

The unique nature of the Vostok atmospheric record leads us to use the available Vostok data to drive climate and ice sheet models for MIS 11. A model of intermediate complexity (LLN-2D model) is used to investigate the sensitivity of the simulated MIS 11 deglaciation to the interplay between insolation and CO2. It is shown that the length of the simulated interglacial depends strongly on the phasing between these two climate forcings. We also investigate the response of the Antarctic Ice Sheet to changing climate through simulations performed with the LGGE 3-D ice sheet model. The results indicate that sea level stands during MIS 11 as high as 20 m. above present level, as suggested by different elevated marine terraces, cannot be explained, except by assuming that MIS 11 was very dry over Antarctica.

U12A-0013 1330h POSTER

Reassessment of Greenhouse Gas and Temperature Covariation From Vostok Ice Core Data

Kurt M Cuffey[1] (510-643-1641; kcuffey@socrates.berkeley.edu)

Francoise Vimeux[2] (vimeux@lsce.saclay.cea.fr)

[1]Department of Geography University of California, 507 McCone Hall, Berkeley, CA 94720-4740, United States

[2]Laboratoire des Sciences du Climat et de l'Environnement UMR CEA-CNRS, CEA Saclay Batiment 709, Orme des Merisiers, Gif-sur-Yvette 91191, France

A major and widely recognized failure of the Milankovitch theory is its inability to predict the 100 kyr beat of the ice ages, and the synchroneity of major climate changes in the northern and southern hemispheres. Feedbacks between climate and biogeochemical cycling, and corresponding changes in atmospheric chemistry, have had a significant role in these aspects of ice-age climate cycling. This was first demonstrated by Barnola and colleagues using gas and water-isotope data from the Vostok ice core. We have re-evaluated the relationship between temperature and greenhouse gas forcings as revealed by Vostok ice, by using a temperature reconstruction model that incorporates deuterium excess to correct for artefactual source region climate effects. The covariance of carbon dioxide and temperature is significantly stronger in our new reconstructions than in the original analyses. Covariance of carbon dioxide and temperature is estimated to have been 89% over the last 150 kyr, and 84% over the past 350 kyr. Furthermore, much of the obliquity-period variations in temperature originally inferred from the Vostok ice core are shown to be artefacts of changes in atmospheric transport characteristics associated with changes in the meridional insolation gradient.

U12B MC: 134 Monday 1330h

Oceans Within Our Solar System and Beyond

Presiding: **T V Johnson,** Jet Propulsion Lab**; J R Delaney,** University of Washington

U12B-01 1330h INVITED

Oceans in Planetary Satellites: An Historical Overview

Torrence V. Johnson (+1 818 393 7957; tjohnson@jpltvj.jpl.nasa.gov)

Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr., Pasadena, CA 91109, United States

Planetary astronomers have long recognized that frozen water or frost, as well as more exotic frozen volatiles, may be a major constituent of the surfaces of bodies in the cold reaches of the outer solar system. The idea of large amounts of water, possibly in liquid form, in the interiors of satellites of the giant planets first began to be seriously discussed about thirty years ago (e.g. Lewis, 1971). Since then, theoretical debates concerning the likelihood of these global subsurface oceans have continued. Data from the Voyager encounters with Jupiter, Saturn, Uranus and Neptune (1979-1989) showed the satellites of the outer solar system to be geologically diverse with some showing evidence of young, resurfaced surfaces consistent with the possibility of a subsurface liquid layer. Tidal heating as a significant energy source for these bodies was also spectacularly confirmed with the discovery of volcanoes on Io. Results from the Galileo mission (1995 present) have provided significant support for the presence of a global liquid water layer in all three of the icy Galilean satellites, Europa, Ganymede, and Callisto. The current evidence from Galileo will be reviewed as well as prospects for future exploration.

U12B-02 1345h INVITED

Frequency and Nature of Planetary Water-Dominated Oceans

David J Stevenson (626 395 654; djs@gps.caltech.edu)

Caltech, 150-21, Pasadena, CA 91125, United States

There are three kinds of planetary water-dominated oceans. The first kind is Earthlike, where the overlying atmosphere has modest optical depth. In addition to requiring sufficient water, such an ocean requires a rather narrow range of circumstances to exist (sometimes erroneously labeled "the habitable zone"). Early Mars, and early Io and Europa may have had this kind of ocean but it could be rare as a long-term stable state. The second kind of ocean is kept warm by a dense atmosphere. For example, an earth mass body that retains a kilobar hydrogen atmosphere in interstellar space can have an ocean maintained by radioactivity alone. Bodies such a Uranus and Neptune can be thought of as grossly exceeding the necessary conditions (i.e., their water component is actually too hot to produce a well-defined ocean). There is no reason to suppose that this second kind of ocean is rare; it may well be the most common kind and a common occurrence throughout the universe. I will discuss the difficulties of detecting these bodies. A solid layer of ice caps the third kind of ocean. All large satellites are thought likely to have such an ocean; in the cases of Europa and Callisto the best evidence is the magnetic fields observed by the Galileo spacecraft and attributed to the induction response of a salty water layer. These water layers can be sustained by radioactivity alone in bodies the size of about Callisto or larger, while tidal heating is probably important in Europa. The antifreeze properties of ammonia may extend the domain of ocean worlds to considerably smaller bodies, perhaps including Triton and Pluto. In summary, oceans are probably common and diverse.

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Sources of Water for Oceans on Planets

Tobias C Owen (1-808-956-8007; owen@ifa.hawaii.edu)

University of Hawaii, Institute for Astronomy 2680 Woodlawn Drive, Honolulu, HI 96822, United States

Studies of D/H in the H2O carried by three Oort cloud comets have shown that such comets could not have contributed all of the water in the Earth's oceans. The extent of the cometary contribution depends on the value of D/H in water brought directly to the planet as hydrous minerals or adsorbed solar nebula H2O. That some cometary water was in fact delivered to the inner planets is strongly suggested by the value of D/H in Shergottite minerals when viewed in the context of other isotope geochemistry on Mars (Owen and Bar-Nun, FARADAY DISCUSSIONS 109, 453-462 (1998)). This scenario is also consistent with noble gas and siderophile element abundances on Earth. The identification of comet-produced water vapor around the aging carbon star IRC +10216 (Melnick et al., NATURE 412, 160-163 (2001)) provides concrete support for the widely held assumption that a cometary reservoir for the irrigation of inner planets should be a common feature of planetary systems throughout the galaxy.

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Microbial Life in the Subseafloor at Mid-Ocean Ridges: A Key to Understanding Ancient Ecosystems on Earth and Elsewhere?

John A. Baross[1] (206 543-0833; jbaross@u.washington.edu)

John R. Delaney[1] (206-543-4830; jdelaney@u.washington.edu)

[1]University of Washington, School of Oceanography, Seattle, WA 98195, United States

Some planets and moons in our solar system were similar to Earth in their geological properties during the first few hundred million years after accretion. This is the period when life arose and became established on Earth. It follows that understanding the geophysical and geochemical characteristics of early Earth could provide insight into life-supporting environments on other solar bodies that have not evolved "Garden of Eden" conditions. Hydrothermal systems are primordial and their emergence coincided with the accumulation of liquid water on Earth. The interactions of water and rock associated with hydrothermal systems result in predictable suites of dissolved elements and volatiles. While the concentrations of these chemicals vary at different vent locations and were certainly different during the early Archaean, the overall chemical composition of aqueous hydrothermal fluid is likely to be the same because of the basaltic nature of oceanic crust. In present-day hydrothermal systems, those environments not contaminated by electron acceptors produced from pelagic photosynthesis would most closely mimic the earliest conditions on Earth. These conditions include the subseafloor and high temperature, anaerobic environments associated with hydrothermal systems. The microorganisms associated with these environments derive energy from sulfur, iron, hydrogen and organic compounds. New seafloor eruptions and diffuse flow vents provide unprecedented access to deep subseafloor microbial communities. For example, 12 new eruptions have occurred in the past 15 years including five in the Northeast Pacific. Hyperthermophiles were isolated from 5-30°C diffuse vent fluids from new eruption sites at CoAxial within months of the June, 1993 eruption and from the 1998 eruption at Axial Volcano, and from plume fluids within days of the February, 1996 eruption at the N. Gorda Ridge. The presence of such organisms in fluids that are 20 to 50°C below their minimum growth temperature indicates that they originated from a hot subseafloor habitat. Based on the 16S rRNA sequences and the RFLP patterns of the 500 base sequence between the 16S and 23S rRNA genes (intergenic spacer region), these heterotrophic archaea represent new species, and a new genus, within the Thermococcales (Summit and Baross, 1998; 2001). These isolates grow over an unusually wide temperature range and in low levels of organic material. While Thermococcus and Methanococcus species are the most commonly isolated species of hyperthermophiles from subseafloor biotopes, preliminary phylogenetic analyses based on 16S rRNA sequences of microbial communities in the diffuse flow fluids at new eruption sites show a high diversity of archaea that are not related to cultured organisms. Results to date support the hypothesis that subseafloor microbes associated with hydrothermal systems have nutritional, physiological and bioenergetic characteristics that reflect the physical and geochemical properties of their habitat. Moreover, we propose that deep-sea subsurface environments are analogs of ecosystems on other solar bodies. Thus, by examining the chemical and microbial ecology and energetics of the subsurface, and particularly the subsurface associated with hydrothermal systems, a framework for studying the prospects of extraterrestrial life can be developed. It is predicted that if there were life on other hydrothermally active solar bodies, the same energy sources would fuel microbial metabolism even though the molecular characteristics of these life forms may not resemble Earth organisms having identical metabolisms.

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Standing Bodies of Water on Mars: A Review of Their Mode of Emplacement, Scale, Behavior and Fate

James W Head (401-863-2526; James_Head_III@brown.edu)

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