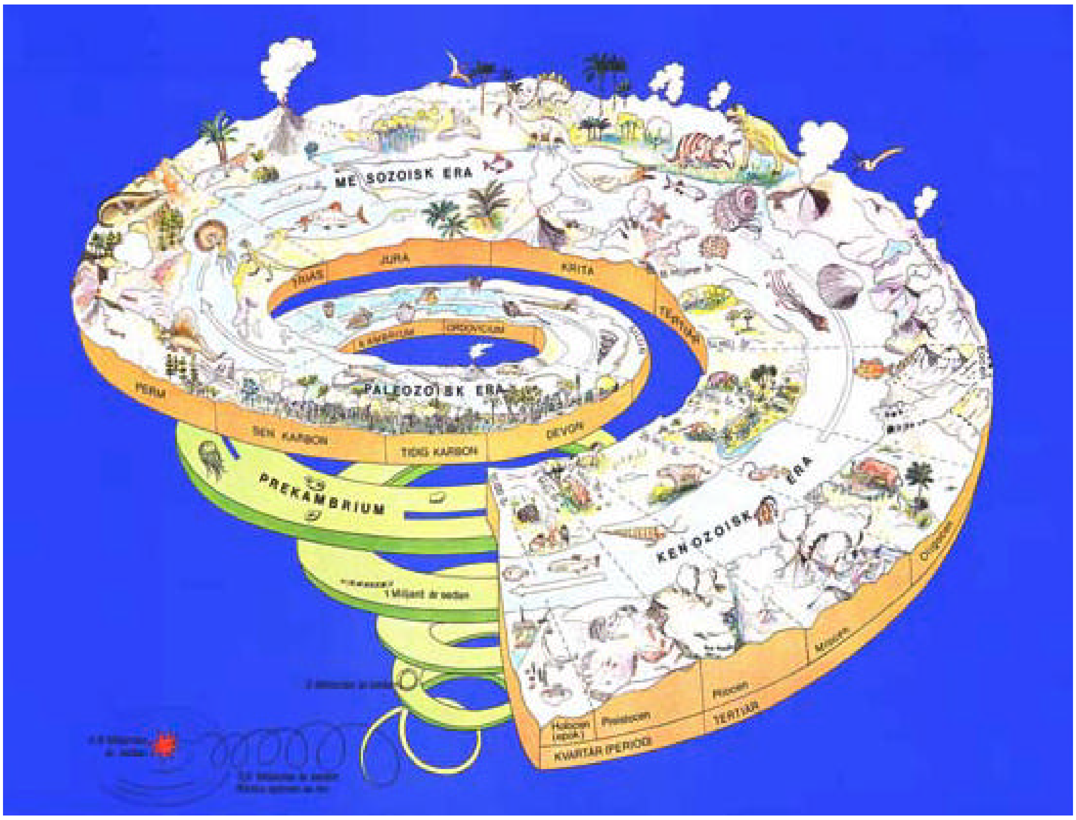
European Geosciences Union



The time spiral, ©Sveriges geologiska undersökning (SGU)
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GIFT - 2005

The History of the Earth

Geophysical Information for Teachers Workshop

Vienna, Austria, 26-27 April 2005

European Geosciences Union

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GIFT - 2005

The History of the Earth

Dear Teacher,

Welcome to the third edition of the EGU GIFT Workshop!

After a one-day workshop in 2003 in Nice attended by 42 teachers from 7 countries, we have had 50 teachers from 11 countries attending the two-days GIFT 2004 workshop, and we have now 70 teachers from 17 countries for the 2005 edition of GIFT in Vienna. In addition, we have also scheduled a "companion" workshop on Natural Risks Assessment (NaRAs), so that 3 full days will be attended by all of you: Thank you for sustaining our action by your presence!

The general theme of the 2005-GIFT workshop, "The History of the Earth" is far too broad for every aspect of the Earth History to be addressed. We have therefore chosen to select major but-somewhat-ill-known aspects of the Earth evolution, which will be addressed by leading scientists in the field.

In addition, innovating from the previous editions, we have scheduled every two scientific talks or so, presentations given by either scientists or science educators specifically intended for classroom activities. These sessions are designed so that every teacher, from elementary to high school, will find something to transport into her/his classroom.

Finally, thanks to a particularly important effort by Barbara Donner of the University of Bremen, the entire afternoon of Wednesday April 27 will be devoted to the study of marine cores and of the foraminifera they contain. Foraminifera carbonate skeletons are the most widely used support for oxygen isotope studies upon which are based most, if not all, of the paleoclimatic reconstructions. The teachers will be "transported" into a research laboratory!

Carlo Laj and Jean-Luc Berenguer
On behalf of the Committee on Education of EGU

GIFT – 2005

Geophysical Information for Teachers Workshop

The history of the Earth

Acknowledgements

This workshop has been organized by the Committee on Education of the European Geosciences Union. The European Geosciences Union has largely contributed to its organization. In addition, GIFT has benefited of the generous help of:

- The French Commissariat à l'Energie Atomique (Atomic Energy Commission), both the Direction des Sciences de la Matière at the Saclay Research Center and the Visiatome at the Valrho Research Center at Marcoule.

- The Specific Support Action "SSA" 2005-2006 of the European Community on Natural Risk Assessment (Na.R.As) lead by Paolo GASPARINI

- The AREVA group

And we thank all the speakers who have contributed to this educational workshop and their Institutions!

Program

European Geosciences Union – General Assembly
GEOPHYSICAL INFORMATION FOR TEACHERS (GIFT) WORKSHOP

Austria Center Vienna

Program

Tuesday April , 2005

08:30 - 09:00	Opening of the Workshop
09:00 – 10:00	**THE EARLY DEVELOPMENT OF THE EARTH, MOON AND MARS** Alex Halliday University of Oxford, UK
10:00 – 10:30	Coffee break
10:30 – 11:30	**THE NATURAL REACTORS AT OKLO (GABON): 2 BILLION YEARS BEFORE FERMI !** Bertrand Barré Areva, France
11:30 – 12:30	**RADIOACTIVITY EXPLORATION IN THE CLASSROOM** Marie-Hélène Leuthereau Le Visiatome, CEA France
12:30 – 13:30	Lunch
13:40 – 14:00	**PRESENTATION OF "GEOLAB"** A didactic tool for secondary schools and high schools Herbert Summesberger & al. Museum of Natural History, Austria
14:00 – 15:00	**EXTREME GLACIATIONS: SNOWBALL EARTH** Gerhard Fischer University of Bremen
15:00 -15:30	Coffee break
15;30 – 17:00	**SEQUENCING TIME AND THE HISTORY OF LIFE: HANDS-ON ACTIVITIES TO INCREASE STUDENT UNDERSTANDING.** Judy Scotchmoor University of California Museum of Paleontology, Berkeley, USA

17:00 – end of day	**GUIDED TOUR OF THE VIENNA MUSEUM OF NATURAL SCIENCES** Gertrude Zulka Schaller and Herbert Summesberger or Visit the General Assembly of EGU

Wednesday April 27

09:00 – 10:00	**THE EARTH MAGNETIC FIELD** Philippe Cardin LGIT, Université de Grenoble, France
10:00 – 10:30	Coffee Break
10:30 - 11:30	**THE ENIGMATIC CLIMATIC STAGE 11** André Berger Institut Catholique de Louvain, Belgium
11:30 - 12:30	**KINESTHETIC ASTRONOMY** Cherilynn Morrow Space Science Institute, Boulder USA
12:30 - 13:30	Lunch
13:30 - end	**RECONSTRUCTING PAST CLIMATES....** Barbara Donner Research Center Ocean Margins Bremen, Germany

Speakers

Alex Halliday
Department of Earth Sciencdes
University of Oxford
Parks Road
Oxford
OX1 3PR
United Kingdom
Telephone : (44) 1865 272030
E-mail :alexh@earth.ox.ac.uk

Education:

Secondary school in Cornwall, U.K.
B.Sc. in Geology and Ph.D. in Physics at the University of Newcastle-upon-Tyne, UK.

Research Interests:

Alex Halliday uses a wide range of isotopic methods to study earth and planetary processes by determining absolute time-scales and tracing the sources of components. Most of his recent work utilizes a new technique called multiple collector inductively coupled plasma mass spectrometry to study the origin and early development of the solar system and recent earth processes such as continental erosion and climate. However, he is also engaged in other studies as different as the mechanisms of volcanic eruptions, the formation of mineral and hydrocarbon deposits and the development of civilization.

He has published about 250 articles in international scientific journals, sits on a variety of science advisory panels and is the recipient of several awards. He is the current President elect of the European Association of Geochemistry.

The Early Development of the Earth, Moon and Mars

Alex N. Halliday

University of Oxford, UK

The formation and earliest history of the Earth is shrouded in mystery, partly because of the absence of any geological record from the first 500 million years (Myrs). Our understanding has taken immense strides forward in recent years however. The development of new isotopic techniques has been the single most important contributor to this. Other important lines of evidence have come from simulations of planetary accretion, as well as observations of other stars and their disks and planets. With new missions to the terrestrial planets and original kinds of data for meteorites we can also make comparisons with how other planets formed. This is particularly important because, unlike the Earth, Mars and the Moon still carry a large amount of information about their earliest histories. One can use this to infer how the Earth is likely to have started.

At the heart of the new discoveries lies the exciting field of isotope geochemistry. Isotope geochemistry is the study of natural variations in the atomic abundance of the nuclides. The field has been developing over 50 years but it is now booming thanks to new technology. Isotopic variations can be used in five main ways relevant to the history of the early solar system.

1. *Nucleosynthetic heterogeneity and the provenance of planetary building blocks*. All elements heavier than helium are, in the main, the products of stars. Stars convert one kind of atom to another, usually heavier, kind by various combinations of nuclear fusion, irradiation and radioactive decay. These processes generate widely different atomic abundances of isotopes. The relatively uniform proportions found in our solar system indicate that, somehow, the dust and debris that formed our solar system became extremely well-mixed. However, variations in some elements (like oxygen) do exist between different kinds of meteorites and these provide an indication of where the material that built the planets came from. For example we can show from their oxygen isotopes that the Earth and Moon were made from material derived from the same portion of the solar system, despite their great difference in chemical composition today.

2. *Radioactive isotopes and the discovery of time.* Radioactive isotopes undergo decay to daughter isotopes of other elements. Those with half-lives of a few hundred thousand to a few billion years accumulate in the planet and result in an increase in the proportion of the daughter isotope. The amount of the change is a function of time and the ratio of the amount of the parent element relative to the daughter element. For

example nearly all of the ^{235}U and half of the ^{238}U present at the start of the solar system have decayed to ^{207}Pb and ^{206}Pb over the billions of years since the Earth formed. This is how we know the age of the Earth and solar system. Most of the Earth's original Pb has followed its iron and nickel into the core. However, the uranium has stayed in the silicate rich mantle and crust. For this reason the U/Pb ratio of the silicate portion of the Earth is very high and this has generated Pb that has a high proportion of ^{207}Pb and ^{206}Pb, formed by decay of ^{235}U and ^{238}U, relative to ^{204}Pb. The exact amounts provide information on time, i.e. when the silicate Earth and metal core separated, which is roughly the same time as when the Earth formed. Therefore we can use such techniques to provide absolute ages but also to determine the rates of various processes and the time-averaged geochemical evolution of a planet. For example with U-Pb dating we know the age of the Earth and solar system is 4.5 to 4.6 billion years. We know from ^{182}Hf-^{182}W, a short-lived (T_=9 Myrs) chronometer, that the Earth formed within about 50 Myrs of the start of the solar system.

3. *Time-averaged chemistry.* The same decay systems provide us with the opportunity to measure time-integrated chemical compositions. Put simply one determines time knowing a radioactive parent to radiogenic daughter element ratio, and a daughter isotopic composition. One can turn this around if one knows the age of an object independently and from this deduce the average parent / daughter elemental ratio between the start of the solar system and formation of an object. For example, ^{87}Rb decays to ^{87}Sr with a very long half-life. The initial $^{87}Sr/^{86}Sr$ ratio of the earliest rocks on the Moon implies a Rb/Sr that is an order of magnitude higher than the Rb/Sr of the Moon. Therefore, at some point prior to or during the formation of the Moon, large amounts of volatile Rb were lost relative to refractory Sr.

4. *Early solar system radioactivity.* The abundances of short-lived radionuclides at the start of the solar system provides information on the kinds of stars that might have just preceded our sun and potential provided a trigger for its formation. Also these nuclides would have been an important source of heat in the early solar system.

5. *Stable isotope fractionations and the conditions of planet formation.* Some processes produce mass dependent isotopic fractionations. That is, light isotopes are enriched relative to heavy and vice versa. These can be process and environment dependent and provide clues as to how the planets formed. For example there is a hint that the Fe in the Moon is slightly heavy relative to that in the Earth. This might be caused by vaporization of molten iron metal during the Moon-forming Giant Impact.

With these four kinds of isotopic tools we can piece together the mechanisms and timing of planet formation processes. This leads us to the following conclusions.

1. The initial abundances of short-lived nuclides provide evidence that the Sun formed by collapse of part of a large molecular cloud of gas and dust in response to a shock wave provided by a supernova or perhaps a red giant.
2. The earliest objects in the solar system are now dated remarkably precisely and appear to have formed 4.5672±0.0006 billion years ago. This is thought to be very close to the age of the Sun and all the planets.
3. The planets formed from a swirling circum-solar disk of gas and dust that became relatively well mixed.
4. Formation of small (asteroidal-sized) objects took place early. These are probably best represented by iron meteorites some of which appear to have formed within the first ~1 million years of the solar system. Therefore, melting and core formation were also early. New isotopic evidence shows that there as a considerable amount of live ^{60}Fe as well as ^{26}Al in the early solar system and this would have provided a huge amount of radiogenic heat sufficient to cause melting.
5. Mars also formed very quickly. Isotopic data for martian meteorites and modelling suggests that it too accreted, probably by a runaway gravitational growth mechanism, and commenced core formation in about a million years.
6. Mars appears to be a planet that stopped growing at an early stage. One possible reason for this was that Jupiter achieved sufficient mass that it perturbed the trajectories of material that otherwise may have contributed to further Mars growth.
7. The Earth formed over much longer timescales of 40 to 50 Myrs as a result of a series of highly energetic stochastic collisions between planetesimals and planets in the inner solar system.
8. The last major event in the accretion of the Earth was the formation of the Moon, 40 to 50 Myrs ago. The best current explanation for this is that a Mars-sized planet called Theia collided with the proto-Earth in a "Giant Impact" when it was 90% of its current mass. This resulted in Moon-forming debris and the angular momentum of the Earth-Moon system.
9. The proto-Earth and Theia were formed at similar heliocentric distance and this may explain their eventual collision.

10. Theia was probably much more volatile rich than the Moon. In fact its time-integrated chemistry indicates it was more like Mars. Therefore objects that resembled Mars in chemistry and mass may have been commonplace in the inner solar system prior to being lost or accreted to other planets.
11. The origin of Earth's water is an enigma. The three hypotheses that are generally considered are that (1) the water was added from late infalling water rich planetary embryos from the far Asteroid Belt, (2) comets brought in the water after the giant impact and (3) the Earth was always water rich and this feature somehow survived its extreme accretion history. All these theories have apparent problems at this time.
12. The later stages of accretion were enormously energetic because so much heat is liberated from increased gravitational energy. Toward the end of Earth accretion, following the Giant Impact it is thought there was a magma ocean extending to perhaps 700 km into the mantle. Temperatures at the surface may have been several thousand Kelvin.
13. The Earth's earliest atmosphere was probably large and dominated by nebular gases (hydrogen and helium). Xenon isotopes provide evidence of extreme atmospheric loss more than 50 Myrs after the start of the solar system.
14. The first evidence of a cool hydrosphere comes from zircon grains recovered from Australian sandstones. These have ages extending back to 4.44±0.01 billion years and carry oxygen isotope signatures characteristic of low temperature water.
15. What happened to the geological record until the formation of the earliest rocks at 4.0 billion years is unclear. However, we know from the record of cratering and isotopic resetting on the Moon that a late bombardment happened close to the time defined by the earliest terrestrial rocks. What this bombardment represented is unclear.
16. The issue of when and how the first life formed is more contentious now than it has been in many years. We do not know if it is easy or hard for life to form. This and the definition of what it takes to make a planet that is truly habitable form the basis for much of the current interest in exploring other planets of our solar system. It is also a major driver behind the search for habitable or even inhabited "Earth-like" planets around other stars.

Bertand Barré

AREVA

A brief personal history

Bertrand Barré is Advisor for Scientific Communications to the Chairperson of the AREVA group. He is also Professor of nuclear engineering at the Institut National des Sciences et Techniques Nucléaires, INSTN. He was previously, from 1994 to 1999, at the head of the Nuclear Reactor Directorate of the French Atomic Energy commission, CEA, and from 1999 to 2002 Vice-president in charge of R&D in COGEMA.

B. Barré joined the CEA in 1967 and has been working ever since, both in France and abroad, for the development of Nuclear Power. Alternating scientific and managerial positions, Mr Barré was notably Nuclear Attaché near the French Embassy in Washington (USA) and Director of Engineering in TECHNICATOME, an engineering company now in the AREVA Group.

Bertrand Barré is presently President of the European Nuclear Society (ENS) and of the International Nuclear Societies Council (INSC). A former Governor of the European Joint Research Center, JRC, B. Barré has been a member of the EURATOM Scientific & Technical Committee, STC since 1995.

February 2005

The natural Reactors at Oklo (Gabon) : 2 billion Years before Fermi!

Bertrand BARRÉ,
AREVA

1. The Italian Navigator has landed in the New World.

On December 2, 1942, this cryptic message announced that the team gathered around Enrico Fermi in Chicago had managed to sustain a fission chain reaction in the first ever man made nuclear reactor, CP1. This was the climax of a decade long search, starting with the discovery by Chadwick in 1932 of the neutron, a particle able to interact with the nuclei without being hampered by their electric charges, the series of experiments by Fermi sending "moderated" neutrons against every nucleus of the Mendeleyev Table, the discovery of the fission of uranium by Otto Hahn and Lise Meitner in 1938. When the team led by Joliot discovered, a few months later, that 2 to 3 new neutrons were emitted during the fission, they were able to conceptually design a nuclear reactor, a facility using a sustained fission chain reaction to generate vast amounts of energy, but World War 2 shifted the research efforts to America.

And for three decades, it was believed that CP1 was not only the first man made reactor, but the first nuclear reactor ever – full stop.

2. Radioactive Earth.

Not everybody realizes that geothermal energy is just another name to describe the radioactivity of our planet. Among the heavier elements retained during the formation of Earth (most of the lightest elements escaped its too small gravity), a number have only radioactive isotopes. Potassium[1], Thorium and Uranium are the most abundant remaining today. The energy they keep releasing during their radioactive decay is the central heating system which supplements what we receive from the Sun.

Natural uranium is (today) composed of three major isotopes, ^{238}U (abundance 99.2744%), ^{235}U (abundance 0.7202%) and ^{234}U (abundance 0.0054%). This very precise composition is the same – almost – everywhere on Earth. All these isotopes are radioactive and decay with time, but not with the same speed. The half-life of ^{238}U is 4.51 billion years while ^{235}U decays by half in "only" 710 million years. Therefore,

[1] ^{40}K in our bones is responsible for half of the radioactivity of our own body, which amounts to about 8000 Bq for an adult.

the relative abundance of ^{235}U increases if we go back in time: at the creation of the solar system, it was close to 17%, and about 3.58% two billion years ago. 3.5% is the level to which we painfully enrich the uranium today to fuel our Light Water Reactors… In the 50s, some authors played with the idea that fission chain reactions could have occurred naturally when the enrichment was so high, but so many conditions would have been required that it seemed far fetched, and there was no evidence left anyway.

3. A Nuclear Detective Story

In June 1972, at the Pierrelatte enrichment plant devoted to Defense Applications, a routine mass spectrometry analysis of UF_6 feed material exhibited a discrepancy: only 0.7171% of the uranium in the samples ^{235}U, instead of the magic 0.7202 ! Even though the discrepancy was small, it was so unusual that the French Atomic Energy commission CEA, operator of the plant, started a thorough investigation. First, it was not an artifact: the anomaly was confirmed on several measurements on other samples. Accidental contamination by depleted uranium from the plant itself was then eliminated and so was the use of reprocessed uranium as there was no ^{236}U in the samples. The investigators then traced the anomaly back through all the stages of uranium processing, from Pierrelatte to Malvesi to Gueugnon where the concentrates exhibited the same low ^{235}U concentrations. These concentrates all came from COMUF which operated two uranium mines in Gabon, at Mounana and Oklo, the mill being located at Mounana. Very soon it appeared that all the anomalous ore came from the northern part of the – very rich – Oklo deposit. In some shipments, the level of ^{235}U was as low as 0.44%. Between 1970 and 1972, in the 700 tons of uranium delivered by the Mounana mill, the deficit of ^{235}U exceeded 200 kg, hardly a trifle !

Oklo mine uranium was indeed different from natural uranium everywhere else. Why ?

“Natural” isotopic separation was excluded : if it had produced depleted uranium, where was the enriched fraction ? As soon as August, the hypothesis of very ancient fission chain reactions was formulated, and investigators started to search for fission products (or, rather, the granddaughters of hypothetical fission products). The spectrum of fission products is so distinctive that it constitutes an unmistakable marker that fission reactions have taken place. The presence of such fission products was clearly identified : at some point in the uranium deposit history, it had become a “natural” nuclear reactor. The discovery was duly heralded [1, 2] but many questions remained. When did the reactor “started”? How long did it “operate” ? How was it “controlled”? The detective story was not finished.

Later on, it was found that there were actually 15 reactor sites in Oklo, and another one in Bangombé, 30 kilometers away from the main deposit.

4. Current answers to some questions about Oklo.

To run a nuclear reactor, you need a high concentration of uranium with a minimum percentage of ^{235}U[2], you need water to slow down the neutrons[3] and evacuate the calories and you must avoid those elements which absorb neutrons greedily like boron, cadmium, hafnium, gadolinium and other "poisons". You need also a minimum size (in the case of a deposit, a minimum thickness of the seam) to prevent too many neutrons from escaping from the reaction zone.

It is only around 2.2 billion years ago that the patient work of photosynthesis accomplished by the first algae released enough oxygen in our atmosphere for the surface waters and ground water to become oxidizing. Only then could the uranium diluted in granite be leached out and concentrated before mineralization in places where oxido-reduction would occur. Rich deposits cannot be older. On the other hand, since 1.5 billion years, ^{235}U abundance has decayed below a level which makes spontaneous fission workable. It took a lot of studies, in geology, chemistry and reactor physics to narrow the bracket of time to the present estimated value : the reactions must have started **1 950 ± 30 million years ago**.

The deposits were located in very porous sandstone where the ground water concentration may have been as high as 40%, probably due to the partial leaching of the silica (quartz particles) by the hot groundwater, at a time where, the radioactivity of Earth being higher than today, the thermal gradient underground was probably higher too. During the reactors operation, the water temperature rose significantly, accelerating this "de-silicication" process and, by difference, increasing the concentration in uranium, therefore compensating for its depletion by fission. As a matter of fact, the concentration of uranium in the reaction zones is extremely high, sometimes above 50%, and the higher the uranium concentration, the lower its ^{235}U content. Furthermore, losing its silica, the surrounding sandstone became clay and thus prevented an excessive migration of groundwater and keeping the uranium in place.

From the fine analysis of the spectrum of fission products, we know that a number of the fissions occurred in plutonium, bred by neutron capture in ^{238}U and now fully decayed to ^{235}U since its half-life is only 24 000 years (By the way, so much for the

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[2] You can operate reactors with natural uranium but only if you use heavy water D_2O or very pure graphite as moderator and a specific "heterogeneous" fuel/moderator pattern, like in CANDU and Magnox types. It would be very unlikely to find such pattern in nature.

[3] Neutrons emitted during fission move too fast to split easily other nuclei, but if the neutrons can "bounce" off the nuclei of a moderator, this will slow them down and make further fission more likely.

notion that plutonium is "artificial"). This allowed the physicists to calculate that, varying from one zone to another, reactions did take place during an enormous period of time ranging **from 150 000 to 850 000 years** !

The reactors where "controlled" by several mechanisms, the main one being temperature : as the fission power was released, the temperature rose. Higher temperature means both an increase in absorption of neutrons (without fission) by ^{238}U and a decrease in the efficiency of water as a moderator : at a given temperature level, a level varying with time and the progressive depletion of fissile uranium, the reactions stabilize, as they do in our reactors[4].

By combining geology and temperature considerations, it is now believed that the reactors in the northern part of the deposit operated at **a depth of several thousand meters**, under deltaic then marine sediments. At such depth, the conditions of pressure and temperature were close to those of the Pressurized Water Reactors of today (350 to 400°C, 15 to 25 Mpa), while the southern zones operated at roughly 500 meters deep, with conditions resembling more to those of a Boiling Water Reactor (250°C, 5 Mpa)[5] : even the Oklo designers did not choose between the present fierce competitors !

Even though significant alteration occurred in recent times when the tectonic uprising and erosion brought the reactors close to the surface, and especially when the Okolo Néné River gouged the valley, the heavy elements thorium, uranium and plutonium did not move at all, nor did the rare earths fission products, as well as zirconium, ruthenium, palladium, rhodium and a few others. On the other hand, krypton, xenon, iodine, barium and strontium have moved, but maybe only after a few million years.

5. Oklo as a "natural analogue" of a radioactive Waste Disposal Site ?

Soon after the discovery, and beyond the pure scientific thrill, the nuclear community was very excited by its implications, notably as a "natural analogue" for the geologic disposal of High Level radioactive Waste (HLW).

There is more and more an international consensus that the best way to dispose of HLW issued from the production of electricity by nuclear reactors is to install them, with a proper conditioning and packaging and additional engineered barriers, in a stable underground geologic stratum where the radioactive decay will progressively reduce their toxicity to a harmless level. But this decay takes a long time, and it is

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[4] Radioactive decay of some absorbing fission product also played a role over such long periods.

[5] If the operating time was immense, the power density in the « core » was only **one millionth** of its value in a commercial reactor today.

quite a challenge to demonstrate the containment of the radioactive products over such a long period of time, ranging from tens to hundreds of thousands of years. It can only be done through physico-mathematical modeling, with the inherent uncertainties associated with the completeness and accuracy of the models and their propagation along the calculations.

There, in Oklo, Mother Nature had contained *precisely the same radioactive elements* not for hundreds of thousands, not for millions, but for a couple of billion years, and without engineered barriers or special packaging.

So much is true, especially for the heavier elements which constitute most of the radiotoxicity of the HLW packages[6]. But the comparison cannot be pushed too far. To use a teenager's expression, the Oklo reactors are "too much"… If we could find a similar phenomenon one million years old, that would be perfect, but we have seen this is physically hopeless. For instance, most of the migration occurred during the reactions themselves, over close to a million years, when the conditions were far more troubled than what we expect in a steady and cozy disposal facility : the site has been deeply modified, losing by de-silicication three quarters of its substance, minerals have been altered by irradiation, temperature have run high and significant water convection did occur! Let us say Oklo provides a good presumption, but not a demonstration.

6. Conclusion : A unique Phenomenon ?

Let me borrow my conclusion from the foreword by the late Jules Horowitz to the book by Roger Naudet [3] which I have used extensively for this paper : "*It is after all plausible that fission chain reactions might have spontaneously occurred about two billion years ago, during a period of time long enough to provoke locally significant anomalies in the isotopic composition of some elements, notably uranium. What constitutes a miracle is that, despite the upheavals that the Earth surface has undergone since this ancient era, the evidence did survive to our time, in Oklo, to be discovered owing to the watchfulness of the CEA analysts*".

There is no reason to believe that what occurred at lest 16 times near Oklo did not happen anywhere else on the Earth, especially in old and rich deposits like exist in Australia or Canada… but more than three decades after its discovery Oklo remains unique. It remains unique as a geologic curiosity, and it remains unique as a nuclear detective story.

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[6] They have been retained within the UO2 crystallites themselves

A few References

The Discovery (September 1972)

[1] R. Bodu et al. Sur l'existence d'anomalies isotopiques rencontrées dans l'uranium du Gabon. CR Académie des Sciences Paris 275 D p.1731

[2] M. Neuilly et al. Sur l'existence dans un passé reculé d'une réaction en chaîne naturelle de fissions dans le gisement d'uranium d'Oklo (Gabon) ibid. p.1847

Synthesis

[3] R. Naudet OKLO : Des réacteurs nucléaires fossiles. Etude physique. Eyrolles, Paris, 1991

Selected Websites

www.wonuc.org/nucwaste/oklo.htm (with many interesting links !)

www.science.uottawa.ca/est/eng/prof/clark/EVS%203101/nuclear/OKLO%20REACTORS.ppt (PowerPoint™ presentation – I have used part of it)

www.world-nuclear.org/info/printable_information_papers/inf78print.htm (all about uranium)

www.ans.org/pi/np/oklo/

www.energethique.com/notions/oklo.htm (in French)

www.curtin.edu.au/curtin/centre/wairsc/OKLO/index.shtml (good synthesis)

www.ocrwm.doe.gov/factsheets/doeymp0010.shtml (Oklo and HLW disposal

Marie Hélène Leuthereau

Le VISIATOME
CEA VALRHO/CECER
Marcoule BP 64172
30207 Bagnols sur Cèze cedex - France
Telephone : (33) 4 66796508
E-mail : marie-helene.leuthereau@cea.fr

Education:

Secondary school in France.
Studies at University of Montpellier II, PhD in Geological Sciences.

Research Interests:

My first interests were in uranium ore deposits and their host rocks (cadomian granites) evolution in the southern part of French Massif Central

At CEA Marcoule I worked on Thermal Ionization Mass Spectrometry applied to transuranics elements and I developed chromatographic extraction method for americium and curium separation based on new extractants derived from the DIAMEX process

Educational activities:

In charge of educational activities at VISIATOME (CEA France)

“Radioactivity exploration in the classroom”

Marie Hélène Leuthereau
Le VISIATOME
CEA, France

General problem

What is radioactivity ? It is invisible phenomenon. What is the physical phenomenon?

Starting situation :

As an introduction, experiments are carried out with the entire class. They aim showing that the radioactivity exists, that it is natural and that it can be of several types.

Introductory experiments (duration: 25 min.)

Series of experiments 1:

Experimental setup:

- Detector MIP (probe alpha and probeβ γ),
- Uranium mineral Glare, sleeve of camp-site gas (in option shows with phosphorescent needles).

The goal of this first series of experiments is to have the children discover of the different types of radioactivity and very coarsely study their interaction with the matter. A parallel with what they saw in the exposure or what they learned must enable them to formulate the find answers to the above questions.

In a second step, one may then discuss the observable effects of the three types of radiations of their interaction by means of the three screens. It is then necessary to talk about the energy aspect of the radiation in the form of a simplified diagram.

In conclusion of this series it is necessary to present the Wilson cloud chamber who allows "to visualize the invisible things"
I will not present the principles (far too long) but only the experimental setup as a poster with photographs and explanations (available at: http://www.ulg.ac.be/masc/experiencemai.htm) along with the experiments.

Series of experiments 2:

Experimental setup:

KIT Radon (+NaI)
fragment of granite; potash, potassic manure, KCl solution.

The scientific concepts explained during these experiments are

the background noise due to the radioactivity of the surrounding medium
the randomness of the radioactivity phenomenon using different types of samples

One will familiarize the pupils with the handling of histogram by specifying in particular what a Gaussian distribution is.

Formulation of the questions:

How to explain the whole of the observations of the introductory experiments 1 and 2? Which phenomenon does it correspond to? Why are two measuring apparatus necessary? Why are the observations different for the two types of samples? Why does the signal vary according to the distance? Why doesn't one detect anything behind an aluminium and/or paper sheet? Why in the absence of any source, does the KIT (radon + NaI) measure Beta and gamma radioactivity ? Why are the measurements not reproducible?

As many questions as it is necessary to make understanding of this phenomenon possible to the children.

Assumptions:

Furthter assumptions are made by the class and experiments undertaken by small group are carried out
H1: The penetration depth in the matter depends on the various types of radiations. (Note : This property is used for radioprotection)
H2 :Radioactivity exists as a natural state apart from any source.
H3: Radioactivity is a random phenomenon.

Checking of the assumptions

At this stage the pupils will divide themselves into two sub-groups and undertake their experiments in a parallel way:

- sub-group CRAB: study of the penetration depth of the radioactive particles
- sub-group RADON: study of the randomness of the natural radioactivity

We present here the experiment measuring the disintegration of radon 222 with ALGADE-JEULIN meter. The goal is to have the pupils plot the curve of disintegration on the one hand and to lead them to formulate the mathematical expression on the other hand.

This experiment illustrates two concepts

1- it is possible to predict the number of atoms which can disintegrate in a given time interval
by a strongly radioactive sample
2 - each radioactive element is characterized by a characteristic half-life

Final discussion

After having pointed out the knowledge obtained on the various types of radioactivity one can have a final discussion about the useful applications of this phenomenon.

Gerhard Fischer
Geosciences Department and Research Center Ocean Margins
University of Bremen
Klagenfurter Strasse
28359 Bremen,
Germany
Telephone: ++(49) (0) 421 218 3588
E-mail: gerhard.fischer@allgeo.uni-bremen.de
http://www.rcom-bremen.de/Dr._Gerhard_Fischer.html

Education:

High school in Darmstadt (Hessen, Germany)

Studies in Geology and Marine Geology at the Technical University in Darmstadt, and the Universities of Kiel and Bremen, Diploma in Geology, PhD in Marine Geology

Research Interests:

After studying Paleozoic rock sequences and the tectonics in the Moroccan Atlas mountains within my diploma thesis, I moved to the field of marine geosciences. My PhD was on stable isotope geochemistry and on modern carbon cycling in the Southern Ocean. Presently, I am studying modern and past sedimentation processes in the coastal zone and the influence of dust on the biological pump off NW Africa. I have published many articles in international journals on the subjects listed above.

Educational Activities:

Student courses in the field of geology and marine geosciences

Lectures for the public (school classes) at the University

Extreme glaciations: Snowball Earth

Gerhard Fischer

Geosciences Department / Research Center Ocean Margins, University of Bremen, Germany

In 1964, B. Harland realized the global extent of glacial deposits in the geological record of the Late Precambrian (Neoproterozoic) some 600-850 million years ago. The ice age was so extreme that the world virtually froze over and ice sheets even covered the tropics. Thus, glaciation was different in character from any later icehouse world or glaciation in the Phanerozoic Eon (since 540 million years ago). Harland suggested a great Neoproterozoic ice age, a time period now named the Cryogenian. In 1992, J. Kirschvink arrived at a similar conclusion and created the term ‘snowball earth’. But how to explain that glaciers survived tropical heat ? And if the earth was a snowball, how did it escape from such an ‘ice catastrophe’ ? In the 1970’s , physicists first developed mathematical models to describe the earth’s climate and M. Budyko found a way to explain tropical glaciers by calculating the interaction of solar radiation with the earth’s surface. The more radiation the planet reflects, e.g. due to the formation of snow and ice, the cooler the temperature. This phenomenon is named the ice-albedo effect. This feedback may run out of control (runaway icehouse) and the earth’s mean temperature could have decreased strongly to -50°C leading to a totally frozen planet.

More recently, Hofmann and Schrag, studying Namibian rock sequences from the Neoproterozoic, provided evidence for sudden changes from an extreme icehouse world (snowball earth) to tropical hothouse climates. They explained the escape from a snowball world to a hothouse climate by volcanic outgassing of the greenhouse gas CO_2. However, in a snowball scenario with thick permanent ice covering the world ocean, photosynthesis should be shut off and many organisms could not survive. Therefore, since then a controversial discussion emerged whether the earth was completely frozen (snowball earth) or whether it had open or partly open tropical waters (slushball ocean). Some authors argue that equatorial surface waters of a slushball ocean would have been a paradise for the evolution of protists and metazoans on earth. Indeed, following the extreme icehouse world of the Neoproterozoic, the Ediacaran metazoan fauna emerged (600 million years ago) and at about 540 million years ago the Cambrian explosion of metazoans and shelly organisms occurred. But during the last 550 million years, a runaway icehouse leading to a snowball earth or a slushball ocean never happened again, why ? Perhaps, such extreme icehouse climates were prevented by life on earth which may regulate climate in some way.

The lecture will start with the geological time scale to get an impression on the duration of earth’s history. Then we will discuss how glaciations may develop on earth and how glacial periods are documented in the geological record. The effects of greenhouse gases such as carbon dioxide on climate will also be presented. The three major glaciations or icehouse periods occurring since the Cambrian explosion of animals will be described. We then move to the Precambrian, a vast time period when only primitive life was occupying Earth. Organisms such as Cyanobacteria have taken up CO_2 due to photosynthesis and produced free oxygen, thus changing climate on Earth by reducing greenhouse gases and making way for higher developed metazoans with a need for free oxygen. At the end of the Precambrian, Earth's climate was probably cool enough to allow glaciations. We will discuss the geological evidence for a possible snowball earth and a hothouse aftermath which was provided by Hoffmann and others in 1998. The possible mechanisms leading to snowball earth and to a sauna-like climate thereafter will be explained. Finally, the consequences of snowball earth or a slushball ocean for the evolution of life on earth (Ediacara fauna, Cambrian explosion) will be discussed.

References:

Harland, W.B. and J.S. Rudwick. 1964. *The Great Infra-Cambrian Ice Age.* Scientific Amercian. Vol. 211(2): 28-36.

Hoffman, P. F., A. J. Kaufman, G. P. Halverson, D. P. Schrag. 1998. *A Neoproterozoic Snowball Earth*. Science. Vol. 281: 1342-1346.

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Kerr, Richard. 2000. *An Appealing Snowball Earth That's Still Hard to Swallow*. Science. Vol. 287: 1734-1736.

McKay, Ch. P. 2000. *Thickness of Tropical Ice and Photosynthesis on a Snowball Earth.* Geophysical Research Letters, Vol. (14): 2153-2156

Judy Scotchmoor

Director of Education and Public Programs
University of California
Museum of Paleontology
Berkeley, CA 94720-4780, USA
E-mail: jscotch@berkeley.edu

Professional Interests:

I am currently the Director of Education and Public Programs at the University of California Museum of Paleontology. Prior to this position, I was a 7th and 8th grade Science teacher for 25 years. Among my many roles at the museum, I enjoy working with teachers to develop materials and courses that will be useful to them. I am also interested in the use of paleontology and technology as vehicles for improving science education in the classroom. I am currently the Project Coordinator for two NSF-funded programs:

Understanding Evolution (http://evolution.berkeley.edu)
and *The Paleontology Portal* (http://www.paleoportal.org).

Educational activities:

Treasurer, California Science Teachers Association
Past Chair, now member, Education Committee of the Society of Vertebrate Paleontology
I was the editor and co-author of three resource books for teachers, *Learning from the Fossil Record*, *Evolution: Investigating the Evidence*, and *Dinosaurs: the Science Behind the Stories.*

Sequencing Time and the History of Life: hands-on activities to increase student understanding

Judy Scotchmoor,
Director of Education and Public Programs, University of California Museum of Paleontology, Berkeley, California, USA

Deep time is a difficult concept for students, and yet it is critical to our understanding of Earth's history. An initial activity, in which students sequence and assign numerical events in their own lives, engages students in a process that is analogous to that used by scientists to develop the Geological Time Scale. The next step in this process is then to take the students to the rocks themselves as a visual record of time. The evidence contained within those rock layers helps us to understand not only the sequence in which they were deposited, but also the environments in which that deposition took place. The fossils contained within those rocks provide concrete evidence of past life and the evolutionary changes that have taken place over time.

In this session, participants will be introduced to two hands-on activities that will increase student understanding of geologic time and the lines of evidence through which we learn about the history of our earth.

❖ **Sequencing Time:**
http://www.ucmp.berkeley.edu/fosrec/ScotchmoorTime.html

Students assign relative and numerical times to events in their lives to understand how scientists developed the Geologic Time Scale. This lesson covers the following concepts:

- The sequence of forms in the fossil record is reflected in the sequence of the rock layers in which they are found and indicates the order in which they evolved
- Physical, chemical and geological lines of evidence are used to establish the age of fossils.
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❖ **What Came First**
http://www.ucmp.berkeley.edu/fosrec/ScotchmoorFirst.html

Students sequence actual events in the history of life on Earth and place them on a large timeline. This lesson covers the following concepts:

- Through billions of years of evolution, life forms have continued to diversify in a branching pattern, from single-celled ancestors to the diversity of life on Earth today.
- Living things have had a major influence on the composition of the atmosphere and on the surface of the land.

- Fossils provide concrete evidence of past life, including sequences of fossils showing gradual change over time.

Participants will also be introduced to several on-line resources that have been developed for both students and teachers.

- **Understanding Geologic Time**

http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/index.html

This is a web-based module in which students gain a basic understanding of geologic time, the evidence for events in Earth's history, relative and absolute dating techniques, and the significance of the Geologic Time Scale.

- **Understanding Evolution**

http://evolution.berkeley.edu

This new, award-winning website serves as an online resource for teachers to assist them in the teaching of evolution. The site focuses on improving teacher understanding of the nature of science, the patterns and processes of evolution, and the history of evolutionary thought, and thus increasing the teacher's confidence level to teach these subjects effectively. The site also provides classroom resources that include a conceptual framework, a suite of evaluated lessons appropriate for different grade spans, and teaching strategies to avoid or overcome roadblocks to teaching evolution. The lessons are accessible through a relational database, searchable by concept, topic, grade level, lesson type, and/or key word.

- **The Paleontology Portal**

http://www.paleoportal.org

Though currently limited to resources of North America, this site provides a central, interactive entry point to high-quality paleontology resources on the Internet for multiple audiences: the research community, elementary to high-school educators, government and industry, the general public, and the media. Using web-based technology and relational databases, users can explore an interactive map and associated stratigraphic column to access information about particular geographic regions, geologic time periods, depositional environments, and representative taxa. Other features include highlights of famous fossil sites and assemblages and a Fossil Gallery. Throughout the site, users will find images and links to information specific to each time period or geographic region, including current research projects and publications, websites, on-line exhibits and educational materials, and information on collecting fossils.

The University of California Museum of Paleontology (UCMP) has been highly successful in the development of curricular materials and web-based resources. Key to this success has been what we refer to as the UCMP model – scientists, graduate students, and teachers working together through the entire process of development and implementation. Such a team effort results in products that are sound in both science and pedagogy.

Philippe CARDIN
Laboratoire de Géophysique Interne et Tectonophysique (LGIT)
Observatoire de Grenoble
BP 53
38041 Grenoble cedex 9
France

Telephone : (33) 4 76 82 80 44
E-mail : philippe.cardin@ujf-grenoble.fr

Education:

Ecole Normale Supérieure (Physics),
Doctorate in Geophysics at the University of Pierre and Marie Curie (Paris 6).
Post doc in Johns Hopkins University (Baltimore USA)

Research Interests:

My main interests have always been linked to the understanding of the dynamics of the deep interior of the Earth. Because of its cooling, the deep layers of our planet move and their motion are responsible of many geophysic features (plate tectonics, hot spots, polar wander, cooling, geomagnetic field…). I propose theoretical, experimental and numerical model of dynamics to explain the geophysical observations. In the last few years, we concentrate on the understanding of the self generation of the magnetic field in the Earth's Core and we built a liquid sodium experiment to study the dynamo effect.

I have published about 30 articles in international scientific journals.

Educational activities:

Chair of "Theory of Planetary Magnetic Fields and Geomagnetic Secular Variation" in IAGA, IUGG.
Chair of "Diffusion des savoirs", université Joseph Fourier, Grenoble. http://osug.obs.ujf-grenoble.fr/enseignement/dds/
Head of the Geodynamo team in LGIT, Grenoble http://www-lgit.obs.ujf-grenoble.fr/recherche/geodynamo/

The Earth's magnetic field.

Philippe Cardin,

Laboratoire de Géophysique Interne et Tectonophysique,
Observatoire de Grenoble, France.

Two thousands years ago, the Chinese civilization had already discovered the existence of the magnetic field of the Earth, when they observed that a magnetized needle settles in the direction of the South Pole.

In the western world, compasses have been used widely in the Middle Age and the great marine discoveries may be seen as a consequence of the use of compass for navigation.

In order to explain the behavior of the compass needle, Gilbert, in 1600, proposed a theory where the Earth's itself is a giant magnet: "Magnus magnet ipse est globus terrestris".

After the discovery of the temporal variation of the geomagnetic field in the Vita century, geomagnetic observatories were created and measured daily the magnetic field for the last 4-5 centuries. Today, magnetic satellites give high quality measurements (in space and in time) of the geomagnetic field. To complete our general view of the variations of the magnetic field in the pre-instrumental period (years, thousands of years, million of years), the directional and less easily the intensity of the geomagnetic field may be retrieved from the study of the magnetic properties of igneous rocks and sediments, a discipline known as paleomagnetism. Interpreting the demagnetization of rocks, scientists discovered the ancient geometry and in 1905 Bernard Brunhes discovered that some Miocene volcanic formations in the French Massif Central were magnetized in the sense opposite to the present geomagnetic field. He suggested that the geomagnetic field may have reversed its polarity in the past, an hypothesis which all the following studies have proven to be true.

However, if the accumulation of data is impressive and gives a precise picture of the geometry of the magnetic field of our planet, a full understanding of its origin is still missing. It is known with certitude that the geomagnetic field is generated within the Earth, in the core. The core is the central part of our planet and is mainly made of both solid and liquid iron. Geophysicists have elaborated a theory, known as the dynamo theory, to explain the self-generation of the magnetic field by the presence of electrical currents induced by the motions of the liquid iron.

The past decade has seen many advances in the understanding of this effect. Numerical simulations, as well as experiments in the laboratory, describe the mechanisms of the self-generation of a magnetic field by a vigorous flow. Due to the inherent high difficulties of the modeling, the geophysical relevance of some of these models is still questionable and more realistic models are under development. These models are one of the few ways to understand the mechanisms governing the deep interior of our planet: indeed, the earth magnetic field is a probe for the deep earth! Moreover, the recent discoveries of magnetic fields in Jupiter, Saturn, Mars, Ganymede, Io and the Moon enlarge the fundamental question of the generation of the Earth's magnetic field.

In everyday life, the geomagnetic field acts as a magnetic shield, and protects the Earth from cosmic and solar winds and some scientists hypothesize that this shielding has played a role in the evolution of life on Earth.

In this conference, I'll examine all these aspects, and also describe small experiments, suitable for classroom activities, to give a clear view of the mysterious Geomagnetic Field.

André BERGER
Université catholique de Louvain
Institut d'Astronomie et de Géophysique G. Lemaître
Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve, Belgium

Tel. +3210473303
Fax. +3210474722
Email berger@astr.ucl.ac.be

André Berger is Master of Science in Meteorology from M.I.T. (1971) and Doctor of Science from the Université catholique de Louvain (Belgium) (1973). He is ordinary professor and was head of the Institute of Astronomy and Geophysics Georges Lemaître (1978-2001) at the Catholic University of Louvain where he lectures on meteorology and climate dynamics. He is doctor *honoris causa* from the University of Aix-Marseille III, the Université Paul Sabatier in Toulouse and the Faculté Polytechnique de Mons. He was C.R.B. graduate fellow of the Belgian American Educational Foundation (1970-71) and professor at the Vrij Universiteit Brussel and Université de Liège.

André Berger was chairman of both the International Climate and Paleoclimate Commissions and of NATO scientific Panels. He was president of the European Geophysical Society and is Honorary President of the European Geo-Sciences Union. He is fellow of the American Geophysical Union. He serves on several national and international scientific committees dealing with climate and global change. He is, in particular, member of the scientific council of the European Environment Agency.

. He is member of the Academia Europaea, foreign member of the Koninklijke Nederlandse Akademie van Wetenschappen, membre associé étranger de l'Académie des Sciences de Paris et de l'Académie Nationale de l'Air et de l'Espace, membre de l'Académie royale des Sciences, des Lettres et des Beaux Arts de Belgique and associate of the Royal Astronomical Society (London).

André Berger is the author of "Le Climat de la Terre, un passé pour quel avenir ?". He has edited 10 books on climatic variations and has published more than 150 papers on this subject. He is associate editor of Surveys in Geophysics and editorial board member of The Holocene, Climate Dynamics and Earth and Planetary Science Letters. He was editor of EOS for Atmospheric Sciences, associate editor of Atmospheric Environment and board member of Climatic Change.

His main research is about modeling climatic changes at the geological and at the century time scales. He has made notable contributions to the astronomical theory of paleoclimates which explain the recurrence of glacial-interglacial cycles from the long-term variations of the Earth's orbit around the Sun. The climate model that he has developed with his team is also used for simulating the response of the climate system to human activities and the possible impact of such man's induced perturbations on the natural course of climate at the geological time scale. He is a cited pioneer of the interdisciplinary study of climate dynamics and past climate history.

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The Enigmatic Climatic Stage 11

André Berger and Marie-France Loutre

Université catholique de Louvain
Institut d'Astronomie et de Géophysique G. Lemaître
Chemin du Cyclotron, 2
1348 Louvain-la-Neuve

One of the most striking features of the Quaternary paleoclimate records remains the so-called 100-kyr cycle. Such a 100-kyr cycle is characterized by long glacial periods followed by a short-interglacial (~ 10 to 15 kyr long). As we are now in an interglacial, the Holocene, the previous one (the Eemian which corresponds to Marine isotope stage 5e, peaking at ~ 125 kyr BP) was assumed to be a good analog for our present-day climate. In addition, as this Holocene is already 10-kyr long, paleoclimatologists were naturally inclined to predict a quite close entrance into the next ice age.

Simulations using the 2.5-D climate model of Louvain-la-Neuve show however that our interglacial will most probably last much longer than any previous ones. This is related to the shape of the Earth's orbit around the Sun which will be almost circular over the next tens of thousands of years. As this is primarily related to the 400-kyr cycle of eccentricity, the best and closer analog for such a forcing is definitely Marine isotopic Stage 11 (MIS-11) some 400 kyr ago, not MIS-5e. During these minima of eccentricity, the latitudinal and seasonal distributions of insolation will not vary any more. This is because insolation is mainly driven by precession whose amplitude is modulated by eccentricity. Because the CO_2 concentration in the atmosphere plays also an important role in shaping the long-term climatic variations – especially its phase with insolation – a detailed reconstruction of this previous interglacial from deep-sea and ice record is requested. Moreover, the low amplitude of insolation change during MIS-11 as well as during the Holocene and the next tens of thousands of years makes the climate more sensitive to atmospheric CO_2 concentration than at times of higher eccentricity. Since 11 kyr BP insolation is decreasing but CO_2 remains above 260 ppmv with a general increasing trend over the last 8

000 years. This kind of situation leads in both MIS-11 and the future to a long interglacial confirmed for MIS-11 by the EPICA record. Such a study is even more important in the framework of the already exceptional present-day CO_2 concentration (unprecedented over the past million years) and its even more exceptional value predicted to occur during the XXIst century due to human activities. The same model is also used to test the hypothesis by Ruddiman of a very early impact of human activities on climate.

Dr. Cherilynn Morrow
Director, Education & Public Outreach
Astronomer

Cherilynn Morrow spent several years as a solar physicist, including a graduate fellowship at the National Center for Atmospheric Research, High Altitude Observatory and a post-doctoral appointment at the Institute of Astronomy in Cambridge, England. In 1990, she chose to make a transition to working in science and math education. She served as the Assistant Director for Teaching at the Colorado Space Grant College and as the Assistant Director of the University Math Program at the University of Colorado where she taught, developed courses, and led an interdisciplinary team of teaching assistants. She spent two years (1992-1994) as a Visiting Senior Scientist at NASA Headquarters, Office of Space Science, where she was responsible for developing strategies for engaging the scientists, research facilities, and data resources of the space science community in support of national education goals. She delivered the first presentations on education to the NASA Space Science Advisory Committee.
Cheri now serves as Director for Education and Outreach at the Space Science Institute (SSI). Her work involves bringing science to educators and education to scientists. She is one of seven Principal Investigators for the NASA Space Science Broker program to facilitate productive partnerships between space scientists and educators. She is also an accomplished math, astronomy, and earth system science educator, workshop facilitator, and developer of educational materials and programs that integrate art and science (e.g. the Saturn Educator Guide for NASA's Cassini Project, Kinesthetic Astronomy, and AstroJazz). Her audiences have included wilderness instructors, scouts, primary & secondary teachers & students, museum educators, and undergraduate students. In addition, Dr. Morrow directs the education programs for SSI's large, interactive traveling exhibits.
Cheri served for 4 years as the Chair of the Solar Physics and Aeronomy Education Committee for the American Geophysical Union (AGU). She is currently a member of the NASA Space Science Education and Public Outreach Executive Council, co-chair of the Astrobiology Science Communication Working Group, and a new member of the Science & Technology committee for the Conference on World Affairs.

Cheri loves to sing, dance, fly, dive, practice yoga, and climb almost anything. She has two cats, Sufi and Rocky. See http://mmp.planetary.org/scien/morrc/morrc70.htm for more about Cheri's personal and professional history.

Kinesthetic Astronomy®

Cherilynn A. Morrow, PhD
Space Science Institute, Boulder CO, USA
EMAIL: morrow@spacescience.org
WEB: http://www.spacescience.org

Kinesthetic Astronomy® lessons offer innovative ways to teach basic astronomical concepts through choreographed bodily movements and positions that provide educational sensory experiences. The lessons are science-rich and fun. They confront common misconceptions in astronomy through asking the learner to rotate, revolve, tilt, bend, twist, and perceive in new ways. They are designed for sixth year students up through adult learners in both formal and informal educational settings, but many educators have modified them to be developmentally appropriate for younger learners. The lessons emphasize astronomical concepts and phenomenon that people can readily encounter in their "everyday" lives such as time, seasons, and sky motions of the Sun, stars, and planets.[7]

Kinesthetic Astronomy lesson plans are fully aligned with the latest research on how people learn. In particular, the upgraded *Sky Time* lesson employs a complete learning cycle (i.e., open inquiry, address prior knowledge, lead lesson experience, reflect, apply new knowledge) with written assessment options embedded throughout the lesson. These assessments help learners translate their kinesthetic and visual learning to the verbal-linguistic and logical-mathematical realms of expression. They also enable teachers to better monitor progress in student understanding throughout the lesson rather than only at the end.

Field testing with non-science undergraduates, secondary science teachers, middle grade students, youth groups, museum & planetarium educators, and outdoor educators has been providing evidence that kinesthetic astronomy techniques allow learners to achieve a good intuitive grasp of concepts that are much more difficult to learn in more conventional ways such as via textbooks, lecture, or even animation.

The *Sky Time* Lesson

In the summer of 2004, we completed a significant upgrade to the first in a series of experiential, kinesthetic lessons. The *Sky Time* lesson reconnects students with the astronomical meaning of the day, year, and seasons. Modern association with time involves watches, clocks, and calendars instead of the astronomical motions that were the original bases for time keeping. Through a series of simple body movements, students gain insight into the relationship between time and astronomical motions of Earth (rotation about its axis, and orbit around the Sun), and also about how these motions influence what we see in the sky at various times of the day and year. To begin *Sky Time*, the teacher arranges students in a Kinesthetic Circle (see figure below). NOTE: to avoid introducing misconceptions, it is essential to start off by demonstrating an appropriate Sun-Earth-Star scale (the full lesson write-up provides this).

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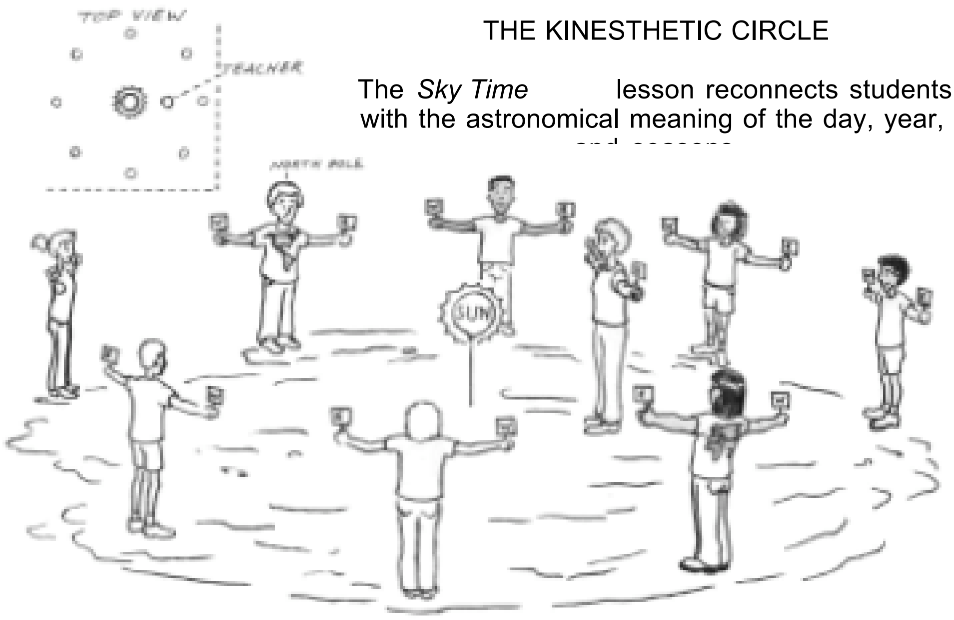
[7] The public holds a remarkable number of misconceptions about such astronomical concepts. For example, the *NSF Indicators of Science & Engineering 1996*[7] reports that 53% of a representative sample did not know that it takes one year for Earth to orbit the Sun.

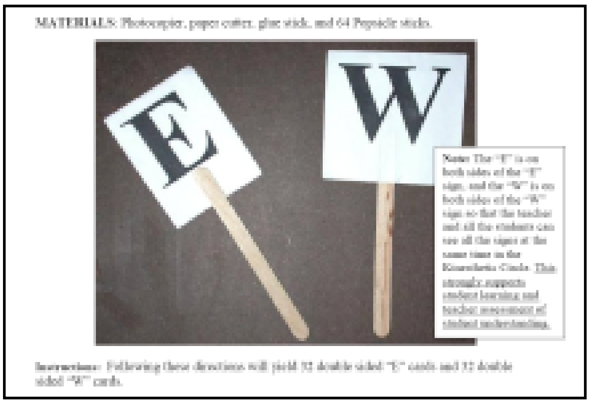
Sky Time leads learners to experience which way the Earth must turn for the Sun to rise in the East; why the Sun is higher in the sky in summer; why we see different stars at different times of year; and why we see essentially the same stars tonight as our fellow humans in China saw who live at a comparable latitude. The lesson also offers reasons for seasons and how Earth and Mars seasons compare.

Sky Time takes 3-6 hours to implement, depending on the prior knowledge of the learners and the choice of assessments. It may be used with a group of 10-30 participants in a space where they have room to be in a circle with arms outstretched to their sides. The lesson does not *require* the use of special materials except for a central object that represents the Sun (a helium balloon works very well). However, the lesson benefits greatly from having seasons and Zodiac signs, as well as East (E) & West (W) signs for each learner (see figures below). These props (with instructions for their assembly), the complete lesson plan, and all the assessment options can easily be downloaded from our website.

THE KINESTHETIC CIRCLE

The *Sky Time* lesson reconnects students with the astronomical meaning of the day, year, and seasons

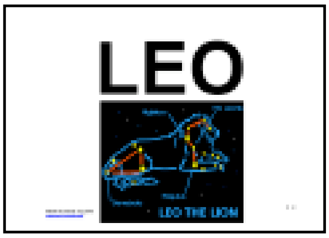


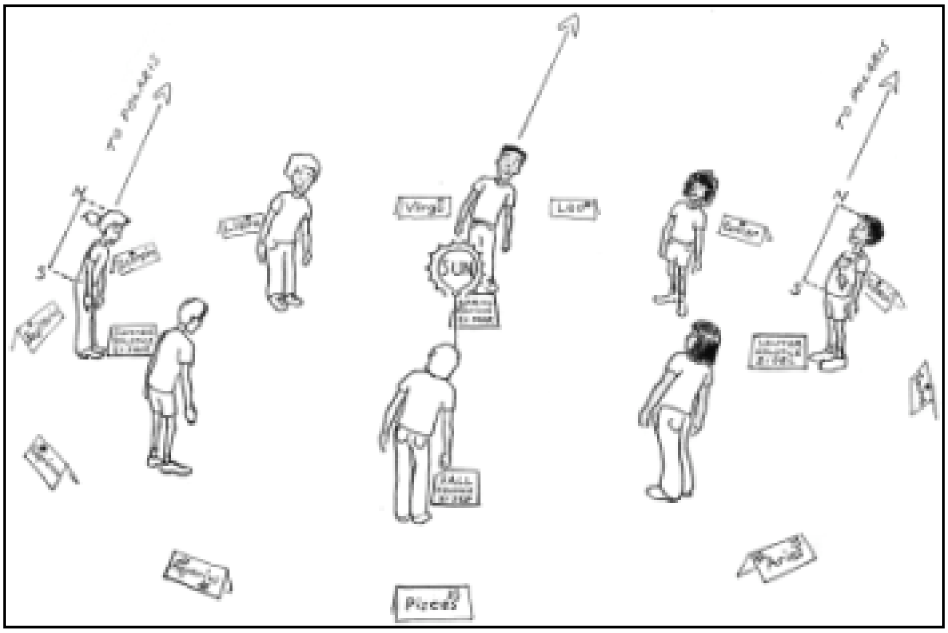


MATERIALS: Photocopier, paper cutter, glue stick, and 64 Popsicle sticks.

Note: The "E" is on both sides of the "E" sign, and the "W" is on both sides of the "W" sign so that the teacher and all the students can see all the signs at the same time in the Kinesthetic Circle. <u>This strongly supports student learning and teacher assessment of student understanding.</u>

Instructions: Following these directions will yield 32 double sided "E" cards and 32 double sided "W" cards.





Dr. Barbara Donner
Research Center Ocean Margins (RCOM)
Bremen University
P.O. Box 330 440
28334 Bremen
Germany
Phone: (49) 421 218 65521
Fax: (49) 421 218 65505
E-mail: donner@uni-bremen.de**Education:**

Diplom and PhD in Biology, Bremen University
Special training in didactics/presentation, Hoechst AG, Frankfurt

Research Work:
Marine geology, paleoceanography, paleoclimate, particle flux studies, calcareous microfossils: benthic and planktonic foraminifera

Educational activities:
University lectures, tutorials and practical courses on
- Marine geology
- Methods in marine geology
- Stratigraphy in marine sediments
- Micropaleontology

Advanced training courses in marine geology, paleoceanography and paleoclimate
- for school teachers
- for senior citizens

Special school courses on geological research highlights
- for school children (several levels)

Member of panel: "Teaching and learning - from science to school practice"

Reconstructing past climate…

Dr. Barbara Donner
Research Center Ocean Margins (RCOM), Bremen, Germany

Why we reconstruct past climate

Geoscientists investigate the climate history of the Earth, because this is the only way to understand present climatic conditions and connections on the one hand and to estimate possible future developments of climate on the other hand.

Theoretical part A: Climate archives

Analysing past climate has its difficulties:

If scientists want to measure PRESENT climate conditions, they can register climate parameters DIRECTLY, parameters like temperature, precipitation, sunshine, wind direction, wind speed etc..

That is not possible with climate parameters of PAST times, years or even millions of years ago. Scientists have to follow an INDIRECT way: they choose an appropriate archive where the information about the past is saved. This is not a man made archive. Reliable man made records of climate only date back hundreds of years. This is not long enough for geoscientists.

The archives they use most often, are preserved remains of plants and animals (= fossils) or they analyse the chemical or physical composition of deposits.

Important climate archives are

- tree rings
- corals
- lake sediments (varves)
- polar and glacial ice shields (ice cores)
- marine sediments

and there are even more! The archives differ with regard to the recorded

- climate parameter (temperature, precipitation etc.)
- time interval (decades ago or millions of years ago)
- time resolution (months, seasons, years etc.).

These can be reconstructed with the help of the archive. Before geoscientists start their investigations, they have to find out which archive is the most appropriate for their objective target.

Marine sediments

In Vienna - as in our institute - we shall focus on the marine sediments archive. There are different methods to sample sediments from the sea floor: they can be drilled or stamped. The sediment core, which we want to investigate in Vienna is a stamped one. With the stamping method it is possible to get material younger than one million

years. The youngest material is lying at the top of the sea floor and the sediment core, the oldest at the bottom.
Marine sediments consist of terrigenous and biogenous material. The terrigenous material like mud, clay and sands originates from the continents and is transported into the oceans by rivers and winds. The biogenous material is a composition of the remains of small plants and animals, that have lived in former times in the water column, then have died and sunk to the sea floor = the microfossils. We use these fossils of plants and animals as our climate indicators.

Practical session A: Sampling of a sediment core
During our practical session we want to have a closer look at the sediment core, we call this procedure a core description. Looking for example at the colour and the grain size of the particles often gives a first impression about the material composition and - related to this - about the prevailing climatic conditions.
Then we take samples out of the core with syringes, wash and dry them in order to get the climate indicators. The most favourite fossils are foraminifers, zooplankton organisms. You will get to know them!

Theoretical part B: Climate parameters and proxies
Climate parameters which can be reconstructed are:
sea surface temperature, ice volume, sea level, salinity, productivity and ocean currents (to mention only the most popular ones). The most important of these is the sea surface temperature (SST).
But, if geoscientists want to get information about the SST of former times, it is not possible to measure it directly. The indirect way is to choose an approximation parameter (= proxy), that can be recorded in the archive and correlates with the SST of the past. There are four proxy parameters for SST:

- faunal or floral assemblages of plankton fossils in the sea floor
- oxygen isotope ratios of foraminifers
- alkenones in coccolithophorids
- Mg/Ca ratios in foraminifers

Geoscientists try to apply all four methods in parallel to reconstruct past SST. As soon as the results obtained by four different methods correspond, they support each other. We will hear more about the faunal assemblages, because what we are going to investigate in our practical session part B is the occurrence or non-occurrence of two different foraminiferal species.

Practical session B: Biostratigraphy
The foraminifers we want to investigate are closely related to each other. In the Atlantic Ocean they occur only during warm periods. In cooler periods their number decreases until they vanish completely. So they show us – as a first hint – if the sediment sample originates from an ice age or a warm period.

We shall investigate the complete sediment core with regard to the occurrence of these two species.

Discussion of results

From our practical work we have obtained three different data sets:

- colour of the sediment core
- grain size in the sediment core
- occurrence pattern of two foraminiferal species

All three data sets give us information about past climatic conditions. We will compare the results, discuss and learn about the difficulties and reliability of the different methods.

In total my objective is to give you a first insight in how past climate can be reconstructed, how geoscientists deal with difficulties that are emerging during investigation sand how fascinating and interdisciplinary this field of natural sciences can be.

Barbara Donner