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Large picture: Mammoth Hot Springs, Yellowstone National Park, Park County, Wyoming, USA
Small picture: Alpine ibex, (*Capra ibex*). Brienzer Rothorn, Berner Oberland, Switzerland.

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1
The origin of the Earth and its volatiles

Alex N Halliday

Oxford University

The origin of Earth is well explained by oligarchic accretion of planetesimals and planetary embryos over tens of millions of years. The last major event is thought to have been the Moon forming Giant Impact which added about 10% of the planet's mass. Tungsten isotopic evidence demonstrates that the Earth's core grew during accretion. Comparisons with meteorite data for other bodies suggest that it may also have grown in relative proportion over time. The depletion of slightly siderophile elements such as vanadium is consistent with a primitive mantle that was more reduced during the earlier stages of accretion. This is confirmed by isotopic evidence that the core had sequestered a significant amount of silicon before the Giant Impact. Despite these advances in our understanding of the past 20 years there are significant issues that have not been resolved. The timing of the Giant Impact is still argued about with recently proposed ages ranging from 30 to 200 million years after the start of the solar system, extending to the ages of the oldest detrital zircon grains yet discovered on Earth. Similarly there still is no consensus about how water and other highly volatile elements were added to Earth. The final (<1%) stage of accretion is often thought to be the addition of a late veneer that provided the mantle and crust inventory of highly siderophile elements (gold, platinum etc) and volatiles such as water, carbon and nitrogen. The fact that this veneer is a far smaller proportion of the Moon's budget is hard to explain unless it was added to Earth by just a few very large bolides. It is generally modelled as relating to the last stages of accretion of all terrestrial planets. The isotopic and relative elemental abundances of highly volatile elements (noble gases, H, C, N) provide evidence of accretion from chondrite-like, as opposed to solar reservoirs. On this basis carbon and nitrogen are the most depleted elements in the silicate Earth. Some process, possibly core formation, removed them prior to partial reinstatement via the late veneer. However, it can be shown that a major fraction (>70%) of the hydrogen (water) budget is earlier, which is hard to reconcile with the hot dry early Earth models advocated by some.

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Emergence of an Aerobic Biosphere during the Archean-Proterozoic Transition

Lee R. Kump

Department of Geosciences, Pennsylvania State University, University Park, Pennsylvania 16802, USA. (lkump@psu.edu)

The Archean-Proterozoic transition witnessed a revolution in the biosphere attendant upon the establishment of an oxygen-rich atmosphere. Perhaps for the first time, and apparently for the rest of Earth history, oxygen, the most potent of electron acceptors, became widely available to fuel aerobic metabolism and oxidative weathering of reduced materials on land. The timing for the passage of the rise of oxygen through the threshold for the cessation of mass-independent fractionation of sulfur isotopes (~ 10^{-5} of the present atmospheric level) is fairly well established (ca. 2.4 Ga). However, the reason that the atmosphere was anoxic in the Archean and oxygenated thereafter is not conclusively known. We have hypothesized that the transition to an aerobic biosphere was effected by a reduction in the volcanic sink for oxygen driven by a shift from a predominance of submarine volcanism to a more equal expression of both subaerial and submarine volcanism, itself a result of the stabilization of continents at the end of the Archean. In addition, we have discovered what may be the largest negative carbon isotope excursion of Earth history, occurring at the end of a ~ 400 m.y. interval of atmospheric oxygen rise (at ~2.0 Ga), and possibly reflecting the initial deep oxidative weathering of Archean and Paleoproterozoic organic-rich sedimentary rocks exposed on land. This oxidative weathering event may also be linked to the generation of the Oklo natural fission reactors and the widespread supergene enrichment of iron ores at this time.

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'Mass Extinctions' in the Geological Record: Causes and Consequences

MacLeod Norman*

**Palaeontology Department, The Natural History Museum, Cromwell Road, London, UK SW7 5BD, (N.MacLeod@nhm.ac.uk)*

With its decidedly biblical overtones, the phenomenon of 'mass extinction' has intrigued and puzzled scientists in many different disciplines ever since the first summaries of (palaeo)biodiversity data began to appear in the middle 1800s. Over the intervening 150 years an impressive number of hypotheses and mechanisms have been suggested to account for these global biotic turnover events (e.g., Benton 1990). Unfortunately, few of these hypotheses have been tested via reference to empirical observations.

This situation changed in 1980 with the proposal of the bolide extinction hypothesis for the Cretaceous-Tertiary extinction event (Alvarez et al. 1980) which predicted the existence of a globally distributed layer of sediments enriched in rare earth elements (e.g, Ir) coincident with the extinction. When an enriched zone of the predicted magnitude was recovered from many K-T boundary localities worldwide in sediments that appeared to be biostratigraphically coincident with a mass faunal and floral turnover the prima facie case for an extraterrestrial cause of this mass extinction appeared to have been made; especially in the light of subsequent discoveries of additional physical impact markers (e.g,, shocked quartz) and the likely impact crater. However, most palaeontologists remained skeptical of the bolide impact hypothesis as a sufficient explanation for the K-T (or now, K-P) extinction event (Archibald et al. 2010). Moreover, despite initial claims for a 26 million year periodicity in extinction intensity peaks (Raup & Sepkoski 1984, 1986), little credible evidence has been produced to support the idea of bolide impact as a general cause for 'mass extinctions'.

For most palaeontologists very notion of 'mass extinction' is problematic insofar as there is no generally accepted technical definition of the term. Raup & Sepkoski (1984) identified five stage-level extinction-intensity peaks that 'stood apart' in terms of magnitude from the remaining data. These became the 'big five mass extinctions'. However, the distinctiveness of these intensity peaks was always the result of *a priori* filtering of these data (e.g., elimination of Cambrian stage data). More importantly, when new stage-level palaeobiodiversity data are plotted in rank order the resulting extinction-intensity distribution is continuous. This suggests there is no objectively definable 'mass extinction' class and implies that the mechanisms responsible for smaller extinction events are also responsible for the larger events. The 'big five' peaks stand out not because they are intrinsically large, but because the stage level intensities surrounding them are small. In order words the explanatory signal is not in the magnitude of the larger events, but in their temporal placement.

Results of statistical simulation studies localized extinction-intensity peaks and the the temporal distribution of causal mechanism activity are instructive in terms of identifying the causes of these larger events. Evaluations of stage-level coincidences between the distributions of extinction intensity peaks and causal mechanisms against a randomized null model shows that LIP volcanism exhibits the only mechanism-based time series that exhibits a statistically significant association (⍰=0.05) with the 'mass extinction' record. Additionally, if a multiple-cause model involving LIP volcanism, large bolide impact, and sea-level regression is also evaluated against the extinction peak record, this association is also found to be significant. The multiple cause model is favoured by most palaeontologists because it provides a better fit with the complex taxonomic and ecological responses exhibited by different groups to environmental changes across the K-P boundary.

The quality of data collected from the stratigraphic literature of mass extinction intervals also remains suspect. For example, initial reports of the planktonic foraminiferal extinction event listed all but 1-3 members of the diverse Maastrichtian fauna as becoming extinct coincident with the K-P boundary and the Ir anomaly. It is now known that at least 30% of Maastrichtian fauna survived the K-P event (whatever its cause) and numerically dominated the lowermost Palaeocene oceans for up to 500,000 years before giving way to indigenous Danian forms. Until and unless similar investigations can be carried out in other groups the true character of these turnover episodes will remain uncertain. Regardless, it's not just the fine-scale patterns that are influenced by this source of error. Stage level summaries of planktonic foraminiferal biodiversity at the genus and family levels are also erroneous.

Although controversy continues to dog the issue of 'mass extinction' causality, there is much less disagreement over the significance of extinction to the process of evolution. Whether the extinction of the non-avian dinosaurs happened in less than a year as a result of a bolide impact or progressively over tens of thousands of years as a result of a chance coincidence of major extinction mechanisms, it happened and the result was that ecological space was opened up for colonization by new groups. But in addition to the traditional stories told about evolutionary contingency and the rise of the mammals, a key but under-appreciated macroevolutionary trend that appears to be driven by extinction is the accumulation of extinction resistance in the survivors of previous extinction events. Evidence for this can be seen in the character of the smaller stage-level extinction events, whose magnitude undergoes and substantial and highly structured decrease over time.

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Geosphere-Biosphere Interactions: Methane-based life at the ocean floor

Antje Boetius

HGF MPG research group on Deep Sea Ecology and Technology, Alfred Wegener Institute for Polar and Marine Research, and Max Planck Institute for Marine Microbiology

Natural gas and oil are currently the most important sources of energy to mankind. The ocean floor contains large quantities of these hydrocarbons. But although they are constantly escaping from natural seeps, neither oil nor gas accumulate in the sea. This can be attributed to the activity of hydrocarbon-degrading microorganisms, comprising specialists for consuming the simplest hydrocarbon – methane – as well as those oxidizing complex substrates contained in petroleum and tar. The ability of marine hydrocarbon degraders to clean the ocean from oil and gas spills has been recently stressed in the aftermath of the catastrophic explosion of the Deep Horizon drilling platform in the Gulf of Mexico. But still surprisingly little is known on the development and activity of environmental microorganisms responsible for oil and gas degradation. This presentation makes a journey from some of the hot spots of microbial methanotrophy in the deep sea such as methane hydrate deposits and erupting mud volcanoes, to natural asphalt seeps and its fascinating tar-degrading microbial consortia, which form the basis of a chemosynthetic food web. All of these extreme environments host the anaerobic methanotrophic archaea (ANME), which may be the most relevant group in controlling methane fluxes from the seafloor to the hydro- and atmosphere. The ANME represent special lines of descent within the Euryarchaeota and appear to gain energy exclusively from the anaerobic oxidation of methane (AOM), with sulfate as the final electron acceptor. They are widely distributed in the marine seafloor, and can form the densest biomasses of microorganisms known on Earth if both methane and sulfate are available as energy sources. The presentation will summarize the current knowledge on AOM habitats and its challenges.

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Will research save planet Earth?

Dieter Imboden*,**

* *President of the Swiss National Science Foundation Research Council*
** *Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Universitätstrasse 16, 8092 Zurich (dieter.imboden@env.ethz.ch)*

Politics and scientific research have well defined goals and tasks - so the general wisdom. The later produces knowledge (some would say 'true facts', what ever true means), the former normative boundary conditions for society which, in an ideal world, would be based on scientific facts and not contradict them. – Yet, this idealistic picture of the partition of responsibilities between science and politics has never hold. Science has never been just a fact finding enterprise, not now and not in the past. It has always (consciously or inadvertently) included a normative component, and thus scientists have always played politics, as well. This holds true not only for the 'softer social sciences and humanities', but also for the 'hard' sciences like physics and chemistry. In turn, politics has always been selective regarding the incorporation of scientific knowledge into its action. While there is hardly any government which would ignore the basic laws of statics in its regulations for the construction of buildings and bridges, things are more complex when it comes to issues like sustainability, a term once invented by science but meanwhile taken over (conquered?) by politics. Conflicts of interest exist on both sides, in politics because of some 'inconvenient truth', in science because of the enormous financial means invested in research. In order to avoid a disturbance of the research system similar to the collapse of the financial bubble it is of vital importance to critically analyze the role of science in society with respect to its real potential as well as to its inherent limits.