# NEWSLETTER GEOBRASIL
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?? **EARTH PAGES**

Anthropology and geoarchaeology

Did the earliest agriculture kick-start global warming

Most climate scientists encourage us to believe that planetary warming caused by gas emission from our energy intensive life style is both new and an inevitable context for our future. Yet, one leading authority on past climates, William Ruddiman of the University of Virginia, reminds us that it isn't only cars and power stations that release warming gases (Ruddiman, W.F. 2005. How did humans first alter global climate. *Scientific American*, v. **292** March 2005, p. 34-41). New evidence from air bubbles in the Vostok core through Antarctic ice shows a strange deviation of atmospheric CO2 around 8000 years ago, from a downward trend in the early Holocene to one that relentlessly rises to the levels that characterised the recent pre-industrial world. At around that time early agriculturalists in Europe and China began to chop down forest to make fields, thereby releasing the carbon content of felled trees to the atmosphere as CO2. By 5000 years before present, rice cultivation in East Asia had begun the release of methane from waterlogged paddy fields, and the methane content of ice bubbles reveals a reversal of methane decline at that time exactly.. Ruddiman's view is that the release of both "greenhouse" gases reversed a natural cooling trend, and that growing populations sustained growth in atmospheric CO2 (methane is quickly oxidised in the atmosphere). Comparing the rising CO2 of the Holocene with its records in ice-bubble for the previous three interglacials, shows that in each previous case the gas rose to a maximum early in the interglacials and then declined steadily. The invention of agriculture and its spread from around 11000 years ago in the Near East, he claims, could have staved off the onset of global cooling and the climatic descent into another glacial epoch, by eventually adding 40 parts per million of CO2 to the air. To support his hypothesis Ruiddiman compares the more recent ice-core records with historic catastrophes, mainly plagues that wiped out substantial proportions of the word population . Sure enough, there are falls in CO2 at the time of each major plague; that between 540 to 542 AD in Europe, the Black Death of the Middle Ages, and the reduction of the population of the Americas by maybe 90% when "Old World" diseases such as smallpox and measles met no resistance among native peoples.

In many respects Ruddiman's ideas seem plausible, until we see the data. The problem with ice core data is that its resolution degrades through time, and before 70000 years ago, no annual layers are preserved in glacial ice. Moreover, records from different Antarctic cores differ wildly for the historic period and Ruddiman does not show the record from Greenland ice. Finally, records of ice volume and ice-cap temperatures, derived from marine and glacial oxygen isotope records, show that each previous interglacial involved very different fluctuations in many other climate-related parameters. If nothing else, Ruddiman's ideas will be challenged and the issue will "run and run" until the next "big thing".

Climate change and palaeoclimatology

Making sense of glacial-interglacial cycles?

The competing periodicities of the three astronomical "drivers" of climate - orbital eccentricity (~100 ka), axial obliquity (~40 ka) and axial precession (~20 ka) – lie behind several models for the climate changes of the last 0.7 Ma. Taking in the theories that sway towards the influence of variables in the Earth system itself, around 30 models have some currency at present. Since climate forecasters have to take account of which factors drive climate in the absence of human emissions, as well as piece together their own particular models, it is easy to see how critics of global warming get a wide hearing: compared with creationists, they have it easy! Is there any way of resolving what is quite bluntly a theoretical mess? It is a mess simply because the available data are so complex, and in the case of both main sources, ocean -floor sediments and ice cores, not only are their devils in the detail, but there are whopping contradictions, such as the mismatches in timing between the Greenland and Antarctic ice cores. Add all the other sources, such as stalactites, tree rings etcete ra, together with caveats like the difficulty in time calibration using 14C dating, and the volume of diverse records become bewildering.

It is tempting that a reversion to a statistical approach, that includes more bells and whistles than hitherto (see *Evolutionary rhythms* below), can resolve matters. Peter Huybers and Carl Wunch, of Woods Hole Oceanographic Institution and MIT, have tried that for pacing of the last 0.7 Ma of climate cycles (Huybers, P. * Wunsche, C. 2005. Obliquity pacing of the late Pleistocene glacial terminations. *Nature*, v. **434**, p. 491-494). Generally accepted "wisdom" holds that the last 7 glacial-interglacial cycles are paced by ~100 ka eccentricity forcing, even though it has the weakest effect on solar heating, by a very long way. But there are smidgens of evidence for some interaction between that and the much stronger influence of changes in the Earth's axial tilt or obliquity. Huybers and Wunsch go for the Popperian rigor of first defining a null hypothesis, that obliquity has no effect, and then designing a test. It isn't easy to decide how the contrary hypothesis that it does can be evaluated though. The clearest features in all climate records are the ends of glacial epochs or termination: they are sudden, sharp and generally look the same. Most other features have some kind of pattern, but little consistent comparability. Using the most advanced statistical techniques, which employ many iterations to test for stability in statistical models, they can show that the null hypothesis fails. The positive result is that the time between terminations that are repeatedly modelled falls into two envelopes, around 120 and 80 ka, which simple arithmetic shows are divisible by 40 ka.

But how can axial obliquity only have an effect every two of three of its cycles, while a single cycle does not appear in the time -series; is it nature skipping beats somehow. One means that the authors suggest is that the underlying pace of eccentricity can effect the temperature at the base of ice sheets, depending on their thickness. If they are thin, then the heating is insufficient to trigger ice -sheet collapse because the base is very cold, whereas if ice is thick the effects of thermal conductivity and heat flow makes the ice base warmer and more subjec t to perturbation beyond its failure limit. It was at this point that I gave up, but wish the authors good luck in promoting their possibly unifying hypothesis for what finishes off glacial epochs…..

Environmental geology and geohazards

Yet more Indian Ocean earthquakes? Sadly, yes

The shores of the Indian Ocean and the people who live near them will take years and maybe decades to recover from the awful events of 26 December 2004. While relief and reconstruction efforts are underway, so too is the scientific analysis of what happened. Throwing a malevolent shadow is the uncertainty of whether there may yet be more tsunamis so soon after the first in the region for 150 years. The Sunda trench where the massive earthquake took place had remained stable for a long time. Stresses built up, eventually to cause the subduction zone to fail catastrophically. However stress relief in one place redistributes that which remains along other fault lines, and can create space in which new breaks might occur. Geophysicists from the University of Ulster have analysed the likely disruption of stress in the eastern Indian Ocean (McCloskey, *et al*. 2005. Earthquake risk from co -seismic stress. *Nature*, v. **434**, p. 291) following the distribution of about 20 m displacement on the Sunda subduction zone over a N-S length of around 500 km. They feared that such a huge perturbation may activate other large faults. A changed stress field seems to have been the cause of the Izmit earthquake that devastated central Turkey and also set in motion repeated seismicity along the subduction system off Japan in the past. McCloskey and colleagues foresaw two worrying possibilities for the Sunda subduction system: stress localised just to the south of the Boxing Day event could migrate southwards to trigger release again on the subduction zone; a large strike -slip fault that runs down the centre of Sumatra, itself linked to subduction, may fail soon. fear that the second is the more likely.

Since modern seismology emerged, so few earthquakes have occurred in the area compared with other large subduction settings that prediction is difficult. The Ulster scientists were correct, very soon after their prediction was published. On 28 March 2005, a magnitude 8.7 earthquake occurred on the subduction zone about 150 km south-west of that on Boxing Day 2004. Its motion involved vertical displacement, so it was feared to trigger yet more tsunamis and sirens sounded throughout the previously devastated areas. The warnings were heeded. Apart from some panic that cause two deaths in Sri Lanka, people moved quickly to safe ground. Thankfully, perhaps miraculously considering an energy release not far short of that at the end of 2004, there were no tsunamis of any consequence. Yet the places on the nearby Indonesian island of Nias were devastated by the shock waves, killing upwards of a thousand people. This is a grim warning that McCloskey and colleagues' interpretation of stresses moving southwards along the main ocean floor fault system is happening. The risk of further devastation soon is by no means over

Geobiology, palaeontology, and evolution

Evolutionary rhythms

The late Jack Sepkoski did a lasting service for those who study life's record by combing the literature to compile the first and last appearance of each marine fossil genus. It is from this archive that we have been able to visualise mass extinctions and those less in magnitude numerically. As well as the "Big Five" there are other die-offs, particularly through the Mesozoic and Cenozoic record. To some extent the extinction patterns also appear among terrestrial taxa that have been less well documented, partly because few have had Sepkoski's determination and partly because land organisms leave fewer traces. It quickly became apparent to him and other palaeontologists that extinction occurred sharply, which is why the biologically-determined division of Phanerozoic time since 542 Ma is so well defined world-wide. What also emerged from inspection of the time series of genus and family numbers was a pulse in the timing of significant extinctions, which appears to have been between 25 and 30 Ma. That struck a chord with specialists in volcanic activity, and there is a good correlation between the occurrence of flood-basalt outpourings and extinctions. But at least one of the five largest extinctions, at the K-T boundary, coincides with abundant evidence for a major impact by an extraterrestrial body. Planetary scientists then began looking for a pulsed variation in the intensity of bombardment of the Inner Solar System. There is no tangible evidence of that, although there are theoretical arguments that suggest that the Sun in its ~250 Ma orbit around the galactic centre wobbles through dust arranged in bands close to the galactic plane every 30 Ma.

Extinctions are not, of course, the only features of the fossil record. Primarily it charts variations in diversity, of which suddenly lowered numbers are one aspect in broader fluctuations. Each extinction eventually precedes an increase in diversity as adaptive radiation from surviving taxa fills ecological niches left vacant or under-populated. That part of the record has its fascinations, as complexity seems to have emerged in three great pulses, through the Palaeozoic, Mesozoic and Cenozoic Eras, each producing more diverse forms than its predecessor. There are also slackenings in the pace and periods of apparent stasis. Getting to numerical grips with the full record requires analysis that uses similar mathematical techniques to that which unlocked proof of Milankovich's theory of astronomical pacing of climate from finely calibrated oceanic-sediment records. It is possible to analyse time series in terms of discrete frequencies from which the curves can be reconstructed. Physicists Robert Rohde and Richard Muller of the University of California have used this Fourier analysis on the 36 thousand strong catalogue published after Sepkoski's death, with some recalibration of the time scale and some pruning of data – they removed genera with only a single record or whose age is poorly known (Rohde, R.A. & Muller, R.A. 2005. Cycles in fossil diversity. *Nature*, v. **434**, p. 208-210). There are definitely distinct frequencies that dominate the record, and they cannot be present by chance, although that is a purely statistical view. But to their surprise, and everyone else's, they are completely unexpected ones at 62 and 140 Ma. It is proving exceedingly difficult to come up with plausible Earthly or extra-terrestrial explanations. There are two interesting features: the 62 Ma periodicity dominates the record of relatively short-lived genera; and the "Big Five" seem to fit neatly into the patterns of diversity, albeit at unequally spaced intervals, when the effects of background fluctuations have been removed. That filtering may allow for increasing preservation towards recent times. One major control over diversity is, logically, a mixture of the number of potential niches and their geographic isolation, and both are probably related to plate tectonic activity. Unfortunately, fluctuations in 2 and even 3 geographic dimensions have only the broadest calibration to time. Added to that is the complex way in which global sea level has changed with time. So we can expect a great deal of head scratching, and it may come as a relief that the crowing of some volcanologists and impact theorists may have been silenced at a single stroke!

**See also:** Kirchner, J.W. & Weil, A. 2005. Fossils make waves. *Nature*, v. **434**, p. 147-8.

Planetary, extraterrestrial geology, and meteoritics

Curiously low-velocity material at the core-mantle boundary (CMB)

One of the oddities of the deep Earth is the presence of zones of the order of 1 to 10 km thick close to the boundary between the lower mantle and the outer core that have seismic wave speeds well below those expected at such depths. Because wave speed is inversely proportional to density, the chances are that they are "ponds" of extremely dense solid materials. Denser in fact than basalt might become in the form of eclogite, even compressed appropriately to these extreme depths. The zones have been a puzzle, but that seems to have been resolved by work from University College, London (Dobson, D.P. & Brodholt, J.P. 2005. Subducted banded iron formations as a source of ultralow-velocity zones at the core-mantle boundary. *Nature*, v. **434**, p. 371-374). The densest materials found commonly at crustal levels are iron oxides and hydroxides, but today they are disseminated through much larger volumes or quartz-rich sediments. Up to about 1.8 billion years ago, they were produced in huge abundance in sedimentary rocks, along with interbedded cherts, to form banded iron formations (BIFs). That is widely agreed to have been a phenomenon only possible when the ocean was oxygen free so that iron could be dissolved in the oceans, and that they were precipitated when that Fe(II) came into contact with oxygen being produced by photosynthesising blue-green bacteria in shallow water. Without any shadow of doubt, BIFs are the densest sediment that the Earth has ever produced, with a 50:50 mix of iron oxide and chert having a density of 3900 kg $m^{-3}$ at near-surface pressures, compared with 3100 for the upper mantle. Long ago, Bob Newton of the University of Chicago reckoned that they "didn't oughta be around still": Precambrian BIFs are so vast and so dense that they are even more likely to be subducted than oceanic basalt converted to eclogite. And they would not even need to be metamorphosed to do that. So, it has taken a long time for someone to cotton on to Newton's typical prescience.

Quite possibly, BIFs were a tectonic driving force at a time when the basalt-eclogite transformation was thermodynamically unlikely. Dobson and Brodholt observe that BIF density can only get larger (much larger; 6600 kg$m^{-3}$ at CMB pressure) if they sink This is a nice hypothesis, for BIFs fit the bill exactly for the ultra-low velocity zones, and carries some interesting corollaries. BIFs contain a great deal of oxygen, in fact probably the entire productivity of the early Precambrian biosphere: that would have a biogenic isotope signature. Could that be added to any plume material emanating from the CMB? Equally, BIFs contain unusually high concentrations of transition metals, and there is another possibility for deep-mantle geochemists to juggle with. The authors also observe that iron-oxides have high electrical conductivity compared with silicates, and ponder on the electromagnetic consequences of that so close to the core. One thing seems certain; iron oxides probably would not melt, but, depending on the amount of oxygen in the core, they might dissolved in the molten outer core.

Remote sensing

Mineral maps of Mars

Lots of space has been devoted in science journals to results from NASA's robot rovers on Mars. Well, haven't they been exciting? Iron-oxide "blueberries, a cliff with bedded sediments and some iron-aluminium sulphate in a combined traverse of a kilometre at most: imagine a geologist coming back from a terrestrial field trip costing a year's GDP of a small poor country and writing a report for the funding agency! That is a bit cruel, for in planetary exploration the themes are context, context and context, but we did know that Mars is red and orange, which is enough for most of us to feel happy with a lot of iron coloration. At the same time as the rovers were deployed, the European Space Agency's Mars Express was going into orbit (so named because it was assembled in something of a hurry). That bristles with the geoscientist's other modern tools: those aimed at sensing materials from their electromagnetic spectra. There is the High-Resolution Stereo Camera that produces images to rival high-altitude aerial photos of the Earth, and with stereoscopic overlap from which accurate models of Mars' topographic elevation can be calculated, of which more in the next item. The principal mineral and rock mapping tool is the Observatoire pour la Minéralogie, l'Eau, les Glaces, at l'Activité (OMEGA), that builds on the spectral mapping by NASA's Thermal Emission Spectrometer deployed by the earlier Mars Global Surveyor and a similar instrument aboard Mars Odyssey. OMEGA is every remote sensing geologist's dream machine, because its coverage of the short-wave end of electromagnetic radiation by 350 narrow bands can match spectra reflected from rocks and soils with those measured under laboratory conditions for several hundred important minerals.

Research geologists don't get much of that quality of data from Earth, mainly because it is com mercially successful in mineral exploration, and very expe nsive (for much of the Earth, such hyperspectral data is not very useful, because vegetation masks most mineral signatuires). But data are free from Mars Express (or will be when the main investigators have had a reasonable time to satisfy their curiosity) and has a terrestrially useful resolution down to 100m. They also cover an awful lot of the planet's surface and should eventually give 100% coverage. The 11 March 2005 issue of *Science* devotes 24 pages (p. 1574-1597) to summarising OMEGA results. Various papers reveal variations in the composition of pyroxenes in the predominantly mafic Martian surface rocks, those minerals, such as the sulphates gypsum and jarosite, which contain water and signs of weathering by water, and an awful lot about water and CO2 ices around the poles. But this is not the geology in full of course, but driven by the search for potential habitability. Common rocks are not made of sulphates and ice, but silicates, which can be assessed by multispectral thermal emission data that pr ove very useful on Earth. The lack of information about such fundamental divisions of Martian igneous rocks as ultramafic, mafic, intermediate and felsic is a great disappointment, but perhaps the thermal instrument aboard Mars Odyssey will eventually come up with those more mundane goodies. Oddly, the planetary treasures of Mars are not being revealed by such sophisticated instruments, but by what is still the work horse for a great deal of geological image interpretation, black and white stereo images.

The triumph of the old on Mars

Except perhaps for some of the current generation of geologists, who are immersed in their remote sensing training by false colour images of spectrally revealing multispectral image data, a great many professionals who engage in mapping cut their teeth on what is known simply as photogeology. And it is simple. Provided images are taken of an area from different angles, with the simplest of instruments most people's innate stereoscopic vision enables them to see startling illusions in three dimensions. Stereoscopy has been to geologists of the mid to late 20 th and early 21 st centuries what the binoculars were to those earlier scientist who discovered the great nappes of the Alps and thrust belts of the Rockies. A stereoscope of some kind is the latter-day analogue of that "Swiss Hammer". Two stereo images reveal a great deal more than twice the information of one flat image, no matter how detailed. Using complex software, which converts the parallax differences that enable us to see 3-D to the differences in topographic elevation that cause relative shifts in the position of features on overlapping images creates accurate models of the elevation itself. That enables quantitative measure of many features related to topography, and allows the images to be viewed in perspective, as if they were indeed captured by binoculars from a high view point.

Results from the Mars Express High-Resolution Stereo Camera (HRSC) have proved able to revolutionise our understanding of the Martian surface. The 17 March 2005 issue of *Nature* reports three important new results that stem from HRSC data. For several years the possibility of glaciers having carved some features on Mars have been suspected

from lower resolution elevation data. Now it is certain from exquisite perspective views of debris aprons that record the flow of smashed rock from large mountains, almost certainly because the debris was once extremely dirty glacial ice (Head, J.W. *et al*. 2005. Tropical to mid-latitude snow and ice accumulation, flow and glaciation on Mars. *Nature*, v. **434**, p. 346-351). The flows are reminiscent of rock-rich glaciers in the hyper-arid Dry Valleys of Antarctica. These authors present evidence that suggests that the flows are as young as 130 Ma, and may yet contain water ice. A second paper also reveals the influence of near-surface ice on Mars (Hauber, E. *et al*. 2005. Discovery of a flank caldera and very young glacial activity at Hhecates Tholus, Mars. *Nature*, v. **434**, p. 356-361). In its case it seems to have been mobilised by an explosive volcanic eruption, possibly as young as 20 Ma, to produce debris flows and also very well preserved drainage channels at a much smaller scale than those known from Mars' earliest history. The drainages might have resulted from subsurface ice melting by high heat flow and emergence of the "groundwater" to carve the meandering channels. There is an important caution: any dating on Mars depends on assuming a timescale based on counting impact craters and noting their relations to each other and different kinds of surface.
The third paper observes something very different (Murray, J.B. *et al*. 2005. Evidence from the Mars Express High Resolution Stereo Camera for a frozen sea close to Mars' equator. *Nature*, v. **434**, p. 352-356). HRSC images reveal an area about the same size as the North Sea that is not only completely flat, but shows features very like those associated with pack ice in the Arctic and around Antarctica. They are plates whose edges can be fitted together, and in some cases islands have resulted in pressure ridges very like those seen where terrestrial pack ice meets land. There are even examples of impact craters that have been flooded. Murray and colleagues attribute all this to a large volume of subsurface water released by very recent volcanism along fissures close to the Martian equator. Basalt floods had been identified in the region before, but not evidence for a possible sea-sized, frozen lake. Similar, but not so revealing features elsewhere on Mars have been interpreted as lava rafts that once floated on flood basalts. Naturally, Mars scientists are very excited about the possibility of a large ice sheet at the equatorial surface, which may be as much as 45 metres deep. Unfortunately, the observations are from an area not yet covered by spectral data that would resolve whether the surface is ice-rich or more mundane lavas.

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ANALYTICAL RESEARCH FORUM (ARF 05)
University of Plymouth, 18 – 20 July 2005
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The closing date for abstracts for 2005's Analytical Research Forum has been extended to 11th April. If you would like to give an oral or poster presentation at ARF 05, please email a brief abstract to conferences@rsc.org

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