Climate change and palaeoclimatology

Climate change and the penguin (*February 2007*)

The Adélie penguin nests on rocky outcrops in coastal Antarctica. Because the climate is extremely dry, their nesting sites are rich in mummified remains. It would not occur to everyone to date penguin mummies (Emslie, S.D. *et al*. 2007. A 45,000 yr record of Adélie penguins and climate change in the Ross Sea, Antarctica. *Geology*, v. **35**, p. 61-64; DOI: 10.1130/G23011A.1), but since the Adélie, like all penguins, is oddly choosy it is a useful thing to try. Not only do Adélies demand dry sites, but they have to be within easy reach of open water during the nesting season. Abandoned sites are a proxy for those demands as they existed in the past. Emslie and colleagues were able to show that from 45 to 27 ka conditions for Adélies prevailed in the Ross Sea area, but penguins abandoned it until 8 ka, when they returned. Conditions did not suit them throughout the Holocene, however, and most modern colonies were established only in the last two millennia.

An early Greenland ice cap (*May 2007*)

Around 34 Ma the oxygen isotopes in deep-water forams from ocean-floor cores show a jump towards more 'heavy' ^{18}O. Together with the sudden appearance of coarse debris in oceanic sediments around Antarctica, the early Oligocene isotopic shift has been taken to represent the first sizeable build-up of land ice since the Carboniferous-Permian glacial epoch over 200 Ma earlier. It is also a marker for the later decline in overall surface temperature, culminating at 2.5 Ma with the onset of cyclical glaciation of high northern latitudes. This has to be revised after discovery of older ice-rafted debris in ocean-floor sediments in the North Atlantic between Greenland and Norway (Eldrett, J.S. *et al*. 2007. Continental ice in Greenland during the Eocene and Oligocene. *Nature*, v. **446**, p. 176-179; DOI: 10.1038/nature05591). The debris occurs in layers dated between 30 to 38 Ma. Direct evidence for cooling that supported ice-cap formation in both polar areas from the end of the Eocene is not matched by indirect evidence for the contemporary state of the global 'greenhouse'. Proxy data suggest that the CO_2 content of the atmosphere was around 7 times higher than in recent, pre-industrial times, falling dramatically in the middle Oligocene (~30 Ma) to about twice those in the Holocene, then slowly declining through the Neogene.

Magmatic link to the Palaeocene-Eocene warming (*July 2007*)

The abrupt 5° C global temperature rise at the Palaeocene-Eocene boundary around 56 Ma ago stemmed from massive release of methane, probably from gas-hydrates on the sea floor. What triggered that blurt is not so well constrained, although the development of the North Atlantic large igneous province has long been suspected, as flood basalts in Greenland and northern Britain have about the same age. The North Atlantic LIP involved between 5-10 million km^3 of magma, much residing beneath the continental margins, and was associated with the opening of the northernmost Atlantic Ocean.

The Palaeocene-Eocene methane release is recorded in sea-floor sediments by a sharp decrease in the proportion of ^{13}C in carbonates within ocean-floor sediment cores.

Magnetostratigraphy suggests that the release lasted only for about 20 ka at the start of around 210 ka of warming. Such a short duration is a challenge for establishing a precise absolute age and a linkage to any possible causes. In the Western Approaches to the English Channel a core contains a volcanic ash layer just above the carbon-isotope anomaly, as a target for precise dating (Storey, M. *et al*. 2007. Paleocene-Eocene thermal maximum and the opening of the northeast Atlantic. *Science*, v. **316**, p. 587-589; DOI: 10.1126/science.1135274), to match with igneous events in the LIP. A total of 50 Ar-Ar total-fusion ages shows that this ash and a tuff high in the East Greenland flood basalts are statistically identical in age (55.12±0.09 Ma). This and other considerations virtually prove that the methane release coincided with the LIP. However, it remains to be established whether the link was through volcanically induced warming that destabilised submarine gas-hydrates or direct triggering of the greenhouse-gas exhalation. The ages fall within error of the age of continental break-up itself. Because vast areas of the rifted margins contain sills emplaced in the LIP, the authors suggest that the release was due to thermal metamorphism of carbon-rich sediments at the new tectonic margin; i.e. the released gas may have been CO_2.

See also: Kerr, R.A. 2007. Humongous eruptions linked to dramatic environmental changes. *Science*, v. **316**, p. 527.

An iron age for climate engineering? (*July 2007*)

In 1989 American oceanographer John Martin proposed that the low plankton levels in ocean surface waters far from land, despite their containing many nutrients, was due to a dearth of dissolved iron. He suggested that adding iron-2 compounds would cause massive blooms of photosynthesising phytoplankton; a potential means of drawing down atmospheric CO_2, should their dead remains become buried on the ocean floor. Martin did not live to see his ideas vindicated by several iron-seeding experiments that did significantly increase plankton. Unfortunately they were inconclusive because of rapid mixing of small test areas with their surroundings. There are, however, natural phytoplankton blooms that cover thousands of km^2. Examining the associated water chemistry is a means of assessing the role of iron (Blain, S. and 46 others 2007. Effect of natural iron fertilization on carbon sequestration in the Southern Ocean. *Nature*, v. **446**, p. 1070-1074; DOI: 10.1038/nature05700).

Blain and French, Australian, Dutch and Belgian colleagues focussed on the large bloom that regularly appears above the Kerguelen Plateau on the floor of the southern Indian Ocean. Indeed, it does depend on iron-rich upwellings from deep levels, but also on silica as well as nitrate and phosphate. The researchers estimate of the amount of carbon sequestered per unit mass of iron in the water gave surprising results. Compared with estimates from controlled iron-seeding experiments, the natural process is between 10 to 100 times more efficient as a means of fixing CO_2 in phytoplankton so that it becomes available for burial, despite the fact that zooplankton consumes some of the phytoplankton bloom. The Kerguelen bloom is of the order of 50 thousand km^2 in area, and potentially affects atmospheric CO_2 and global climate significantly.

For iron to dissolve in such waters as Fe^{2+} ions would require anoxic conditions, yet it seems that iron is transported in nano-scale mineral particles that must somehow be broken down to soluble forms by some kind of reworking in the upper ocean layers. A plausible explanation for the decrease of atmospheric CO_2, and therefore greenhouse warming, during glacial periods is that particulate iron minerals – probably hematite or goethite coatings to dust grains – were supplied to the ocean surface far from land by wind blown dust. In both the Greenland and Antarctic ice cores there is a close correspondence between the amount of dust preserved in ice layers and the CO_2 content of air bubbles trapped in them. Yet iron(III) ions are notoriously insoluble, so just what is the process that converts iron(III) minerals to soluble Fe(II) ions? It clearly happens, and that has encouraged a company called Planktos to release 90 t of hematite into the Pacific west of the Galapagos Islands to see if the widely available mineral can be used for future climate engineering. The financial side of Planktos's venture is interesting; they plan to use the experiment to calculate the tonnage of carbon sequestration that results from it, and then sell 'carbon credits' on the world offset market.

See also: Schrope, M. 2007. Treaty caution on plankton plans. *Nature*, v. **447**, p. 1039. Boyd, P.W. 2007. Iron findings. *Nature*, v. **446**, p. 989;DOI: 10.1038/4471039a.

Whizz-bang view of Younger Dryas (*July 2007*)

News is beginning to break of a potential controversy to rank with that surrounding the K-T boundary event. At the May AGU meeting in Acapulco, Mexico, two dozen scientists presented evidence to suggest that the sudden cooling at 12.9 ka that led to the Younger Dryas millennium followed upper atmosphere explosions of cometary material (Firestone, R.B. and 25 others. Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling. *Proceedings of the National Academy of Sciences*, v. **104**, p. 16016-16021; DOI: 10.1073/pnas.0706977104). The usual signs are said to be around: excess iridium; spherules; fullerenes and evidence for huge wildfires. They seem to lie directly above the last known occurrences of the superbly crafted spear and arrowheads known as Clovis points, which are the hallmark of the earliest known humans in North America. The YD seems to have finished off the mammoths as well, if they hadn't already been eaten by the Clovis hunters.

Short-lived events, no matter how massive, seem unlikely to have created conditions for thousand-year 'nuclear winters' forced by dust blocking solar irradiation. The loose consortium involved in the discovery suggests that an air-burst by exploding debris from a comet melted part of the remaining Laurentian ice sheet. That would have caused a surge of fresh water into either the Arctic or North Atlantic Oceans to disrupt Gulf Stream circulation – the original model by Broeker, but ascribed by him and others to breaching of ice dams to proglacial lakes. The impact concept has been gathering followers for several years. But it has been attracting many critics too, not least because among the consortium are scientists who produced similar evidence for an end-Permian impact, that has never been independently reproduced since. The more excitable are scouring satellite images of North America for signs of actual impact sites that may be of the same age – for instance a series of elliptical depressions known as the Carolina Bays of eastern USA. But, the idea resurrects an old hypothesis about mammoths. Not only are mammoths found in Siberian permafrost with flesh that can be eaten, if a little gamey for some tastes, but their stomachs contain barely digested grasses and flowers. It was once suggested that the mammoths were flash-frozen by extremely cold air from the upper atmosphere that rushed down in the aftermath of some kind of volcanic or impact-induced blast.

See also: Dalton, R. 2007. Blast in the past. *Nature*, v. **447**, p. 256-257; DOI: 10.1038/447256a. Kerr, R.A. 2007. Mammoth-killer impact gets mixed reception from Earth Scientists.*Science* v. **316**, p. 1264-1265 ; DOI: 10.1126/science.316.5829.1264

Cyclicity of Neoproterozoic glacial epochs (*September 2007*)

The concept of 'snowball' conditions on Earth in the late Precambrian is that climate reached a state that drove it into semi-permanent frigidity so encasing the globe in ice. The idea has been challenged by several lines of evidence since its first proposal in the late 1990s. Few doubt that the Neoproterozoic was punctuated by several periods of extreme cold whose effects extended to tropical latitudes, but many reckon that climate never reached runaway 'snowball' conditions. It now seems that the glacial episodes had something in common with those of the Pleistocene, and exhibited cyclicity (Rieu, R. *et al*. 2007. Climatic cycles during a Neoproterozoic 'snowball' glacial epoch. *Geology*, v. **35**, p. 299-302; DOI: 10.1130/G23400A.1). The evidence comes from the thick glacial and non-glacial sequence of the Fiq Formation in Oman, one of the youngest in the Neoproterozoic. It is in the form of mineral and geochemical data expressed as indices of alteration, based on the climate dependence of chemical weathering in the source area for sediments.

Both the chemical and mineralogical indices show considerable variation in the Fiq Formation, peaks and troughs in both data sets correlating well. There appear to have been three glacial-interglacial cycles. Troughs in the indices coincide with diamictites that contain dropstones and are usually interpreted as having been deposited partly from floating ice shelves. Peaks are found in mudstone and sandstone sequences that contain no evidence for glacial conditions. Unfortunately, the lack of precise dating rules out useful knowledge of cycle duration. An extremely crude estimate based on assumed deposition rates and the 200-500 m thickness of each cycle suggests far longer periods (1 to 5 Ma) than in the present glacial epoch.

The Fiq Formation is by no means the only Neoproterozoic sequence containing repeated diamictites. For instance, the 900 m thick Port Askaig Formation from the Dalradian of Scotland and Ireland contains around 30 separated by non-glaciogenic siltstones and sandstones. Were those alternations to be shown to involve similar variations in indices of alteration, a similar crude estimate of cycle duration would be of the order of hundreds of ka; comparable with Pleistocene cycles.

See also: Lorentz, N.J. & Corsetti, F.A. 2007. Another test for snowball Earth. *Geology*, v. **35**, p. 383-384; DOI: 10.1130/Focus042007.1