GEOBROWSER

Is global warming a long-term option?

The latest published Climate Change Synthesis Report (2014) reinforces the majority view that climate change is proceeding apace, stating that: *Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.* For Britain, obvious impacts over the last 20 years were the destructive storms that flooded coastal and inland areas. Their increased frequency and intensity reflect the greater energy and water content of weather systems in a warmer globe, exacerbated by a complex interplay of natural factors such as El Niño and jetstream configuration. Only a few climate researchers would now argue with the report's conclusion that … *Human influence on the climate system is clear, and recent anthropogenic emissions of green-house gases are the highest in history.*

Climate change *per se* has been occurring throughout the planet's history, however, and fluctuations of the current ice age did not prevent, and may even have accelerated, the evolution of anatomically modern humans about 200,000 years ago (*www.sciencebasedlife.the-timeline-of-human-evolution)*. Through adaptation and migration, *Homo sapiens* ('wise man') lived through two major Quaternary glaciations that rendered much of Eurasia and North America partially ice-covered or as a tundra terrain. Conditions are relatively benign in the current, interglacial times, but looking far into the future, at least on the human scale of perception, our climate will naturally cool once again due to orbital forcing (Milankovitch cycles). Thus, by drastically curtailing anthropogenic greenhouse gas emissions, another glaciation may result, and even allowing for technological advances this would pose massive geopolitical problems as whole nations could be threatened by advancing ice sheets.

Given a future that potentially involves natural global cooling, a better emphasis might be to regard greenhouse gases as a valuable resource for regulating the planet's climate. To achieve this, accurate global emission-control models will be needed to give an optimum climatic balance that attempts to maintain the current environmental, demographic and political *status quo*, undesirable as that may be to some communities. Researchers are just beginning to think in that way; for example, the Potsdam Institute for Climate Impact Research (*Nature, 2016: 10.1038/nature16494*) finds that…'*relatively moderate additional anthropogenic CO_2 emissions from burning oil, coal and gas are already sufficient to postpone the next ice age* (ie glacial interval) *for another 50.000 years. The bottom line is that we are basically skipping a whole glacial cycle, which is unprecedented. It is mind-boggling that humankind is able to interfere with a mechanism that shaped the world as we know it.'* It also concludes that even …'*moderate future anthropogenic CO_2 emissions of 1000 to 1500 gigatonnes of carbon are bound to postpone the next ice age by at least 100,000 years.'*

So perhaps a nuanced greenhouse gas strategy would be more appropriate, taking into account oft-neglected factors such as emissions from livestock, already 14.5% of total, anthropogenic, greenhouse gas according to a UN FAO study (*www.fao.org/news/story/en/item/197608/icode*), as well as natural sources, such as methane emitted from decomposing vegetation (*e.g. http://www.wetlands.org/Carbonemissionsfrompeatland*). In this complex equation other emissions that cause climate cooling, such as dust from volcanic eruptions, and man-made industrial aerosols (*www.metoffice.gov.uk/aerosols factors*), also need to be factored in. Current estimates suggest that 'fairly dramatic' cuts to anthropogenic greenhouse gas emissions, mainly from the burning of fossil fuels, would be needed in order to stabilise current global CO_2 concentrations of around 400 ppm (*NOAA, 2016*). If we fail to do this, then not only will anthropogenic global warming proceed apace, destroying environments, rendering many countries uninhabitable and drowning coastal cities (*Nature Climate Change, 2012: 10.1038/nclimate158*), but we will also have exhausted the planet's strategic supplies of fossil fuels, the very materials that could stave off the more gradual catastrophe of a future glaciation.

Record Atlantic tsunami recorded

Last year's *Mercian Geologist* (*pp 243-251*) described in lavish detail the volcanic geology of Fogo Island, in the Cape Verde archipelago. Another fascinating aspect of Fogo is that all of the recent activity is confined by an arcuate cliff, the Bordeira, up to 1000 m in height. This is not simply an old caldera rim: it has long been recognised as the scar of a massive landslide that, given the volcanic context in which it occurred, would be classified as a flank collapse. A vast amount of material must have suddenly entered the sea, inevitably creating an east-directed tsunami, but the question is: how extensive or devastating would this have been?

As recounted by Emma Brown in *Nature News* of October 2015 *(10.1038/nature.2015.18485)*, the first clues came in 2011 when a team of European scientists found evidence for tsunami-type deposits on Santiago Island, about 55 km east of Fogo (*Sedimentary Geology 239, 129–145*). This article triggered a recollection by Ricardo Ramalho, who while working there in 2007 had noticed extremely large boulders scattered across a wide plateau about 200 m above sea level. The boulders were derived from the cliffs below, and marine fossils


source: Ricardo Ramalho, Bristol University

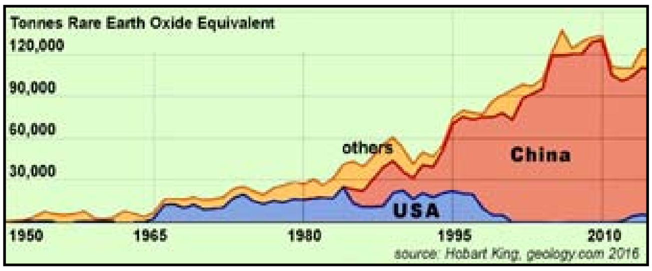
were also present among the debris. Putting two and two together, the most plausible causative event would have been the tsunami generated by the flank collapse on Fogo Island. Calculations showed that a wave powerful enough to carry the largest boulder would have been at least 170 m high when it hit the island, before reaching elevations up to 270 m above its coastline. To date this event more precisely, collaborators at Columbia University's Lamont–Doherty Earth Observatory in Palisades, New York, measured the amount of helium-3 on the boulder surfaces that have been exposed since the wave hit, pinpointing the tsunami, and thereby the Fogo flank-collapse, at roughly 73,000 years ago (*Science Advances* 2015: *10.1126/sciadv.1500456)*.

This evidence recalls the alarm raised by a paper (*American Geophysical Union, 2001*) suggesting that a giant west-facing flank collapse of the Cumbre Vieja volcano on La Palma Island, in the Canaries, could generate a tsunami large enough to travel across the North Atlantic and devastate cities such as New York. Subsequently however, many scientific bodies, including the Tsunami Society (*http://www.lapalma-tsunami.com/),* pointed out that that the power of such an event has been wildly exaggerated, and even the BBC published a partial retraction saying that this 'tidal wave threat', the subject of its *Horizon* program, was '…. over-hyped'. Nevertheless, submarine debris fields resulting from flank collapses have been found in many archipelagos with steep-sided volcanoes (*www.earth.ox.ac.uk/~tony/watts/downloads/Masson_Gee_Landslides.pdf),* the Canaries being a classic example (*Geobrowser, 2000)*. As yet there is no eye-witness account of an ocean-island flank collapse, but the Santiago Island example gives some indication of the damage to coastal settlements and tourist resorts that such events could cause in the future.

Coal: a new mineral resource?

As technology becomes increasingly sophisticated, so too is our reliance upon rare-earth elements (REE), such as scandium, yttrium, lanthanum and cerium, for producing both necessity and luxury items, such as computers, smart phones, rechargeable batteries, electric vehicles, magnets and chemical catalysts. However, rare earths are seldom concentrated in mineable amounts, accounting for the scarcity of prospects worldwide. Moreover, the graph shows that China has controlled the market in recent times, with more than 85% of world production. So it was able to sell rare earths at very low prices in the late-1980s and early-1990s, forcing mines to close in the United States, the next-largest producer. But when it cut exports in 2010, rare earth prices skyrocketed, stimulating new exploration in the USA and several other countries (*Geology.com,* May 2016).

It has long been known that rare earths are found in coal seams, but it was always costly to extract them. The current burgeoning market, however, has stimulated the search for readily accessible sources, and some of this research has been highly innovative. In the USA, the West Virginia Water Research Institute has already identified treated acid mine drainage from coal mines as an enriched



source of rare earths, particularly the more valuable, heavy elements (*www.sciencedaily.com/releases/2015*). In Britain we may have missed the boat here because, although some abandoned mines continue to be pumped out, the last, deep-working mine (Kellingley) closed in 2015. However, there are still eight mines supplying the remaining coal-fired power stations, and the ashy waste produced from these could yet be investigated as a further source of rare earths. Again the USA leads the way, with a team from Penn State University reporting cost-effective and environmentally friendly ways to extract these metals from coal-burning waste using ion-exchange techniques. Up to 0.5% of rare earths were extracted in a preliminary study, but the team are confident that this can be increased to a commercially viable 2% (*Metallurgical Materials Transactions E, 2016*). The Penn State team also investigated *in situ* coal deposits and found that coaly shales, at the very tops of some seams, contained the largest amounts of rare earths. This is currently a growth area for research in the USA and worldwide, so perhaps it is not too late to test it out in the 20–30 opencast coal sites that are still working in Britain.

Fracking does not contaminate aquifers

Few things are predictable in local politics, but one issue that is bound to heat up the East Midlands within the next few years revolves around the potential impacts of hydraulic fracturing (fracking) for shale gas. We raised this spectre in *Geobrowser* for 2010 and 2012, and this year in Nottinghamshire a start has been made at a site near Blyth, which has received planning permission for a single exploratory well. There are many objections to fracking, but one that usually receives prominence is the possibility of contamination by leakage of natural gases into aquifers supplying local drinking water.

This concern has been addressed in the USA, where large-scale fracking was pioneered and where its side-effects have been monitored over the past three decades. A team from Ohio State University has used noble gases, such as helium and neon, which leak out along with the methane, to identify a key source of groundwater contamination (*Proc. National Academy of Sciences*, *2014)*. After analysing eight clusters of contaminated drinking-water wells in Pennsylvania and Texas, the team found that neither horizontal drilling nor the fracking of shales were involved. Instead, it appears that poor casing and cementing in the parent wells caused natural gas to travel up the outside of the borehole and into any adjacent aquifers. This is good news because it means that any methane contamination should be strictly localized, and can be easily addressed by a few simple improvements to well integrity.