Geohazards

Arsenic risk in the Mekong Delta of Cambodia (*January 2009*)

Since the awful discovery in the 1980s that millions of people in the delta plains of the northern Indian subcontinent were at risk of chronic arsenic poisoning if they drank water drawn from wells in alluvium, that hazard has been found to exist in other alluvial areas close to sea level. The arsenic is of natural origin and is released when iron hydroxide, the most common sediment colorant and powerful medium for adsorption of many elements including arsenic, breaks down. Iron hydroxide is destabilised in strongly reducing environments, when its component Fe^{3+} gains an electron to become soluble Fe^{2+}. The most common source of reducing conditions is vegetation buried in alluvial sediments. In Bangladesh and West Bengal, India, the problem is peat layers buried by rapid sedimentation since about 7 thousand years ago that filled channels cut by rivers when sea level was much lower during the ast glacial maximum. The risky areas in the Mekong Delta are more complex (Papacostas, N.C. *et al*. 2008. Geomorphic controls on groundwater arsenic distribution in the Mekong River Delta, Cambodia. *Geology*, v. **36**, p. 891-894; DOI: 10.1130/G24791A.1). Areas at risk are strongly focused by recent landforms associated with channel migration, rather than extending across entire flood plains as in Bangladesh. Features such as meander scrolls, point bars and islands that have grown to be incorporated in older floodplains show the highest arsenic concentration in groundwater. These accumulate organic debris in large amounts, whose decay releases arsenic from iron hydroxide veneers on sand grains. Older features of the same kinds show less arsenic contamination in their groundwater, suggesting that eventually either the reductants become exhausted or available arsenic is flushed out. So, careful mapping and dating of fluviatile geomorphology may be a means of screening for arsenic risk in the Mekong and other low-lying delta plains.

Chinese dam implicated in the 2008 Sichuan great earthquake (*March 2009*)

Four years after the completion of the Koyna Dam in India's Maharashtra State in 1963, the surrounding area experienced a magnitude 6.5 earthquake. Because the region is free of active tectonics, the earthquake was a surprise. The possibility that it could be linked to filling of the reservoir behind the Koyna Dam became a proven fact when the region subsequently became plagued by minor seismicity. In the immediate aftermath of the magnitude 7.9 Wenchuan earthquake in Sichuan, China on 12 May 2008, which killed 80 thousand people, there were alarms about the possible failure of weakened dams and lakes blocked by landslides in the Longmen Shan mountains. But now suspicion has fallen on the earthquake having been caused by the load that filling a new reservoir created only 5 km from the epicentre and 500 m from the fault that failed during the disaster (Kerr, R.A. & Stone, R. 2009. A human trigger for the great quake of Sichuan? *Science*, v. **323**, p. 322; DOI: 10.1126/science.323.5912.322). Calculations of the stress from this loading suggest that it was 25 times that of the tectonic stresses in the region.

Detecting natural asbestos hazards (*September 2009*)

All forms of asbestos (various serpentines and some amphiboles), but especially the blue variety, are carcinogenic because their dusts consist of minute fibres. Most publicity about the hazard that this mineral presents is from cases that stem from its use as an insulator in housing, shipbuilding and other constructions in developed countries. Areas where it has been mined or outcrops naturally are equally risky if wind can pick up asbestos dust under dry conditions. A large proportion of this now banned industrial mineral was mined in South Africa and many cases of asbestosis and mesothelioma in former mining areas have come to light there since the fall of apartheid. The locations of former asbestos mines are well known, and some attempts are being made to bury the waste. The most tragic cases are where the mining companies have either folded or been engulfed by larger transnational corporations; several legal actions for compensation have been dragging through the courts for a decade or more. However, asbestos minerals are common at what were non-commercial levels in many ultramafic rocks. Such rocks occur in ophiolite complexes and Archaean greenstone belts on every continent, and although ultramafics are in a minority as regards rock outcroppings, they are far from rare. In its natural state such land can shed asbestos-rich dust when dry and urban and communications developments expose the material to wind action.

Asbestos minerals fortunately have distinctive infrared spectra in the short-wave infrared (SWIR), preferentially absorbing photons at around 2.3 micrometres because of their abundance of magnesium-oxygen bonds that such wavelengths cause to vibrate. Remote sensing is therefore a potentially useful means of screening areas of human habitation for asbestos risks (Swayze, G.A. *et al*. 2009. Mapping potentially asbestos-bearing rocks using imaging spectroscopy. *Geology*, v. **37**, p. 763-766; DOI: 10.1130/G30114A.1). The authors, from the US Geological Survey and the California Department of Conservation, used a sophisticated and costly form of aerial remote sensing that covers the visible and infrared part of the EM spectrum with hundreds of narrow-wavelength bands: so-called hyperspectral imaging. It is possible to highlight areas containing asbestos minerals by matching the measured and mapped surface spectra with laboratory standard spectra of the pure minerals. In the case of the test area in northern California, where suburban expansion is likely to occur or has done already, the geology is known in some detail and the expensive airborne hyperspectral surveys could be focused. The approach gave results sufficiently accurate for preventive measure to be taken; not only for asbestos-rich bare soils, but also the specific kind of vegetation that ultramafic soils encourage.

There is another, far cheaper means of assessing asbestos risks that is not so accurate, but capable of covering very large areas of poorly known geology, especially in less well-off parts of the world. This uses the satellite remote sensing conducted by the US-Japanese ASTER instrument carried on NASA's Terra satellite. ASTER data include 5 narrow wavebands that bracket the 2.3-micrometre part of SWIR, so that it is capable of assessing the distribution of ultramafic rock outcrops using software similar to that for hyperspectral data. The USGS/California DoC survey could have tested ASTER data to see how effective it would be if more costly airborne data was unaffordable. Sadly the team didn't foresee how a local test of concept might benefit a great many areas elsewhere by using an ASTER scene that would cover their entire study area, be free to USGS scientists and cost only US$85 for anyone working in the Third World.

Nuclear waste: planning blight writ large (*September 2009*)

The artificial radioactive isotopes generated in nuclear fission reactors have half lives that range from days (^{131}I) to a few million years (^{135}Cs). They pose a thorny problem for disposal since the radiation that they emit collectively is likely to reach 'safe' levels only after tens to hundreds of thousand years, even if they were diluted by leakage into air or water or onto the land surface. They have to be contained, and that demands storage in rock. More over, underground disposal sites must ensure no leakage for geologically significant periods – a great many rare events, such as magnitude 9 earthquakes, large volcanic upheavals and rapid climate changes all become increasing likely the longer the delay time. Apart from Sweden and Finland, no country that uses nuclear energy has a deep disposal site. The focus has been on the temporary measure of reprocessing, and one major facility, that at Sellafield in the UK, is to close down.

In 1987 the US Congress designated only one potential site for investigation as a place for long term water storage in their vast, geologically diverse country: Yucca Mountain in Nevada. The reasoning was that the area is remote and arid, and not so far away from highly secure military sites, so it could be guarded unobtrusively. After 30 years of investigation, Yucca Mountain has been abandoned, with no equally-well researched fallback site (Ewing, R.C. & von Hippel, F.N. 2009. Nuclear waste management in the United States – starting over. *Science*, v. **325**, 151-152; DOI: 10.1126/science.1174594). From a geological standpoint, that is not so surprising as Nevada is seismically active; there has been volcanism in the not-so-distant past, it does have groundwater, and that is present in the volcanic ash proposed for storage. Moreover, the water is oxidising and uranium in spent nuclear fuel easily dissolves under those conditions – storage was to be in titanium casks. Clay saturated in anoxic water is a better bet, while the Scandinavian approach seems safer still: galleries and boreholes in dry crystalline basement rock with canisters packed in clay.

Yucca Mountain has been wrangled over for 3 decades, and one component in its abandonment was a change in the proposed 'regulatory period' from 10 thousand to a million years. How compliance might be demonstrated for a period five time longer than our species has existed, and 500 time longer than the length of the Industrial Revolution is something of a problem for bureaucrats, as of course is judging the cost and time for decommissioning obsolescent nuclear plant. If nuclear energy is to play any role in cutting carbon emissions, the volume of nuclear waste is set to rise enormously, but this does not seem to concentrate the regulatory group mind wonderfully.

See also: Wald, M.L. 2009. What now for nuclear waste? *Scientific American*, v. **301** (August 2009), p. 40-47.

Methane: the dilemma of Lake Kivu (*September 2009*)

A massive discharge of carbon dioxide from the small but deep Lake Nyos in Cameroon in 1986 killed 1700 local people after a small earthquake and landslide disturbed the bottom water. The lake is stagnant, and carbon dioxide released by exhalation from deep magma chambers beneath it had dissolved under pressure in in deepest levels. Once disturbed, the gas came out of solution to reduce bottom water density so a large volume rose to blurt out deadly gas in the lake's immediate surroundings. Lake Kivu in the western branch of the East African Rift system borders the Democratic Republic of Congo (DRC) and Rwanda.

Methane extraction rig on Lake Kivu, DRC. (Credit: Wikipedia)

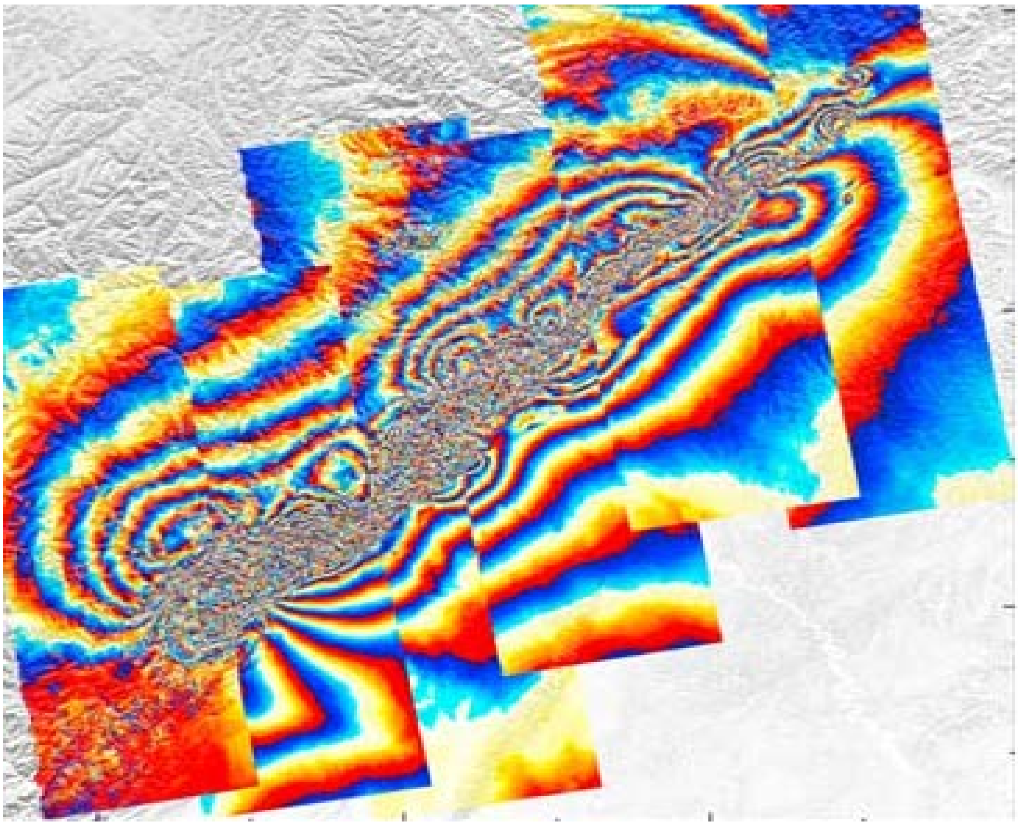
With an area of 2700 km^2 and a depth of over 400 m it is far larger than Lake Nyos, but similar in having stagnant water below a depth of about 75 m, in which gases are dissolved under pressure. Lake Kivu contains an estimated 256 km^3 of carbon dioxide derived from magmas beneath the Rift and 65 km^3 of methane that probably arises by anoxic bacterial reduction of the CO_2. Cores into Lake Kivu's sedimentary floor indicate massive biological die-offs at roughly millennial intervals, which probably result from magmatic destabilisation of the gas-rich lower waters. Experimental vent pipes have been installed in Lake Nyos and nearby Lake Monoun to remove gas from the deep water (see *Taming Lake Nyos, Cameroon* and *Letting Cameroon's soda-pop lakes go flat* April 2001 and March 2003, respectively), but such a solution for the much larger Lake Kivu would be far less predictable and extremely expensive (Nayar, A. 2009. A lakeful of trouble. *Nature*, v. **460**, p. 321-323; DOI: 10.1038/460321a). Energy companies based in DRC and Rwanda are now starting to use the 'soda siphon' approach that relieved Cameroon's deadly lakes to capture the methane potential in Lake Kivu. Perhaps that will dampen down the lake's potential for explosive gas surges, but no one knows if it could instead destabilise its uneasy equilibrium. Furthermore, the deep cool water is nutrient rich and may set off planktonic blooms in Lake Kivu's surface waters. DRC is notorious for bandit mining and politics and security even more unstable than the lake that it shares with its tiny neighbour Rwanda. Population density on the lake's shore, always high because of the fisheries and agricultural potential, rose explosively in the aftermath of the Rwandan genocide of 1994.

Fast-moving rhyolite magma (*November 2009*)

Highly fractionated, silica-rich magma poses the greatest danger of explosive volcanic eruption, characterised by glowing pyroclastic flows that produce the strange rock ignimbrite. For example, in the Andes, ignimbrites extend for large distances from the calderas that emitted them. Fortunately rhyolite eruptions are rare, but that poses a scientific problem – they have not been as well studied as more common magmatic phenomena. Until May 2008 the latest rhyolite eruption had been in Alaska during 1912. In

2008 the Chilean volcano Chaitén erupted for the first time in 9 thousand years. There was no warning. Andesitic and dacitic volcanoes are restless for months before an eruption, though that is not much comfort as exactly when they 'go off' is still unpredictable. But any warning helps prepare local populations for the worst. A volcanoes precursory rumblings and shakings reflect the slow upward movement of magma. In the case of Chaitén, magma rose at about 1 m s^{-1} that flabbergasted the volcanologists who rushed to study such a rare event (Castro, J.M. & Dingwell, D.B. 2009. Rapid ascent of rhyolitic magma at Chaitén volcano, Chile. *Nature*, v. **461**, p. 780-783; DOI: 10.1038/nature08458). The magma rose 5 km from its source in less than 4 hours. It is generally thought that the more silicic magma is, the more viscous and sluggish, which is certainly the case for rhyolite when it emerges: the melting of impurities in a coal fire produces a very silica-rich melt but such slag certainly does not dribble out of the fire box to pool on the hearth. High viscosity allows an erupting magma to retain gas escaping from solution as pressure drops, which is the source of the catastrophic blasts of massive ignimbrite events. Below the surface the Chaitén magma behaved in an extremely fluid manner, perhaps because it contained so much dissolved gas that it became a fluid froth at quite shallow depth. This unique observation is deeply disturbing for populations living in areas blanketed by ancient ignimbrites, as in the Andes. The very worst terrestrial events imaginable are ignimbrite eruptions that can blast out at such high velocities as to groove the ground and carry over thousands of km^2 in matter of minutes. Without warning, there is no escape.

Wenchuan earthquake (May 2008) analysed



Radar interferogram along the Longmenshan thrust around Wenchuan, China. Each of the the blue to red fringes are equivalent to a ~12 cm horizontal shift due to the earthquake. (Credit: Zhang, 2008; Fig. 2)

On 12 May 2008 a magnitude 7.90 earthquake killed more than 80 thousand people and left many more injured and homeless in the Wenchuan area of Sichuan province China. In the worst affected areas up to 60% of the population were killed. The catastrophe occurred at the densely populated western boundary of the Sichuan basin with the Tibetan Plateau, and involved surface displacement that propagated rapidly north-eastwards along a 235 km long zone. There was virtually no warning sign and although crossed by major faults, high-magnitude seismicity was a rarity in the area. Several satellites now repeatedly deploy synthetic aperture radar sensing along their ground swath, so that interferometric methods (InSAR) are able to assess ground motions between separate times of overpass, with sub-centimetre precision. Together with direct measurement of motions at GPS ground stations, InSAR allows an unprecedented 'post-mortem' of this dreadful event (Shen, Z-K *et al*. 2009. Slip maxima at fault junctions and rupturing of barriers during the 2008 Wenchuan earthquake. *Nature Geoscience*, v. **2**, p. 718-724; DOI: 10.1038/NGEO636). The structural architecture of the surrounding area is of five fault-bounded blocks that jostled during the event, resulting in profound shifts in the geometry of motion along two parallel faults that ruptured. The event was so sudden and large because what would otherwise have been barriers to propagation of strain failed at the same time. All the strain cascaded through several fault segments. This is not a scenario that could have been easily predicted, the authors judging it to have been a once-in-4000 years concatenation of crustal failure.

Seismic unpredictability is something that seismologists now recognise (Chui, G. 2009. Shaking up earthquake theory. *Nature*, v. **461**, p. 870-872; DOI: 10.1038/461870a). Active faults turn out not to be 'creatures of habit', and nor can we assume that long-quiet segments are the most likely to fail in future. Ominously, there is a growing body of evidence that great earthquakes are able somehow to trigger others, often far distant. An example is the giant Sumatra-Andaman event of 26 December 2004, tsunamis from which caused a toll of hundreds of thousand lives around the Indian Ocean. It was followed quickly by swarms of small tremors on the San Andreas Fault 8000 km away. Rapid successions of great earthquakes around the world, such as the October 2005 Pakistan earthquake 9 months after that in the Indonesian area, can no longer be regarded as 'bad luck'. Seismic waves are able to weaken far-off segments of active faults.