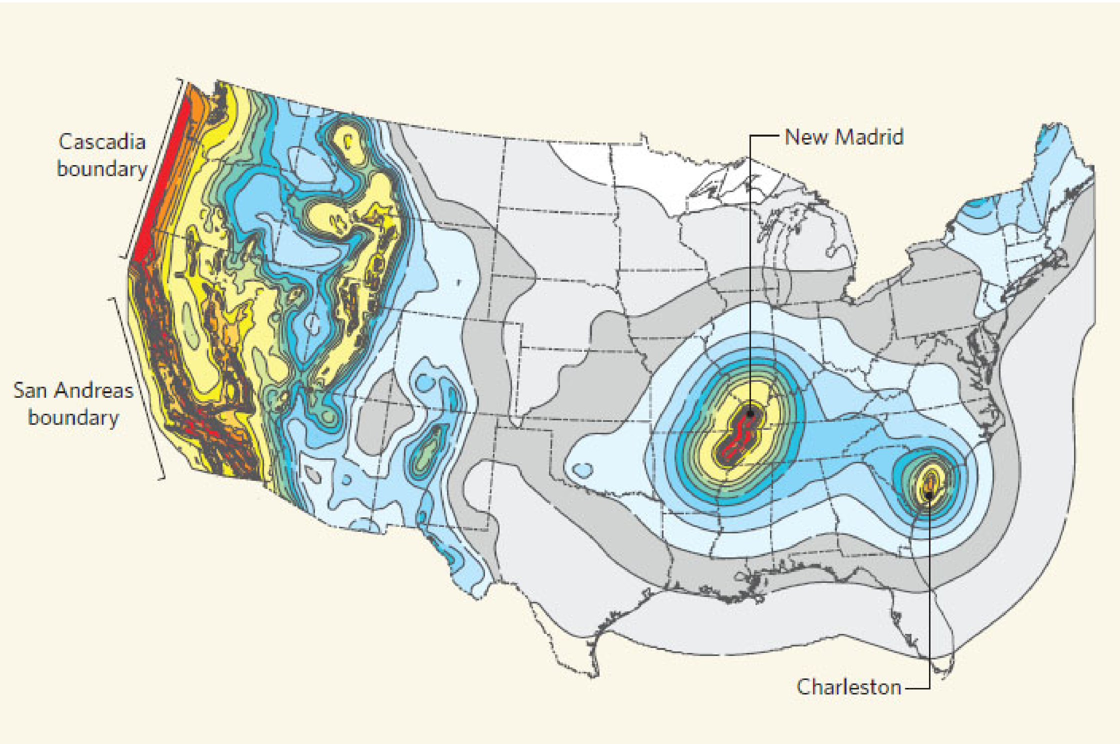
Geohazards

Mid-continent earthquakes: warnings or memories? (*January 2010*)

Perhaps the most infamously unexpected earthquake was that of 17 December 1811 that shook the historically quiescent middle Mississippi valley with an estimated magnitude of 7 on the Richter scale. The area centred on New Madrid has been resonating with seismic events of lesser magnitude ever since. So too has the area around Charleston, South Carolina on the passive Atlantic margin of the USA, which experienced a magnitude 7 earthquake in 1886. Geophysicists now know to expect major earthquakes at some time in some place along active plate margins, especially subduction zones and boundaries dominated by strike slip motion, although prediction is an art to be learned, if indeed it will ever be possible. Yet even small tremors far from plate boundaries within continental parts of plates are a continual worry. The shock of totally unexpected devastation in New Madrid and Charleston makes seismic-risk assessors mark the card of any such events, especially if repeated. Ideally, plate interiors should be rigid and safe. The magnitude 7.9 Sichuan event in May 2008, which caused more than 80 thousand deaths along a fault with no history of activity, reinforced worry. All three examples were situated in areas with old faults, of which most areas of continental crust have plenty, though some are hidden. Somehow tectonic forces had built up and eventually the crust failed.



Seismic risk in the USA (warm colours = high; grey and cool colours = low) showing the New Madrid and Charleston areas. (Credit: USGS)

Protracted activity might seem to foretell more big ‘quakes. However, it now appears that faults in continental interiors behave very differently from those at plate boundaries: aftershocks, even some with magnitude 6, continue for centuries in the first case, but only for a few years or decades at tectonically active margins (Stein, S. & Liu, M. 2009. Long aftershock sequences within continents and implications for earthquake hazard assessment. *Nature*, v. **462**, p. 87-89; DOI: 10.1038/nature08502.). The duration of aftershocks in inversely related to the tectonic load sustained by faults. A lesson suggested is that assigning high risk to continental areas with repeated seismicity overestimates the dangers. But does this mean those seismically stable areas in continental interiors pose underestimated risks? The answer is probably 'Yes', if they are near to old faults. That is not to say that the Caledonian and Variscan structures that divide Britain into many small blocks are about to 'go off' at any time. Some do generate small, noticeable tremors such as that beneath Market Weighton in east Yorkshire at 1 am on 27 February 2008 that woke people up to several hundred kilometres away (including me). Market Weighton was an area of reduced subsidence during Jurassic sedimentation, as a result of flanking Variscan faults in the crust beneath. However, if large structures – high-rise buildings, bridges, dams and power stations – are planned, it would be wise to look in detail at local faults. One approach is to map disturbance of superficial sediments that in Britain would show activity over the last 18 to 11 thousand years since ice sheets melted. Another is to check bedrock geology for the last major movements on faults. It may become possible to develop models of seismic cyclicity for all large structures to give realistic assessments of risk in the future.

See also: Parsons, T. 2009. Lasting earthquake legacy. *Nature*, v. **462**, p. 42-43. [see link for Stein & Liu, 2009]

2010: already a terrible year for disaster (*March 2010*)

Early 2010 witnessed horrific scenes on Haiti following a magnitude 7.0 earthquake on the afternoon of 12 January to be followed on 26 February by one of the largest ever recorded in Chile (magnitude 8.8). Haiti has suffered fatalities on a scale that match those of the Indian Ocean tsunamis of 26 December 2004, while a huge area of coastal Chile affected by seismic energies more than a hundred times greater had estimated fatalities of over 700, though rising at the time of writing. It is easy to ascribe the relative magnitudes of human tragedy, which are the opposite of the relative seismic magnitudes – entirely to the more advanced infrastructure of one of South America's most advanced countries compared with that of one of the world's poorest. But that is not the full story. Haiti suffered from a shallow event very close to major population centres whose energy easily reached the surface. The fault responsible involved transverse horizontal movements that sheared through soft coastal sediments that liquefied beneath Port au Prince. That offshore of Chile was much deeper, on a subduction zone and involved vertical movements, so much of its energy was dissipated deep in the crust, yet the area of structural damage along Chile's narrow coastal fringe is much larger than in Haiti.

Sure, Chile has long had stringent regulations for seismic safety of construction and a policy of emergency preparedness commensurate with its history of devastating earthquakes, including the largest ever recorded on 26 May 1960 with magnitude 9.5 that released ~32 times more energy than the recent one. It is a country well-endowed with income from its huge mining operations, well-developed wineries and much else, especially foreign investment. Haiti has nothing but the horrifying reputation of a string of governments. Until the recent tragedy the majority of its people were left to fend for themselves, close to the playgrounds of the super-rich and the offshore hidey holes of 'non-doms'. Yet survivors in both countries face essentially the same physical privations of having to live rough and the lasting horror that no amount of wealth can remove. After experiencing the great Valdivia earthquake of 20 February 1835, also in Chile, Charles Darwin observed,

'*An earthquake like this at once destroys the oldest associations; the world, the very emblem of all that is solid, moves beneath our feet like a crust over fluid; one second of time conveys to the mind a strange idea of insecurity, which hours of reflection would never create*.'

In both cases lessons may be learned, some socio-economic that are too obvious to repeat here. There is, though, one of a kind that transcends most of the others: the 21st century's first decade has seen a seismic death toll of 640 thousand; a fourfold increase over the previous 20 years fatalities. That is a reflection of increasing drift of especially poor people to cities. If their dwellings are easily smashed they stand little chance. So far, the pledges of aid for reconstruction in Haiti amount to about US$5000 for each damaged structure; a pittance. For geoscientists, however, what is beginning to emerge from these and the various large earthquakes in Indonesia, Pakistan and China since 2004 is that past seismic history is a clue to future events.

Faults zones behave in a segmented fashion, each with its own crude cyclicity but each somewhat prone to being triggered by events from nearby sectors. Between 1750 to 1770 Haiti was repeatedly devastated when the culprit fault unleashed its pent up stresses. Since then it has been locked in the vicinity of Haiti, with tectonic motions of about 8 mm per year accumulating to the 2 m or so motion undergone by the fault on 12 January. Subduction zones accumulate strain in many sectors distributed along the plate boundary, sometimes locking as seamounts start to descend to 'clog' them. Statistical analysis of historical earthquakes and locating their probable epicentres in relation to fault segments, with estimates of their power that would now be measurable from seismograph data, can at least highlight future risk geographically even if timely predictions remain impossible. Yet will there be action that matches up to the potential hazard? 2000 years ago the destruction of Pompeii and Herculaneum in the Bay of Naples by Vesuvius was recorded in graphic detail of which the excavations presented a gruesome reminder. Yet Naples expands to urbanise the very slopes of Europe's most dangerous natural threat.

See also: Bilham, R. 2010. Lessons from the Haiti earthquake. *Nature*, v. **463**, p. 878-879; DOI: 10.1038/463878a.

Ash Wednesday (*May 2010*)

On 14 March 2010 the Icelandic volcano Eyjafjallajökull conspired with a major kink in the stratospheric jet stream, itself a possible outcome of 'quiet Sun' conditions, to load the lower atmosphere with its ash cloud. The cloud arrived over most of Europe the following day with outcomes that need no mention here.

Researchers collected samples from the plume over Britain, finding particles mainly of the order of 0.1 mm diameter ranging up to 3 mm. The larger particles account for much of the mass of suspended ash (Sanderson, K. 2010. Questions fly over ash-cloud models. *Nature*, v. **464**, p. 1253; DOI: 10.1038/4641253a), but that amounted to only 60 mg m^{-3} in the air over Britain compared with a 'danger level' of 2000 mg m^{-3} declared by the Civil Aviation Authority. That volcanic ash – and presumably dust from sand storms – is hazardous to aircraft is a truism, but little is known about the actual processes involved.

At the speed of modern jet aircraft, mineral or glass dust sandblasts flight deck windscreens, may damage or clog the tubes used to measure airspeed, build up electrostatic charge to interfere with communications and may melt to coat turbine blades. Two near-catastrophic encounters of Boeing 747 passenger aircraft with ash clouds in the 1980s formed the basis for precautionary halting of all air traffic over most of Europe in mid-April 2010. In both incidents all four engines overheated and cut out, as the ash melted onto turbine blades and prevented them cooling. Fortunately, descent below the ash cloud cooled and shattered the glass coating so that the engines could be restarted. However, unbalancing of the turbines potentially could have caused them to jam irreversibly. Jet engines run at around 1400º C so can potentially melt ash of any composition: at atmospheric pressure the melting temperature of both felsic and basaltic materials is 1000-1200º C. Both the 1980s incidents occurred suddenly in thick ash plumes close to volcanoes, in which ash particles would have been larger than those in the dispersed cloud over Europe in April 2010. Little is known about how melted ash might accumulate in and damage turbines during prolonged flight through very dispersed, ultra-fine-grained ash clouds.

Disruption of aviation schedules is just one continental-scale hazard from Icelandic volcanoes. In the summer of 1783 an eruption of Laki, a fissure volcano further inland, killed 80% of Iceland's sheep, 50% of other livestock and by the end of the year 25% of its human population. The magma was enriched in fluorine and among the emitted gases was hydrogen fluoride that reacted with ash to form metal fluorides that coated vegetation across wide tracts of the island. Ingesting fluorides leads to fluorosis, a crippling disease to which sheep and cows are especially prone. Most of the human victims probably died of starvation. However, archaeologists who exhumed burials from the time of Laki's last devastating eruption found skeletal signs of fluorosis: bony nodules and spiky fibres in joints (see *Archaeology and fluorine poisoning* December 2004). It is a repeat of Laki's toxic ash eruption that Icelanders most fear. During 1783 there were widespread reports from northern Europe of a bluish, acrid smelling haze, probably rich in sulfur dioxide. Contrary to the cooling effect of sulfuric acid aerosols in the upper atmosphere, this acrid fog seems to have warmed the regional summer to possibly the hottest in several centuries. Followed by a bitterly cold winter, Laki's distant effect was devastation of crops, famine and deaths from starvation. It was not restricted to Europe, drought and famine affecting Egypt, India and Japan at the same time, with an estimated global death toll of more than 2 million. This suggests that some of the sulfur dioxide did become trapped in the stratosphere as climatically cooling sulfuric acid droplets that spread over the whole Northern Hemisphere. There are few records of wind patterns from the mid 1780s, yet the filling of Europe's skies with Icelandic dust in 2010 suggests that a similar, wind system prevailed in 1783 – clockwise from Iceland around a large anticyclone centred on western Britain.

When the Eyjafjallajoekull volcano last erupted in 920, 1612, and 1821-1823, the much larger subglacial volcano Katla, 25 km to the east, followed suit. Around 10 600 years ago Katla emitted 6 to 7 km^3 of ash, recognisable in Scotland, Norway and in North Atlantic sediment cores. Many Icelanders regard Katla as potentially their most dangerous volcano.

Arsenic update (*July 2010*)

Partly because of natural processes and partly due to a shift to avoid pathogens in surface water used for domestic to a massive well-drilling programme much of rural Bangladesh and neighbouring West Bengal in India found itself the epicentre of 'the largest mass poisoning of a population in history', during the 1990s. The agent was soluble arsenic in various forms that reducing conditions in shallow aquifers had released by dissolving its host mineral, iron hydroxide coatings on sand grains. Geological and hydrological attributes of the two hard-hit areas helped develop a model for assessing the risks in other areas. More than a decade on from the world-wide recognition of the tragedy (local geoscientists had their suspicions much earlier) a review of arsenic hazard in both South and Southeast Asia (Fendorf, S. *et al*. 2010. Spatial and temporal variations of groundwater arsenic in south and south-east Asia. *Science*, v. **328**, p. 1123-1127; DOI: 10.1126/science.1172974) is welcome but is not reassuring. The problem now extends to plains of the whole of the Ganges-Brahmaputra-Meghna system, the Red River of Vietnam and the Mekong of Vietnam, Cambodia, Laos and part of Thailand.

Almost certainly the Indus and Irrawaddy plains are affected too, though few data are available. The review highlights a haphazard aspect of the distribution of affected wells, both in geographic location and the depth of the tapped aquifer. In the latter case, it was thought that deeper aquifers were less prone to contamination than those in the top 100 m of wells. It turns out that even at depth up to a third of wells exceed WHO recommended levels of arsenic. The positive feature is that many villagers are within walking distance of safe well water. But it is difficult to predict whether or not new wells will be risky, and little is know about safe well's propensity to become contaminated by groundwater flow from elsewhere. Two clear messages are, first to refine methods of testing and assessing hydrogeological conditions, second to move from hand drawn water from individual wells to provision of piper water from high-yielding safe wells.

The anatomy of a small landslip (*September 2010*)

At the centre of the Peak District National Park in England is a small mountain called Mam Tor, at the summit of which is a large Iron Age fort complete with defensive ramparts and ditches. Complete, that is, except for its southern parts, which are chopped through by a large arcuate cliff. Below that is hummocky ground typical of landslips, but such disturbed ground is common over large tracts in the Peak District that lie below hills, especially those underlain by Lower Namurian shales of the region. Mam Tor is the only one of these that has an active landslip. Since my early childhood the local authority has tried to keep trafficable a once major road linking the cities of Sheffield and Manchester, but to no avail; most winters it was buckled and cracked by continued motion. The road was abandoned in 1979 and is now a magnificent laboratory for judging the kind of motion involved in the Mam Tor slip. The Iron Age people had much the same problem, as the slip began around 1500 BC long before the fort was built. Clearly, they were not engineering geologists, though the unclimbable scar was maybe a defensive bonus, provided the old, the bewildered and the very young were kept well away from it, as they are today.

Records of the movement have been kept since the road was constructed in 1820, and one milestone has moved 50 m in 190 years at a constant annual rate, but just how it moves has only become clear since Manchester University geologists installed tilt and creep meters, and 50 survey stations in 2004-5. Their preliminary results are just in (Green, S. *et al*. 2010. The effects of groundwater level and vegetation on creep of the Mam Tor landslip. *Geology Today*, v. **26**, p. 134-139; DOI: 10.1111/j.1365-2451.2010.00759.x).

NE view of the Mam Tor landslip – note the breached Iron Age fort. (Credit: Google Earth)

Collapsed road beneath Mam Tor (Credit: British Geological Survey)

The creep rate is clearly governed by groundwater level beneath the slip, and has risen as high as 19.5 mm per day. From the logarithmic plot between the two variables it is possible to estimate the creep rate with completely saturated ground, which would be an ominous 0.6 m per day. Thankfully, drainage through the slip is good, as beneath lie highly unstable mudstones; but things could change. The team has also monitored local rainfall, and precipitation underwent a marked increase from 2000 onward (1.64 m per year) compared with the average since 1930 of 1.3 m per year. Fortunately, spring and summer rains are quickly returned to the atmosphere by vigorous evapotranspiration by the lush grasses and ferns on the slipped mass. The greatest creep takes place in the winter when vegetation has died back. Mam Tor is indeed highly instructive, although it poses no great hazard at present. Yet it might become less predictable should annual rainfall increase. In any event it is unlikely to attain the awesome pace of that in Calabria, southern Italy on 15 February 2010 at Maierato near Vibo Valentia.