Geohazards

A supervolcano's plumbing system (*November 2014*)

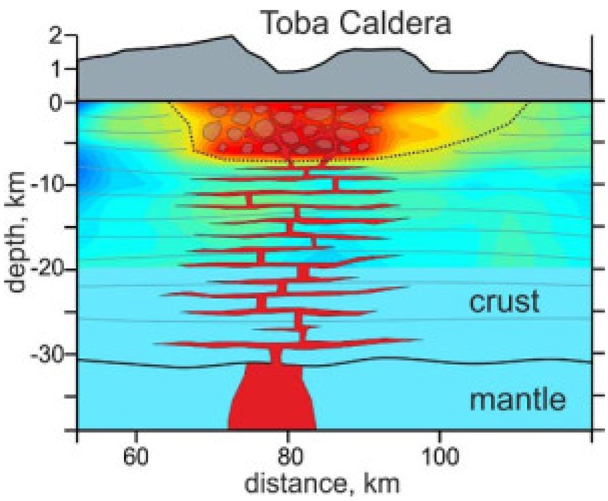
What was the most devastating natural disaster ever to face humans? It would be tempting to suggest the Indian Ocean tsunami of 26 December 2004, but that is because most people remember it with horror. In fact the worst the Earth ever flung at us was much further back in our history and left a huge spike of sulfates in the Greenland icecap at around 73 thousand years ago. This relic of volcanic aerosols that had blasted into the stratosphere was tracked back to a 100 by 30 km caldera in Sumatra now occupied by a lake (Lake Toba) that is 500 m deep in places and almost filled by a slightly off-centre island. The eruption explosively ejected 2800 cubic kilometres of magma, of which an estimated 800 km^3 fell as ash across a wide swath of the tropics westwards of Sumatra at least as far as Arabia and East Africa (see *Toba ash and calibrating the Pleistocene record* Human evolution etc. December 2012); the line of march taken by anatomically modern humans migrating from Africa. In India and Malaysia the Toba ash layer reaches 5-10 m thickness and probably occurs undetected as a thin layer across the entire tropics. Around 10^{10} tonnes of sulfuric acid belched out, some to enter and linger in the stratosphere, which is estimated to have caused an average decrease in average global temperatures of 3.0 to 3.5 °C for several years. Studies of human mtDNA hint at a genetic bottleneck around the time of Toba's eruption and a large decrease, perhaps as much as 60%, in the global population of *Homo sapiens*. But humans survived or quickly filled devastated land in India, where stone tools are found both below and just above the Toba ash layer.

Landsat image (120 km across) of Lake Toba, the largest volcanic crater lake in the world. (credit: Wikipedia)

The largest volcanic eruption in the last 26 Ma, there can be little doubt that no other natural catastrophe had as large an influence on humanity as did Toba. Of course, slower processes such as climate change and ups and downs of sea level lay behind the repeated spread of humans out of Africa and probably their evolution as a whole. The drama of the Toba event has drawn attention to the massive risk posed by supervolcanoes in general, such as that centred on Yellowstone in the NW US, which show signs of activity 640 ka after its last major explosive event. Toba certainly is not dead, for its peculiar island of Samosir has been uplifted steadily since the eruption by about 450 m, probably due to influx of magma deep beneath the surface, and experiences shallow earthquakes. What lies in the guts of supervolcanoes is literally a hot topic and a new 3-D imaging method has been applied to Toba.

Traditional village on Samosir island, Lake Toba. (credit: Wikipedia)

Seismic tomography that uses background or ambient seismic noise (see *Probing the Earth's mantle using noise* Planetary science December 2012) has become a powerful technique for studying the crust and lithosphere when small-amplitude short-wavelength Rayleigh and Love surface waves are monitored to pick up subsurface reflecting bodies and measure variation in wave speed with depth. The greater the density of seismometers deployed, the finer the resolution of deep crustal features and 40 such detectors are in place around Lake Toba. A team of Russian, French and German geophysicists have reported new results bearing on how magma may be accumulating beneath the vast caldera (Jaxibulatov, K. *et al*. 2014. A large magmatic sill complex beneath the Toba caldera. *Science*, v. **346**, p. 617-619; DOI: 10.1126/science.1258582). Down to about 7 km the tomography has picked up a structurally homogeneous low-speed zone directly beneath Samosir Island that the authors attribute to the 73 ka explosive eruption. Beneath that several magma sills appear to dominate the sub-caldera crust, possibly responsible for the post eruption uplift within the caldera: the precursor to a layered intrusive body and each an increment towards a further huge eruption.



Interpretation of seismic tomography cross section of Toba. Greens to reds show increasingly negative shear speed anomaly showing magma sills in lower crust and 74 ka damage zone above 7 km. (credit: Jaxibulatov et al. 2014)

Judging earthquake risk (*December 2014*)

The early 21st century seems to have been plagued by very powerful earthquakes: 217 greater than Magnitude 7.0; 19 > Magnitude 8.0 and 2 >Magnitude 9.0. Although some lesser seismic events kill, those above M 7.0 have a far greater potential for fatal consequences. Over 700 thousand people have died from their effects: ~20 000 in the 2001 Gujarat earthquake (M 7.7); ~29 000 in 2003 Bam earthquake (M 6.6); ~250 000 in the 2004 Indian Ocean tsunami that stemmed from a M 9.1 earthquake off western Sumatra; ~95 000 in the 2005 Kashmir earthquake (M7.6); ~87 000 in the 2008 Sichuan earthquake (M 7.9); up to 316 000 in the 2010 Haiti earthquake (M 7.0); ~20 000 in the 2011 tsunami that hit NE Japan from the M 9.0 Tohoku earthquake. The 26 December 2004 Indian Ocean tsunamis spelled out the far-reaching risk to populated coastal areas that face oceans prone to seismicity or large coastal landslips, but also the need for warning systems: tsunamis travel far more slowly than seismic waves and , except for directly adjacent areas, there is good chance of escape given a timely alert. Yet, historically, deadly risk is most often posed by earthquakes that occur beneath densely populated continental crust. Note that the most publicised earthquake that hit San Francisco in 1906 (at M 7.8) that lies on the world's best-known fault, the San Andreas, caused between 700 and 3000 fatalities, a sizable proportion of which resulted from the subsequent fire. For continental earthquakes the biggest factor in deadly risk, outside of population density, is that of building standards.

A poor neighbourhood in Port au Prince, Haiti following the 12 January 2010 earthquake – magnitude 7.0 on the Richter scale. (credit: Wikipedia)

It barely needs stating that earthquakes are due to movement on faults, and these can leave distinct signs at or near to the surface, such as scarps, offsets of linear features such as roads, and broad rises or falls in the land surface. However, if they are due to faulting that does not break the surface – so-called 'blind' faults – very little record is left for geologists to analyse. But if it is possible to see actual breaks and shifts exposed by shallow excavations through geologically young materials, as in road cuts or trenches, then it is possible to work out an actual history of movements and their dimensions. It has also become increasingly possible to date the movements precisely using radiometric or luminescence means: a key element in establishing seismic risk is the historic frequency of events on active faults. Some of the most dangerous active faults are those at mountain fronts, such as the Himalaya and the American cordilleras, which often take the form of surface-breaking thrusts that are relative easy to analyse, although little work has been done to date. A notable study is on the West Andean Thrust that breaks cover east of Chile's capital Santiago with a population of around 6 million (Vargas, G. *Et al*. 2014. Probing large intraplate earthquakes at the west flank of the Andes. *Geology*, v. **42**, p. 1083-1086; DOI: 10.1130/G35741.1). This fault forms a prominent series of scarps in Santiago's eastern suburbs, but for most of its length along the Andean Front it is 'blind'. The last highly destructive on-shore earthquake in western South America was due to thrust movement that devastated the western Argentinean city of Mendoza in 1861. But the potential for large intraplate earthquakes is high along the entire west flank of the Andes.

Vargas and colleagues from France and the US excavated a 5 m deep trench through alluvium and colluvium over a distance of 25 m across one of the scarps associated with the San Ramon Thrust. They found excellent evidence of metre-sized displacement of some prominent units within the young sediments, sufficient to detect the effects of two distinct, major earthquakes, each producing horizontal shifts of up to 5 m. Individual sediment strata were dateable using radiocarbon and optically stimulated luminescence techniques. The earlier displacement occurred at around 17-19 ka and the second at about 8 ka. Various methods of estimation of the likely earthquake magnitudes of the displacements yielded values of about M 7.2 to 7.5 for both. That is quite sufficient for devastation of now nearby Santiago and, worryingly, another movement may be likely in the foreseeable future.