Two Notable Earthquakes in 2008

John Carney, John Aram and Tony Waltham

Abstract: Reports on this year's very modest earthquake in Market Rasen, Lincolnshire, and the much larger event in Sichuan, China.

The Market Rasen earthquake

by John Carney

On the 27th February 2008, at 00:56 GMT, an earthquake occurred in Lincolnshire, the trace of which was recorded on BGS seismograms (Fig. 1). It was felt throughout the East Midlands and across England and Wales, with the most distant reports coming from Aberdeen, Truro and Ireland (Fig. 2). Most people would have been asleep at that time and the reason for our apparent alertness may be that the 'felt' part of the event lasted for several seconds, beginning with an audible rumble that would have woken many up. The earthquake was widely reported in the British media, and several TV crews filmed on the same day at places such as Gainsborough, where damage occurred, and also at the British Geological Survey at Keyworth.

The details of the earthquake can be found on the BGS website, some of which is summarised here. Its epicentre (Lat. 53.404° N, Long. 0.331° W) was located approximately 4 km north of Market Rasen. The magnitude is estimated at 5.2 ML, making this the largest earthquake in Britain since a magnitude 5.4 ML earthquake struck North Wales in 1984. Earthquakes of this size occur in Britain roughly every 30 years, so this was a significant event locally. In global terms, however, it was only 'moderate' and one of around 590 earthquakes of this size happening somewhere in the world every year.

In terms of energy released, this event was approximately one million times smaller than the magnitude 9.2 earthquake that triggered the devastating tsunami in the Indian Ocean on 26 December 2004 (each unit of magnitude results in roughly 32 times the energy released - Table 1). Most of the world's earthquakes occur at the boundaries between the Earth's tectonic plates, which are continually moving at a few centimetres per year. This process results in the build up of tremendous stress, which is then released in the form of earthquakes. The British Isles sit in the middle of the Eurasian plate and although we are far from any plate boundary some of this stress is transmitted into the core of the plate, where it combines with stress from other geological processes such as uplift, to create so-called "intraplate" earthquakes.

The Market Rasen earthquake resulted from compression in a NW-SE direction, which culminated in the sudden release of stress on a strike-slip fault some 18.6 km below the surface. This depth is constrained by both nearby and distant instrumental

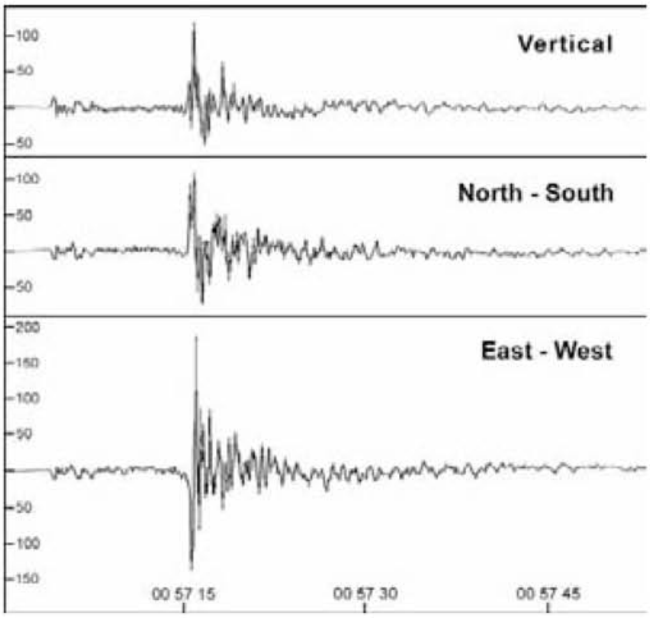

***Figure 1**. The February 2008 event recorded on the Charnwood Lodge siesmogram. The record shows ground displacement on the three directional components, with scales in microns, and times in hours, minutes and seconds (courtesy of BGS Seismology and Geomagnetism section).*

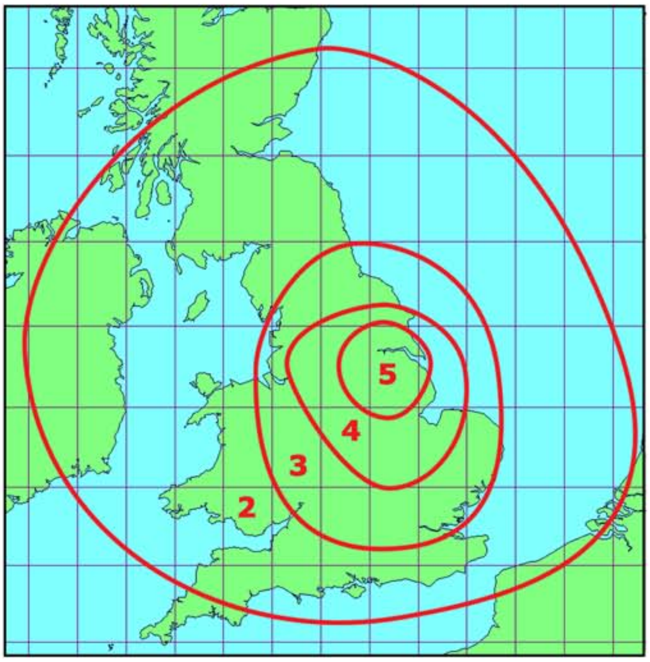

***Figure 2**. Map of the annular zones of earthquake intensity (on the modified Mercalli scale) around the epicentere just north of Market Rasen (after BGS data).*

Relative energy	*Richter Magnitude*	*Example*	*Max Intensity*	*Damage at epicentre*	*Area of influence*
	1 - 3	–	I - IV	Social disturbance, no damage	small
1	4	2008 Market Rasen M4.8	VI	Slight	small (Major earthquake for Britain)
30	5	1979 San Francisco M5.7	VII	Little damage to reinforced concrete	(Minor earthquake for California)
				Severe damage to adobe houses	Intensity VI slight damage to 10 km away
1000	6	2003 Bam (Iran) M6.6	IX	Severe damage to many buildings	Intensity VII damage to 10 km away
30,000	7	2005 Kashmir Pakistan M7.6	X	Major damage to most buildings	Intensity VII damage to 50 km away
1 M	8	1906 San Francisco M7.8	XII	Near-total destruction	Intensity VII damage to 200 km away
30 M	9	2004 Aceh (Sumatra) M9.1	XII	Total destruction (and tsunami)	Intensity X severe damage to 20 km away

Table 1*. Approximate correlations between earthquake magnitude (on the Richter scale) and intensity (on the Mercalli scale), together with the scale and extent of damage caused (from Waltham, 2009).*

recordings of the earthquake, including observations from Canada and Alaska. The Earth's crust under Britain has many such faults, but it would be unusual for an earthquake epicentre to plot directly along a surface fault-line. This is because faults are dipping planes and thus any epicentre, when it is projected vertically upwards, will be displaced to one side of the surface trace of the causative fault. This being so, we can find a structure that may have caused the Market Rasen earthquake. In the vicinity of Market Rasen, very few faults of any significance have been mapped in the Jurassic and Cretaceous rocks that crop out. However, this is misleading, because at greater depths, within the underlying Carboniferous rock sequences, some very large-magnitude structures have been imaged on seismic reflection profiles beneath Lincolnshire. One of these is the Brigg Fault, which trends west-north-west where it lies about 10 km northeast of the epicentre. This fault plane dips to the west-south-west, and a plausible average dip of just over 60° would be sufficient for the epicentre to intersect with the fault plane at 18.6 km depth. At this depth, however, the zone of movement within the fault plane would have affected only sub-Carboniferous, 'basement' rocks, probably of Ordovician age locally.

BGS received reports of damage to chimneys and masonry over a wide area, and Gainsborough furnished instructive examples of the types of incident that resulted. A BGS report (Hobbs et al., 2008) notes that the majority of damage involved chimney stacks and chimney pots. Some remained in a precarious state and these areas were mainly cordoned off to pedestrians and in some cases traffic. All observed damage, with one exception, appeared to have occurred on Victorian terraced properties; the exception being a 1922 terraced property. The report goes on to state that: 'The examples of damage to chimneys are typical and were repeated many times over within the area shown. There were several examples of tiles missing and damaged and a couple of broken out-house roofs. These appeared to have been caused by impact from falling chimneys and subsequent making-safe operations. Examples of wall collapse and fresh cracking of outside building walls were not observed, nor was damage to gable ends and roof ridges. Many chimneystacks showed evidence of disturbance by failure of mortared joints resulting in splaying of the stack; individual bricks having dislodged but the whole remaining in place. In some cases individual chimney pots had rotated and tilted or had fallen leaving the stack largely intact'.

There may be grounds for concern about future earthquakes. This is because, in a country of relatively low seismicity on a global scale, the East Midlands is actually a fairly active region, and some significant earthquakes have occurred before. In recent times, one of the largest documented events was the Derby earthquake (actually centred near to Diseworth), in February 1957. It had a magnitude of 5.3 ML and caused widespread damage, not least to the wall of the Blackbrook Reservoir dam in Charnwood Forest; this is the only heavily engineered structure to have been damaged by an earthquake in Britain. Farther back, in 1185, records show that an earthquake caused serious structural damage to Lincoln Cathedral, which is only 20 km south-west of Market Rasen. That event could have been associated with any of the major buried faults in Lincolnshire, and we can only guess where its epicentre was located, or the depth at which it occurred.

If there is a lesson to be learned this time round, it is to ensure that all brickwork, especially old and ornate chimney stacks, are secure and well pointed. Simple precautions like this would not only protect from a future earthquake comparable to the Market Rasen event, but also from strong gales, which may become increasingly common if certain climate change predictions are fulfilled.

Experiencing the Market Rasen event

by John Aram

Our home is in the village of Fulbeck, beneath the escarpment of the Lincolnshire Limestone, about 40 km SSW of Market Rasen and the epicentre of February's earthquake. Shortly before 1.00 am, Carol and I were awoken from our sleep by a noise that was followed by at least six seconds of violent shaking of the bedroom, the furniture, the creaking doors and everything else. The walls shook strongly, though no plaster fell or was cracked, and the pantile roof over our heads in the old stable building could be heard lifting and falling back several times. As soon as I realised that it was an earthquake, and not a lorry crashing into the house, I started counting seconds, since I remembered this was one of the questions normally asked of the duration of the shaking in seismic events. I counted six seconds, but since the shaking had already started I guess it probably lasted in the region of ten seconds in total.

In the morning we noticed that several pictures were hanging at strange angles, a stack of CDs had fallen over and a framed photograph had fallen over and broken. Going outside I was greeted by a large slab of limestone capping that had fallen from the chimney stack on the main part of the cottage, and now lay on a broken slab of York Stone near the door; bits of broken slate, brick and cement were spread around and onto the lawn (Fig. 3). Just below the brick stack (which was intact, as were the two chimney pots), there was a hole in the slate roof and a broken lath was visible, where the capping stone must have fallen on a corner before rolling or sliding down the roof to hit the ridge of the porch over the front door. Here it broke further, sending a smaller part of the stone to one side, damaging slates on both sides of the ridge tiles before reaching the ground.

The insurance inspectors were kept rather busy in Lincolnshire, and other buildings in Fulbeck were also damaged. An adjacent cottage had part of its brick chimney stack fall away, leaving a chimney pot unsupported and leaning at an interesting angle, while the bricks in the stack of another cottage had also separated. Further damage from the earthquake included the snapping of a wooden post that supported an electric light at the entrance to the village churchyard.

Within the village of Fulbeck, eight houses (out of a total of about 150) suffered minor damage, mainly to their chimney stacks. All eight stand in the higher part of the village where they are founded directly on the Marlstone ironstone, while houses in the lower village suffered no visible damage where they stand on the Lias clay. In classical terms, this is the wrong way round, as earthquake waves are amplified in weaker materials, so that the greatest damage is normally on clays and soils. The key factor is the age of the buildings, and the consequent state of their mortar. The damage was all to the older houses (well over a hundred years old), which are those on the dry ground of the Marlstone, while the newer houses in the lower village suffered less even though they stand on clay. This pattern therefore matches that seen in Gainsborough.

Subsequently I heard several further reports of local earthquake damage, including one of a few centimetres of subsidence of a modern bungalow in the nearby village of Bassingham; this lies on the flood plain of the River Witham, so could be a result of compaction of modern sediments. Further data was gathered while manning a RIGS stand at the Lincolnshire County Show soon after. Two chimney pots had toppled in Doncaster, a fridge and washing machine "walked" out from under the work-top in a scullery in Mablethorpe, an old brick farm building had collapsed at Deeping St Nicholas on the peat Fens, and cracks appeared in the plaster of the kitchen in an old (probably Victorian) house at North Hykeham on the Lincolnshire Limestone near Lincoln.

***Figure 3**. Earthquake damage to John Aram's house, where limestone coping fell from the chimney into the front garden.*

The Sichuan earthquake

by Tony Waltham

Two months after the modest Market Rasen event, a major earthquake struck in the Sichuan province of China. At 7.9 on the Richter scale, it caused massive damage (Fig. 4) when it struck at 2.28 pm local time on 12 May 2008, along the western margin of the densely populated Sichuan Basin (also known as the Red Basin). At least 70,000 people died in the earthquake, and another 18,000 were still counted as missing three weeks after the event.

The earthquake originated on the Longmenshan Fault, a well documented reverse fault. The first break occurred 9 km deep beneath the epicentre, close to the town of Wenchuan (which gives the name used in China for this earthquake). Within a minute, the fault rupture propagated towards the northeast reaching to

***Figure 4**. Total failure of concrete buildings after the earthquake hit the town of Beichuan (photo: Xinhua).*

240 km along the fault over a depth of about 20 km. About 1.5 km of surface faulting was observed.

Maps of the Earth's tectonic plates show no boundary through Sichuan, and place it firmly within the Eurasian Plate. But India is moving steadily northwards at about 4 cm per year. This not only compresses and thickens the Tibetan Plateau, but also squeezes it outwards, mainly towards the east - where a plethora of large active faults accommodate the imposed distortion within the Eurasian Plate. On a local scale, the Tibetan block is advancing eastwards and overriding the Sichuan Basin by about 4 mm per year (Fig. 5). The Longmenshan Fault is part of this boundary, and it had been locked until the relentless movement had accumulated enough strain energy to rupture the fault on May 12. Aftershocks, northeast along the fault, reached a magnitude of 6.0, causing yet more deaths and building collapses.

All the world's largest earthquakes are generated on this type of reverse fault, where massive stresses can accrue in zones of crustal convergence and compression. Normal faults in areas of divergence and tension fail under lower stress and so create only smaller earthquakes (faults in situations of pure shear, such as the famous San Andreas Fault, create earthquakes of sizes in between these two extremes). China straddles no convergent plate boundaries, but its slightly smaller intraplate faults that are in compression zones have created many of the world's most lethal earthquakes simply because of the nation's huge numbers of people living around them

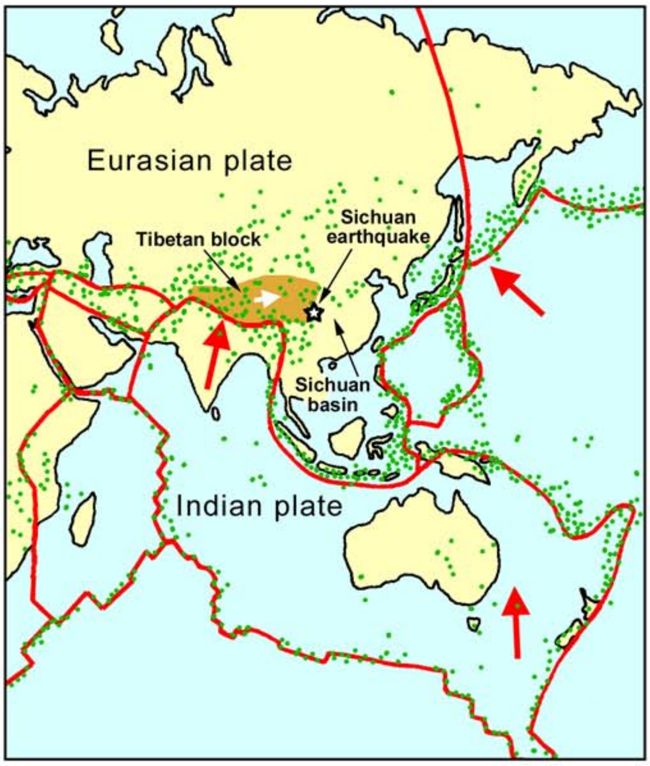

Figure 5. The tectonic setting of the Sichuan earthquake; the large dark arrows show plate movements, and the small light arrow shows slower movement of the Tibetan block within the Eurasian plate.

Mercalli intensity	*Population impacted*	*Features and scale of earthquake damage*
X	600,000	Most buildings collapse (all except those of good reinforced concrete), numerous large landslides, many bridges destroyed.
VIII	4,000,000	Widespread building damage, falling masonry, adobe collapse, many brick houses beyond repair, foundations and roads damaged.
VII	12,000,000 inc. Chengdu 90km away	Damage to poor masonry, plaster falls, chimneys collapse, some small landslides.

Table 2. Impact of the Sichuan earthquake, in terms of population and intensity of damage; maximum intensity was recorded as XI.

Many millions of people were impacted by the Sichuan earthquake (Table 2). More than five million people were left homeless - which is more than the total number in the earthquake's zone of intensity VIII. Over 90 million people experienced ground shaking that was stronger than the strongest experienced at Market Rasen a few months earlier. Concerns about the Three Gorges Dam were totally baseless, as the dam lies 700 km to the east where the Yangtze River cuts through the fold mountains where it drains out of the Sichuan Basin. Like so many other earthquakes in China, the Sichuan event was so destructive because of poor ground conditions - both on the flat land of the alluvial plains and on the unstable slopes of the mountain regions.

Nearly all China's cities and towns (including most of those in the Sichuan Basin) are sited on flat ground - where they are bicycle-friendly. But this also places them on soft alluvial sediments that amplify earthquake waves instead of dampening them; this is the well-known jelly effect (seen when carrying a jelly from kitchen to dining room after turning it out onto a plate as centrepiece for a children's party). Structural damage was exacerbated due to China's recent frenzy of construction, when concrete buildings have not achieved appropriate standards (whether this was due to corruption and bad design or to hasty and inadequate quality control is open to dispute). Especially on soft alluvium, these buildings were among the first to fail (Fig. 6), and when the earthquake unfortunately occurred in mid-afternoon over 11,000 children and teachers died in their collapsing schools. In total, more than five million buildings collapsed in this one earthquake.

The majority of towns built on stable bedrock are those in mountainous areas, where they are then prone to landslide damage. The deeply dissected mountains west of the Sichuan Basin, around the epicentre of the earthquake, are renowned for their slope instability (the tourist trail from Chengdu up to the travertine dams of Jiuzhaigou and Huanglong is a geological treat of landslide features, but is also notorious for the frequent blocking of the roads by fresh landslides in the steep valleys). The May earthquake triggered a host of new landslides. One buried 700 people in a samm town, and another buried a train. There were also 33 landslides whose debris created dams in the valleys, so that towns and villages were drowned by the lakes that were impounded behind them. Such 'quake lakes' are a feature of Sichuan's mountain terrains, and some still survive from the last major earthquake in 1933 in the same region. But these debris dams can fail, as did one in 1933, drowning 2500 people in the resultant flood.

Largest of the quake lakes formed this year is the Tangjiashan, in the valley of the Jian River (Jianjiang or Jianhe in Chinese). Filling to a depth of over 40m, and many kilometres long (Fig. 7) this presented a serious threat should it have been overtopped, when a channel scoured through the landslide debris could release a massive flood wave. The response to such a threat is to engineer a stable spillway across the landslide debris so that the inevitable overflow will cause minimal scour and therefore no great downstream flood. This was done at Tangjiashan, and water began to flow over the debris dam on June 7. Some scouring was inevitable, so that a flood pulse of ten times normal flow caused some further damage in the evacuated towns downstream. Meanwhile, many houses remain beneath the new lake, and add to the toll of this very destructive earthquake.

***Figure 6**. Almost total destruction in the town of Yingxiu, close to the earthquake epicentre (photo: Xinhua).*

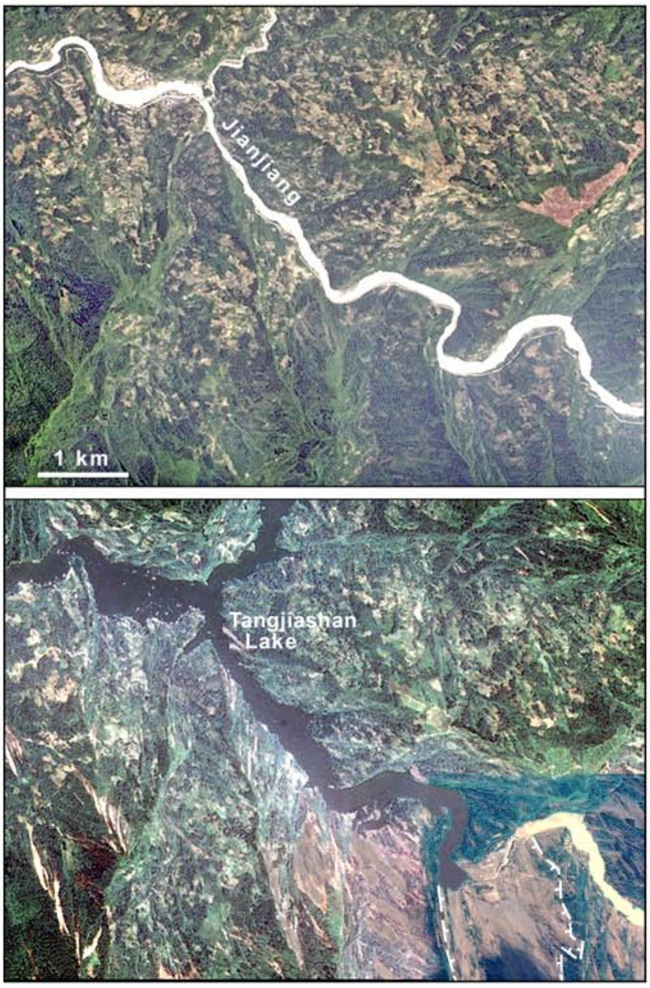

***Figure 7**. A pair of images from NASA's Earth Observatory, showing the valley of the Jianjiang before and after the earthquake. Deep water in the lake appears dark, while the shallow river and its gravel bed appear light. The lower image, taken on June 8, shows the landslide that dammed the river and just part of the newly created Tangjiashan Lake. The edge of the landslide debris is picked out in white dots, while the new channel cut across it is barely visible except where white water is cascading down its downstream bank to return to the river. Many smaller landslide scars are recognised by streaks of pale soil in areas that are intact forest in the upper image..*

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