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The Science Behind China's Sichuan Earthquake

Scientists at the Caltech Tectonics Observatory have started analyzing the devastating earthquake that struck China's Sichuan province on May 12. This tragic event is one of a series of earthquakes in the earthquake-prone region and is likely to be repeated. The earthquake occurred in an area that is deforming as a result of the collision between two tectonics plates, the Indian plate and the Eurasian plate.

Analysis of seismological measurements indicates that the quake reached a magnitude of about 7.9, rupturing the front of the Longmen Shan fault, which marks the eastern edge of Tibet where the steep front of the Longmen Shan mountain range overrides the Sichuan basin. The rupture started at the epicenter and over the next 50 seconds traveled a few hundred kilometers (about 100 miles) toward the northeast, where damage is expected to be even more severe than at the epicenter. The slip (displacement of the two land masses with respect to each other along the fault line) in some places is as large as 12 meters (39 feet).

Shaking in the highly populated basin was amplified by sediments, while shaking in the mountain range triggered landslides that have caused temporary damming of waterways. Within the next few days or weeks, more landslides are expected and some of these dams are expected to undergo catastrophic drainage causing severe flooding, as happened during the nearby 1933 Diexi quake, magnitude estimated at 7.5.

Here we examine the underlying physics.

Figure 1 shows the motion of India (large blue arrow pointing northward) relative to that of Eurasia (three smaller blue arrows pointing eastward). The white star indicates the location of the 2008 Sichuan earthquake. The seismicity recorded since 1964 for earthquakes of magnitude 6.4 and greater is shown by the circles.

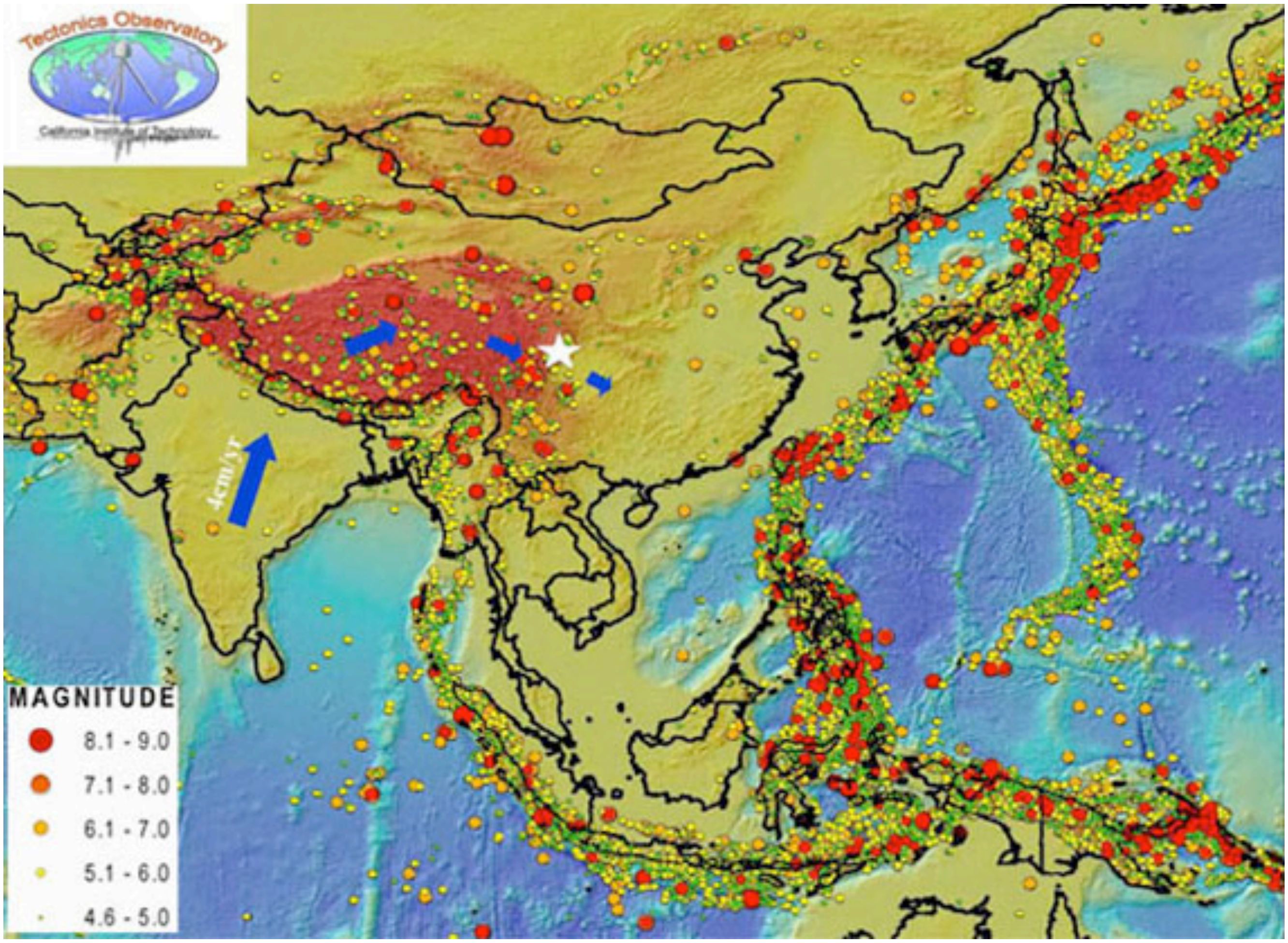

Figure 1. Map showing the location of the 2008 Sichuan earthquake (white star) as well as the location of all earthquakes occurring between 1964 and 2004 with magnitudes between 4.6 and 9.0 (colored circles). Larger red circles represent the largest magnitude quakes, and smaller yellow circles represent lesser magnitude quakes. Areas of dense circles indicate boundaries between plates. This map was constructed using data from seismometers located at various places over the surface of the Earth. The blue arrows show the northerly motion of India and the resulting easterly motion of Tibet. The size of the arrows indicates the relative speed of plate motion.

This collision, which has been going on for 50 million years, is the cause of the high mountains and widespread seismicity observed throughout central Asia. The area of dense circles between India and Asia covers a wide region that is undergoing large strain and deformation. It is this strain that led to the Sichuan quake and will lead to others. India has been moving northward at a rate of about 4 cm/year (2 inches/yr), which is about as fast as fingernails grow, pushing into central Asia and thus pushing Tibet eastward, out of its way. The 2008 Sichuan earthquake occurred where the eastern part of Tibet, forced further eastward, overrides the Sichuan basin at a rate of about 4 mm/year (an eighth of an inch/yr). This is the cause of the ongoing rise of the Longmen Shan mountain range that marks the eastern border of Tibet.

The motion of the land masses is shown in more detail in Figure 2. This velocity data is from Global Positioning System (GPS) stations located in the region. These stations enable us to measure surface velocity to within a fraction of a millimeter per year. The relatively fast northerly motion of India is evident, as is the somewhat slower easterly motion of Tibet. The blue star indicates the location of the 2008 Sichuan earthquake.

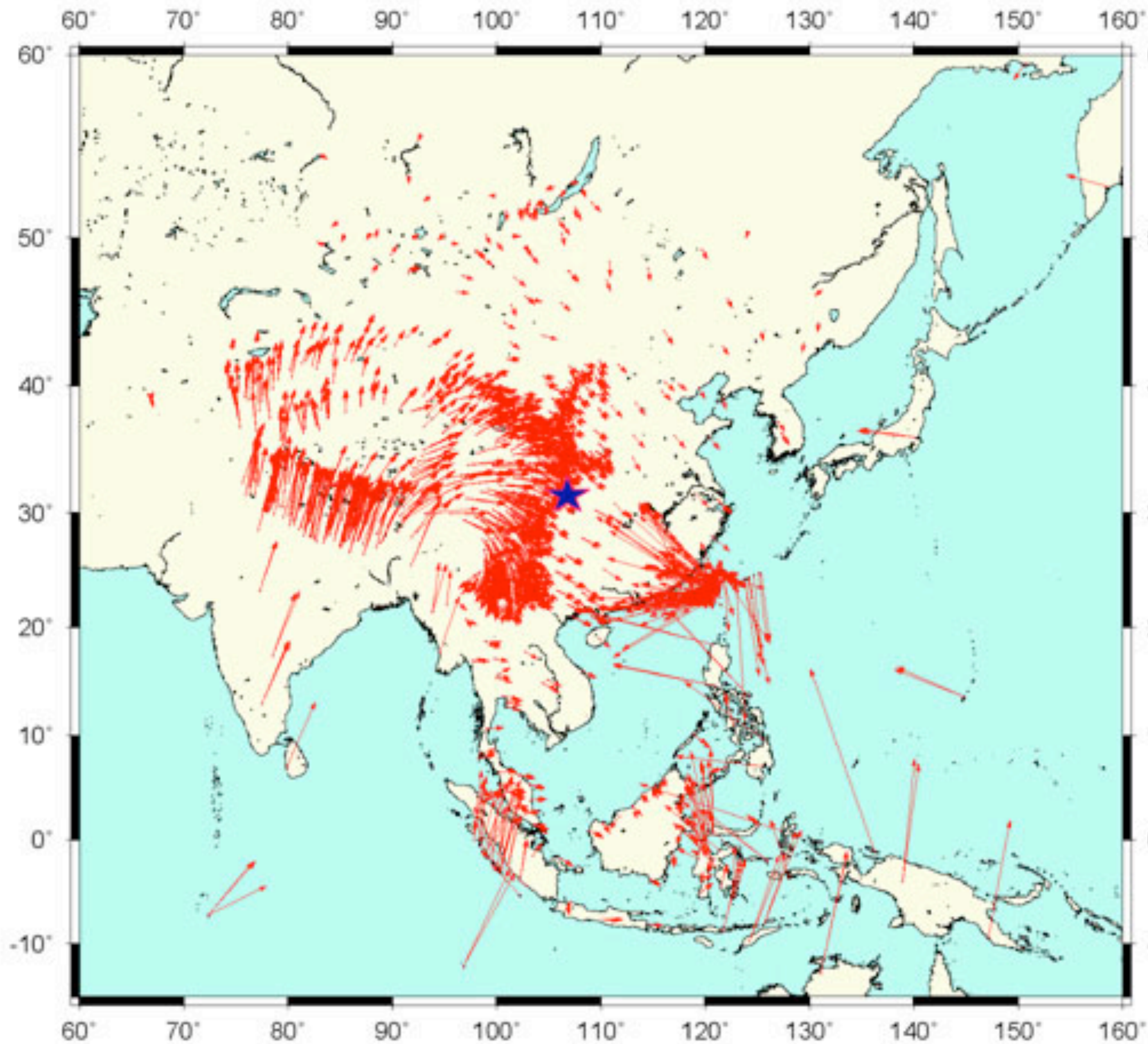

Figure 2. Velocity data from GPS stations located in the region. The blue star indicates the location of the 2008 Sichuan earthquake.

Analysis of seismological measurements indicates that the 2008 Sichuan earthquake reached a magnitude of about 7.9, rupturing the front of the Longmen Shan fault which marks the eastern edge of Tibet where the steep front of the Longmen Shan mountain range meets the Sichuan basin.

A closer look at this region is shown in Figure 3. The rupture of the fault started in the mountains northwest of the city of Chengdu (yellow star in Figure 3) and then, over the next 50 seconds, traveled at least 200 km (100 miles) toward the northeast, tearing apart the land along the front of the mountain range.

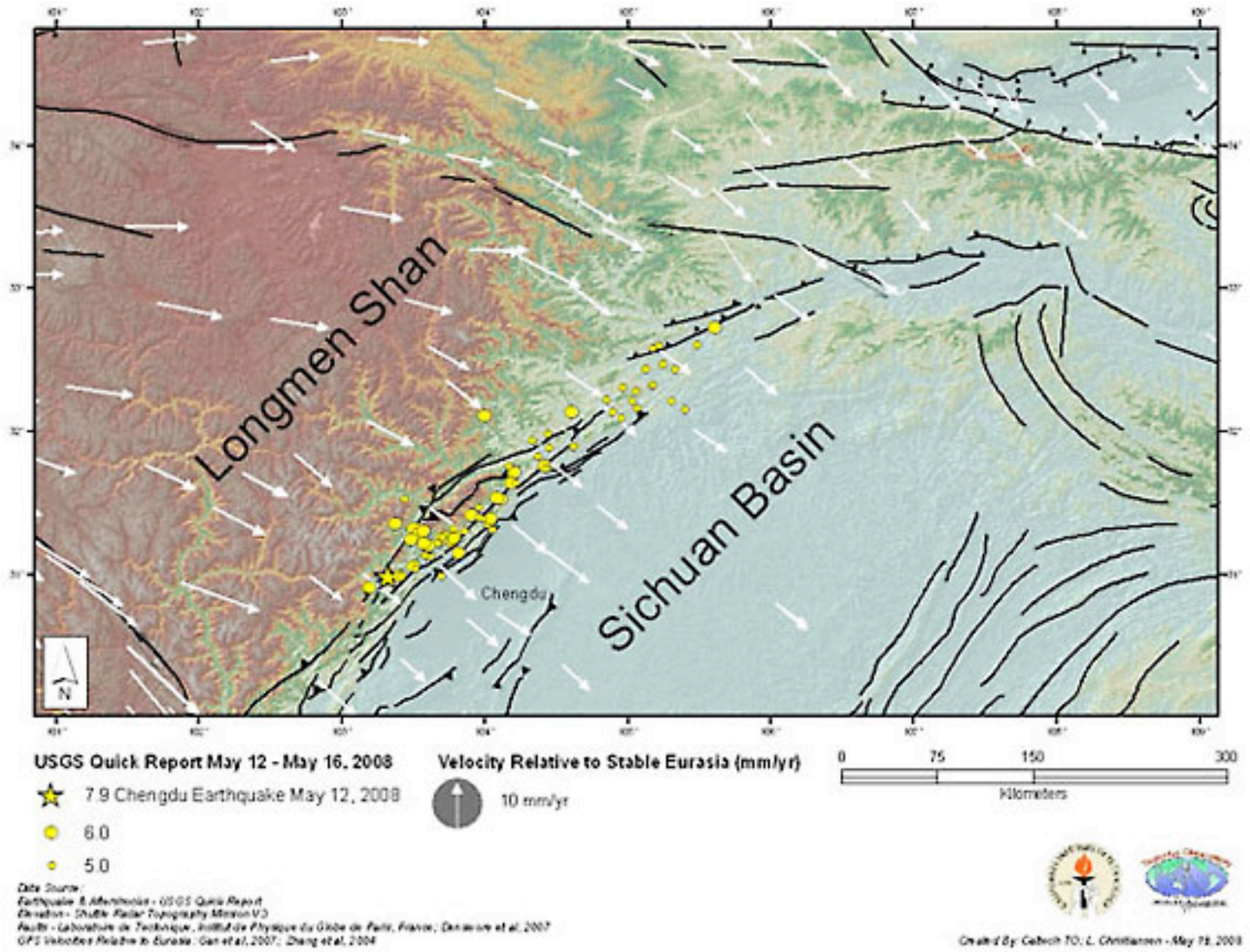

Figure 3. Map of fault region showing the epicenter of the first quake (yellow star) as well as the location of aftershocks (yellow circles) occuring within 5 days after the quake. Note that the aftershocks (USGS quick report) occur mainly along and in the vicinity of the fault line ruptured by the original May 12 quake. The white arrows show the horizontal motion of GPS stations located on the ground at those places, indicating the motion of the land. The arrows on the left-hand side are longer than those on the right-hand side, indicating that the land mass on the left is overtaking that on the right.

There have been many daily aftershocks following the initial rupture, as shown by the yellow circles in Figure 3. Note that the aftershocks are concentrated along the same ruptured fault, as well as in the vicinity. Aftershocks are expected to continue and may do so for months or even years afterward, as happened in the recent Sumatra earthquake, though the frequency decreases with time.

Model results for the earthquake rupture are shown in Figure 4, where the length of the blue rectangle shows the length of the rupture along the surface and the width shows the depth along the plane of the fault. Colors indicate the amount of vertical slippage.

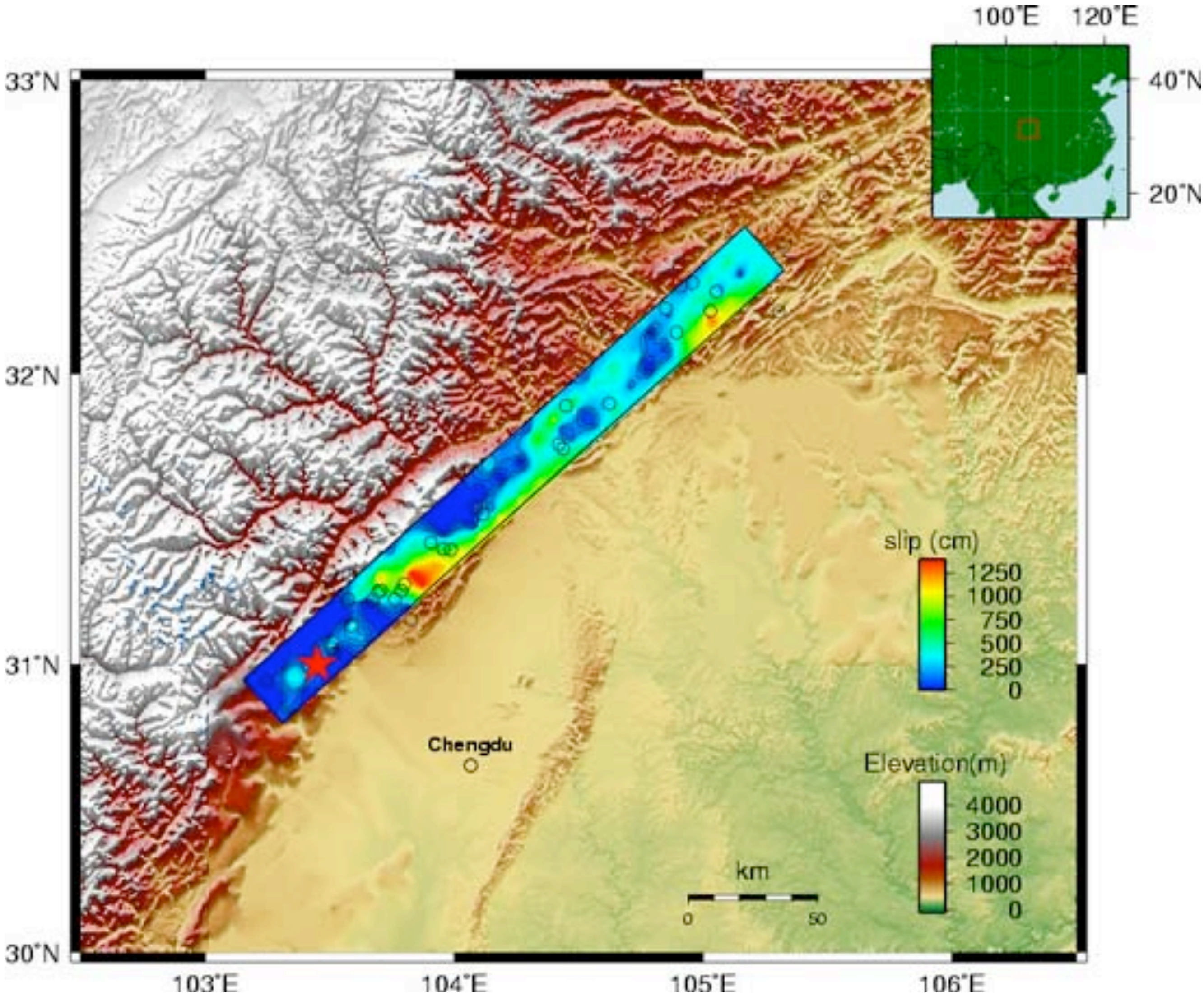

Figure 4. Model results of the ruptured fault line (narrow rectangle) superimposed on the actual fault line (modeling of the seismological data by Anthony Sladen). The length and depth of the rupture zone are indicated by the sides of the rectangle. Colors within the rectangle indicate the length of slip on the fault plane, i.e., the amount by which the land on the northwest side of the fault moved with respect to the land on the southeast side. Note that the location of the largest slip, indicated by dark red, is northeast of the epicenter (red star). The elevation of the terrain is also indicated by color. Note that the fault lies at the boundary between the high mountains and the low plains. Open circles indicate the aftershocks located by the USGS-NEIC in the 36 hours following the mainshock.

In some places, the vertical slippage along the fault line was as large as 12 meters (39 feet), shown by red-shaded areas in Figure 4. Note that this maximum vertical slippage did not occur at the epicenter but at a location about 60 km northeast of the epicenter.

Another view of the amount of slippage as a function of position along the fault (same rectangle as in Figure 4) is shown in Figure 5. Note that at the epicenter (red star), the depth of the rupture was only about 10 km (6 miles) below the surface. The amount of shaking correlates with rupture depth. The closer the rupture is to the surface, the stronger the shaking.

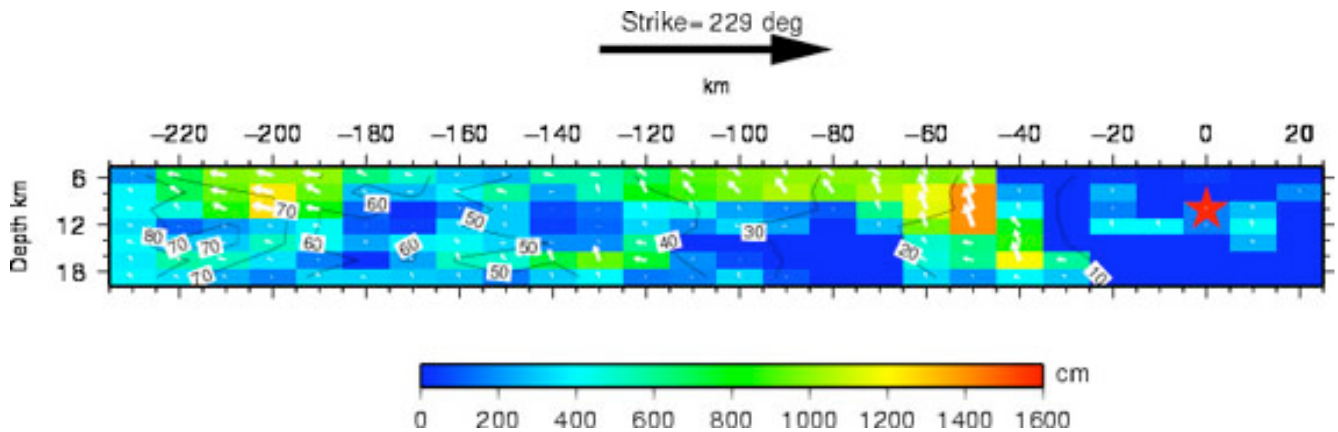

Figure 5. Model results for the amount of vertical slippage as a function of location and depth along the ruptured fault (modeling of seismological data by Anthony Sladen). This rectangle corresponds to that in Figure 4, though it has been rotated so that the epicenter (star) is on the right. The color scale is a bit different, with the maximum slip being indicated by orange rather than red. Note that at the epicenter (red star) the rupture originated about 10 km (6 miles) below the surface.

Motion along the southern edge of the fault was predominantly dip slip (i.e., land on one side of the fault moving under land on the other side), leading to an increment of uplift of the mountain range and subsidence of the Sichuan basin (see Figure 6).

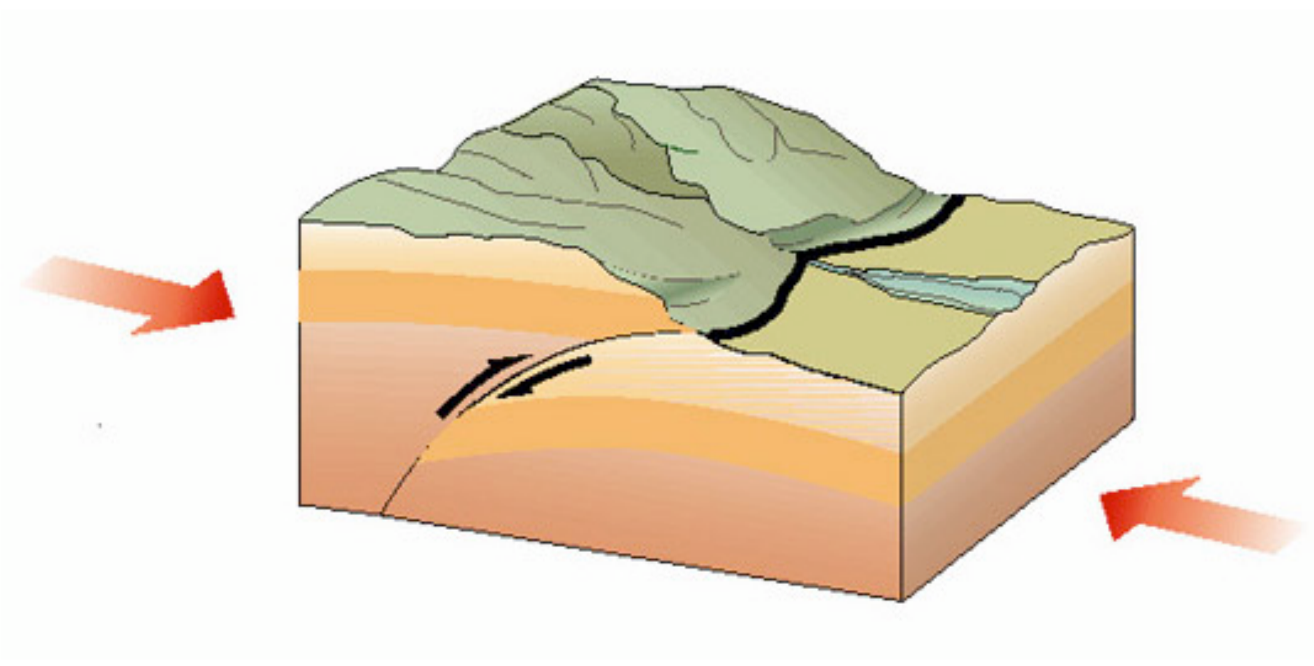

Figure 6. Schematic of a thrust fault (dip slip fault with landmasses coming together). The two landmasses are moving toward each other, as indicated by the red arrows, one landmass sliding under the other.

The effect of the seismic shaking within both the basin and the mountain range has been devastating. Heavy sedimentation in the basin, where close to 100 million people live, amplifies the shaking. As the seismic wave from either the original quake or subsequent aftershocks travels across the basin, the effect of the sediment is two-fold: the waves slow down, so that they spend more time in the area, and their amplitude, or strength, increases. Both effects compound the damage.

Shaking in the mountain range triggers landslides within the range. Tragically, a number of towns have been reported to be completely buried. Rescue efforts were also hindered by slides in the mountain passes, which blocked several of the main roads into the area. Such landslides also block the flow of water, causing natural dams to form, which later can breach or overflow. This occurred for an earlier earthquake in the same region, the 1933 Diexi earthquake, estimated at magnitude 7.5. That earthquake, located further within the mountain range, caused dramatic landslides and catastrophic draining of lakes behind landslide-dams.

Can we expect more earthquakes in the future? Historically this has always been an area of frequent earthquakes. Figure 7 shows the numerous faults in the region. Some of these faults now have higher levels of stress and thus will have been brought closer to rupture because of the 2008 Sichuan earthquake.

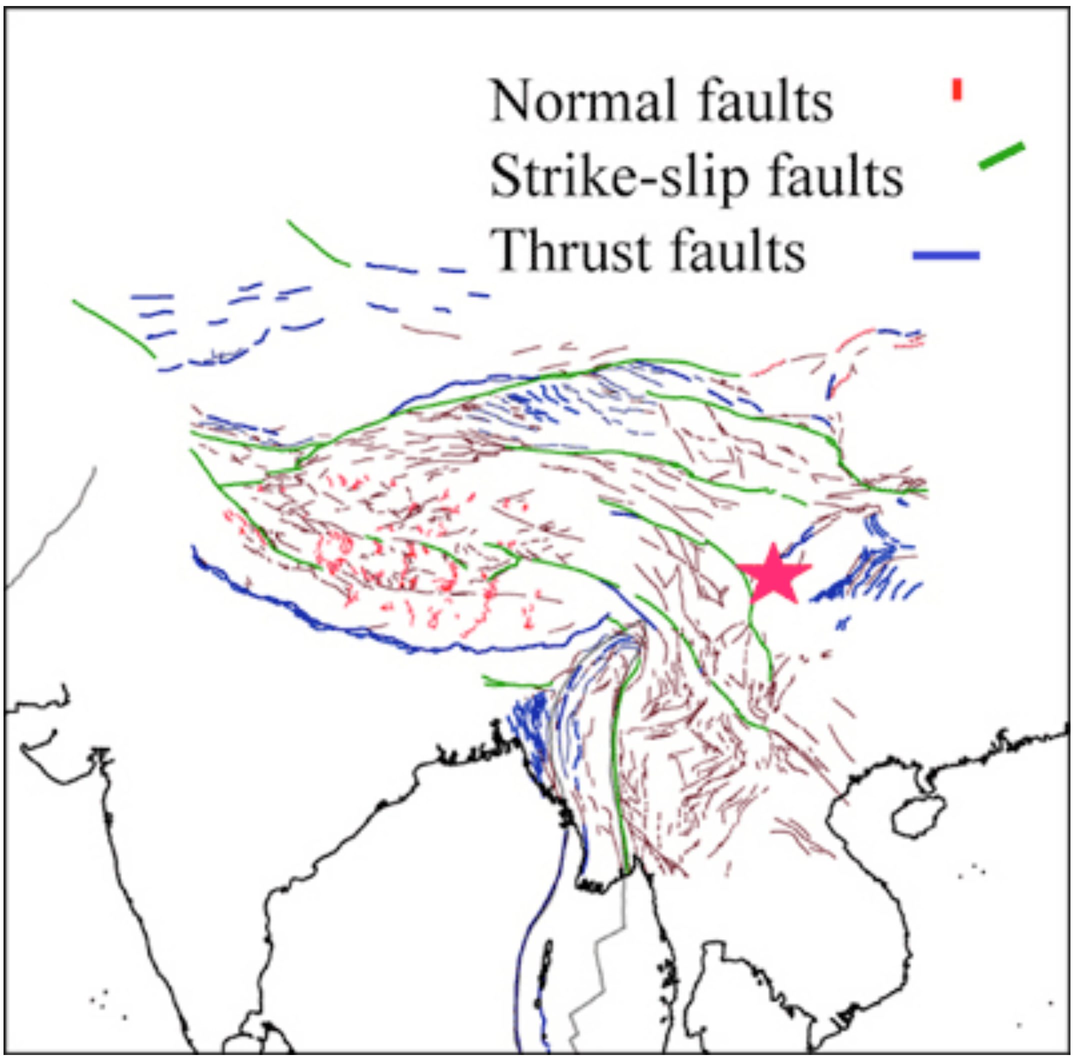

Figure 7. Shows a map of three different types of faults in this region. Red star indicates location of the 2008 Sichuan quake. Note large number of faults that are building up strain. This is an area of high earthquake risk.

Thus, it is likely that more earthquakes will occur in this region. In the absence of prediction and remediation, the best we can do is be prepared for them.

Link to more detailed information on the seismological analysis

Link to more on the science behind the earthquake:
SoCal Quake Experts Study Quake In China (NBC news interview, May 12, 2008)

Link to Local Quake Experts:
7.9 Quake is Unimaginable (CBS news interview, May 12, 2008)

Link to USGS Earthquake Details

Link to Interview with Hiroo Kanamori, MIT's Technology Review

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