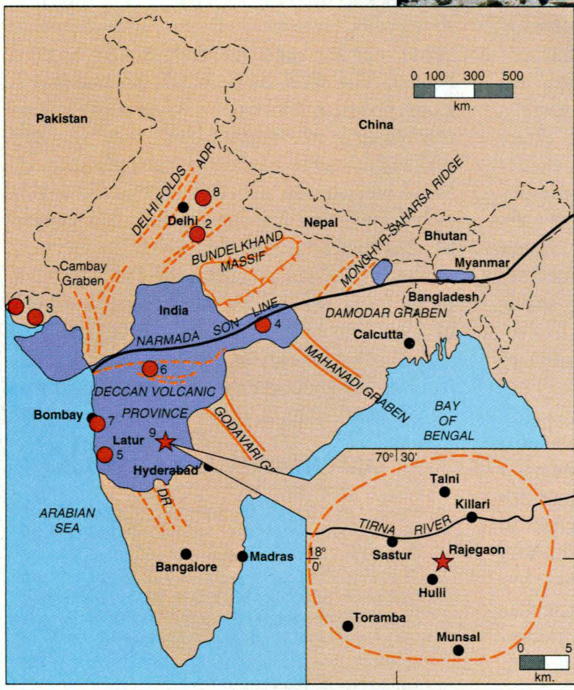
The Deadly Latur Earthquake

Harsh K. Gupta



Tectonic trouble spot. Generalized tectonic map of the stable continental region of India. The star is the epicenter of the Latur earthquake of 30 September 1993. Red circles are previous eight largest earthquakes (*2*); year and magnitude —1: 1819, $M = 7.79$; 2: 1803, $M = 6.65$; 3: 1956, $M = 6.48$; 4: 1926, $M = 6.40$; 5: 1967, $M = 6.3$; 6: 1938, $M = 6.26$; 7: 1618, $M = 6.24$; 8: 1956, $M = 6.05$. Areas marked by purple shading denote Mesozoic-Cenozoic volcanism; DR denotes the Dharwar rifts and ADR the Aravalli Delhi rift (Precambrian). (**Inset**) The meizoseismal area of the Latur earthquake. **Upper right.** Damage in Killari Village in the Latur District. Note the engineered house still standing among the ruins.

A devastating earthquake of magnitude 6.4 occurred in the early morning of 30 September 1993 in the southern part of the Latur District of Maharashtra State in India. The earthquake caused widespread damage in some 80 villages. In the days that followed, more than 11,000 human bodies were extricated from the debris, and the reported death toll is estimated to be much more. Historically, no significant earthquake is reported to have occurred in this area. With the death toll exceeding 11,000 human lives, the Latur earthquake is globally the deadliest earthquake in the stable continental crust to have occurred in recorded history.

The stable continental crust regions are very quiet parts of the continents and far away from the tectonic activity of plate boundaries. According to Johnston and Kanter (*1*), the bedrock shields—some of them more than 3 billion years old—that are the ancient hearts of continents and the platforms of sediment-covered bedrock that surround shields are qualified as stable crusts. Johnston (*2*) has prepared a list of more than 800 stable continent region events with magnitudes greater than or equal to 4.5. However, he points out that the total moment release by these events is 10^{26} dyne·cm per year, or less than 0.5% of the global seismicity. The largest known earthquakes belonging to this category occurred on 16 December 1811 and 23 January and 7 February 1812 in New Madrid (near Missouri in the United States). These earthquakes were of magnitude 8.2, 8.3, and 8.1, respectively. The next largest earthquake, of magnitude 7.8, occurred in Kutch, India in 1819. This earthquake caused a scarp between 6 and 9 m high and up to 90 km in length, which came to be known locally as "Allah Bund" or "Wall of God." The Kutch earthquake is estimated to have claimed 1500 human lives. The largest number of deaths so far are reported for the 1918 China (Nanai) earthquake of magnitude 7.4, having claimed an estimated 10,000 human lives (*3*). In recent years, noticeable events occurred in Tenant Creek, Australia, on 22 January 1988 (*4*). In this unique sequence, three earthquakes of magnitude 6.3, 6.4, and 6.7 occurred within a short period of 12 hours. The latest known example is the Ungava earthquake of magnitude 6.3 in Canada, which occurred on 25 December 1989 (*5*).

The focal depth of the Latur earthquake is estimated to be between 5 and 15 km. With a seismic moment of 1.8×10^{25} dyne·cm, it accounts for about 20% of annual seismic energy release in stable continental region earthquakes. Focal mechanism solutions show thrusting along a northwest-oriented fault, which is consistent with the inferred regional stress regime (*6*). The maximum intensity in the meizoseismal area (region of strongest shaking) of about 10-km radius is VIII on the Modified Mercalli intensity scale. Several villages, including Killari, Sastur, Munsal, Hulli, Talni, Rajegaon, and Toramba, were severely affected (see map).

The style of damage was similar in these villages. The boulders in different sizes and shapes are stacked to form the two faces of enormously thick walls (up to 4 feet), and the gaps between them are just filled with mud, pebbles, and small stones. The load-bearing capacity of the black soil, on which the affected houses were built, is very low. The roofs are also thickly covered with earth. The thick walls built on black soil were basically responsible for large damage. These thick walls just crumbled, bringing down roofs and killing people, especially in early morning hours [0357 IST (Indian Standard Time)]. After the earthquake, the debris cover was almost waist high. Heavy rains, a few days before the earthquake, had further reduced the strength of the soil. In a nutshell, poor construction, bad foundations on black soil with very low load-bearing capacity, the early hour of occurrence, when everyone was asleep, and the high population density were basically responsible for thousands of human lives lost. Some of the well-engineered structures in concrete are unaffected (see figure). In the Killari village itself, which was the most destroyed area, the water tank of 100,000-liter capacity as well as engineered structures withstood the shaking. The intensity dropped to V on Modified Mercalli scale a few tens of kilometers away from the epicenter. However, the earthquake was felt at long distances, up to 400 km away.

Historically, no earthquake of comparable magnitude is known to have occurred in the vicinity of the Latur earthquake (*7*, *8*). However, last year an earthquake of magnitude 4 on 18 October 1992 caused minor structural damages to a few houses in Killari village. In the weeks to follow, there were about 25 reports of felt earthquakes. On 1 and 2 November 1992, four tremors of magnitude 2.2 to 3.8 occurred. People reported felt tremors in the months that followed. Because of the absence of seismic stations in the near vicinity, there is no seismic record of these tremors. The closest station is at Hyderabad at a distance of 220

National Geophysical Research Institute, Hyderabad-500007, India.

km from the epicentral region. Reports exist of felt tremors from this region in 1962, 1967, 1983, and 1984. The epicentral area lies on the fringes of Deccan volcanic province of Peninsular India, and the thickness of volcanic rock is estimated to be between 100 and 200 m. There were no foreshocks of this earthquake large enough to be recorded at Hyderabad Observatory.

Macroseismic surveys and a suite of geophysical investigations are being undertaken in the vicinity of the Latur earthquake by the scientists of the National Geophysical Research Institute in Hyderabad. The aftershock activity consists of several tremors, the largest being of magnitude 4.4 on 30 September 1993 itself. The aftershock activity decreased rapidly in the days to follow. However, there was an aftershock exceeding magnitude 4 on 12 November 1993. There is no major visible continuous fracture on surface associated with this earthquake. There are a few discontinuous ruptures that continue intermittently for a kilometer or so. A maximum upthrow of 0.5 m along a plane dipping 40° northeast has been seen. Soil gas studies carried out in the vicinity of some of the cracks in the rupture zone near Killari have shown very high helium concentration in the range of 1000 parts per billion (ppb), as compared with background values of 200 ppb or less. Repeat measurements are being made. There are reports of smoke or gas emanation from a widespread area to a distance of 200 km from the epicenter as well as reports of ground-water changes 2 to 3 months before and after this earthquake. These reports are being authenticated. There were also reports of elevated surface temperature for the meizoseismal area in the vicinity of Killari. Ground temperatures were measured at a depth of 1 m with a thermistor probe at 16 sites from where smoke emanation was reported. With the exception of a couple of sites, temperatures were found to be normal.

Johnston (*2*) has prepared a list of the 100 largest stable, continent region earthquakes for the entire globe. Eight of them fall within the stable continent region of India (see map). However, all of them are associated with rifts or continent-ocean transition zones, or both. Unlike these events, the Latur earthquake is far removed from any known rift. The closest is a postulated Khurdwadi rift, which is more than 70 km from the epicenter.

As such, it is difficult to assign a definitive explanation for the Latur earthquake. Johnston and Kanter (*1*) have pointed out the rarity of stable earthquakes in continental crust, and the fact that the largest of them occurred long before the modern instruments were developed really makes us very poorly equipped to understand their mechanism. It is hoped that aftershock data collected through the operation of a number of seismic stations, which is under different stages of processing, and other geophysical, geological, and geochemical investigations being conducted in the region will provide much needed insight into the puzzling Latur earthquake.

References

1. A. C. Johnston and L. R. Kanter, *Sci. Am.* **262**, 68 (March 1990).
2. A. C. Johnston, *Electric Power Research Institute, Report TR-102261* (1993), chap 3.
3. Academia Sinica, *Catalog of Chinese Earthquakes*, vol. I (1177 B.C. to 1900 A.D.) and vol. II (1901 to 1949). (Institute of Geophysics, Peking, China, 1970).
4. G. L. Choy and J. R. Bowman Jr., *J. Geophys. Res.* **95**, 6867 (1990).
5. J. Adams, R. J. Wetmiller, H. S. Hasegawa, J. Drysdale, *Nature* **352**, 617 (1991).
6. T. N. Gowd, S. V. Srirama Rao, V. K. Gaur Jr., *J. Geophys. Res.* **97**, 11879 (1992).
7. U. Chandra, *Bull. Seismol. Soc. Am.* **67**, 1387 (1977).
8. I. Mohan, M. V. D. Sitaram, H. K. Gupta, *J. Geol. Soc. India* **22**, 292 (1981).

Cancer, Catenins, and Cuticle Pattern: A Complex Connection

Mark Peifer

Society's investment in basic biological research is often justified by the claim that scientists may discover unexpected connections to problems important to human health and welfare. A spectacular example of such a connection is provided by two reports in this issue of *Science* (*1*), which establish a link between human colon cancer, epithelial cell adhesion molecules, and pattern formation in the fruit fly *Drosophila.*

Colon cancer, one of the most common forms of cancer in the Western world, results from an accumulation of mutations in oncogenes and tumor suppressor genes. Mutations in the tumor suppressor gene *APC* are thought to occur early in tumorigenesis. Although originally identified in families with familial adenomatous polyposis, who are predisposed to colon cancer, the *APC* gene is now known to be altered in many sporadic colon cancers as well. The cellular function of the APC protein has remained elusive because APC has little sequence similarity to other proteins (*2*). In this issue, two research groups use a biochemical approach to cellular function and find that APC associates with an adherens junction protein called β-catenin (*1*).

Adherens junctions (AJs; also called the zonula adherens) are critical for the establishment and maintenance of epithelial layers, such as those lining organ surfaces. AJs mediate adhesion between cells, communicate a signal that neighboring cells are present, and anchor the actin cytoskeleton. In serving these roles, AJs regulate normal cell growth and behavior. Certain stages of embryogenesis, wound healing, and tumor cell metastasis require that cells form and leave epithelia. This process, which involves the disruption and reestablishment of epithelial cell-cell contacts, may be regulated by the disassembly and assembly of AJs. Several lines of evidence have suggested that Src-mediated tyrosine phosphorylation of AJ proteins influences AJ assembly and cell adhesion (*3*), and there is evidence that down-regulation of AJ components often precedes metastasis (*4*). AJs may also function in the transmission of the "contact inhibition" signal, which instructs cells to stop dividing once an epithelial sheet is complete. Faulty transmission of this signal could easily lead to growth deregulation.

The AJ is a multiprotein complex (*5*) assembled around calcium-regulated cell adhesion molecules called cadherins. Cadherins are transmembrane proteins: the extracellular domain mediates homotypic adhesion with cadherins on neighboring cells, and the intracellular domain interacts with cytoplasmic proteins that transmit the adhesion signal and anchor the AJ to the actin cytoskeleton. These cytoplasmic proteins include the α-, β-, and γ-catenins. The genes for the α- and β-catenins have been cloned (*6, 7*) and are unrelated in sequence. The γ-catenin protein, first identified as a band on an SDS gel, may in fact be a mixture of two proteins—a β-catenin relative called plakoglobin that is found in desmosomes (another type of intercellular junction) and an unidentified protein (*8*).

Although the stoichiometry and stability of the AJ protein complex have been well characterized, the biochemical roles of the individual proteins remain mysterious. Several clues have emerged from sequence analysis. The α-catenin protein shares slight but significant amino acid identity

The author is in the Department of Biology, University of North Carolina, Chapel Hill, NC 27599-3280.