tion studies predicted that neither of the signaling-proficient MSP fragments should be able to form filaments (*8*).

How does MSP get released by sperm so that it can carry out its dual signaling task? The standard secretion pathway coupled to protein synthesis does not appear to be an option, because MSP lacks a signal sequence and the sperm lack ribosomes, endoplasmic reticulum, and Golgi apparatus (*9*). Nematode spermatids have an alternative apparatus for delivering prepackaged glycoproteins to the cell surface during spermiogenesis, but this also seems an unlikely route, because mutant spermatocytes that never undergo spermiogenesis are nevertheless signaling competent (*2*). The signaling competence of spermatocytes further indicates that sperm motility and pseudopod formation are also dispensable for signal delivery.

The discovery that a major intracellular cytoskeletal component known to be involved in sperm motility can also behave as an extracellular bipartite signaling molecule is unanticipated and provocative. Because proteins containing a conserved amino-terminal MSP-like domain are found in fungi, plants, and animals, it is possible that MSP-related signaling events may be identified in other phyla as well. Regardless of whether this turns out to be the case, however, the saga of nematode MSP should serve as a poignant cautionary tale for biologists everywhere: Other proteins that we think we know extremely well may turn out to be leading dual lives!

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PERSPECTIVES: GEOLOGY

The Deadliest Intraplate Earthquake

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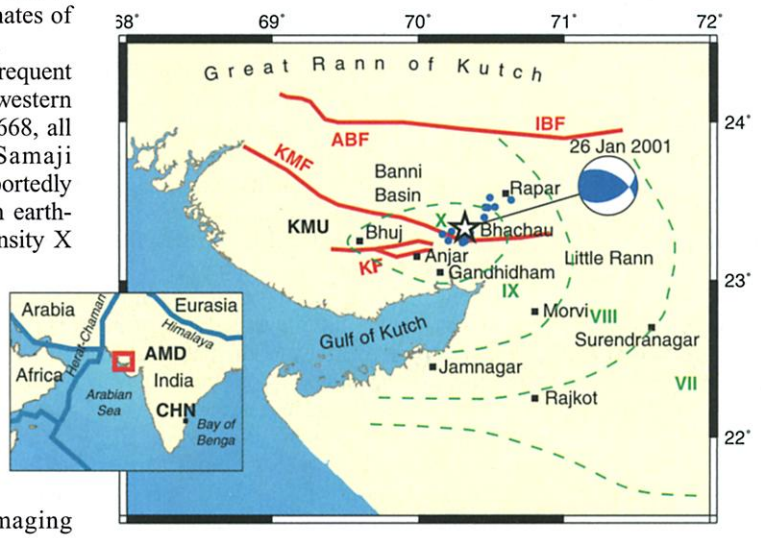
A catastrophic earthquake of magnitude 8 struck the Bhuj-Anjar-Bhachau region of Kutch, Gujarat, in western India on the morning of 26 January 2001 (*1*). The earthquake epicenter (see the figure) was located at 23.326°N, 70.317°E, and its focal depth was up to 23 km. A conservative official estimate puts the number of human lives lost at 30,000 and the economic loss at U.S. $10 billion. News media estimates of the human lives lost exceed 50,000.

In the historic past, large but infrequent earthquakes have occurred in the western part of the Kutch region. In May 1668, all 30,000 houses of the town of Samaji (25°N, 68°E) on the Indus delta reportedly sank into the ground because of an earthquake with maximum damage intensity X on the 12-point Modified Mercalli (MM) scale. An earthquake of magnitude 8 occurred in the Great Rann of Kutch on 16 June 1819, forming a 90-km-long scarp with a height of up to 9 m. It came to be known locally as "Allah Bund" or "Wall of God." The earthquake claimed 1500 lives in Kutch and 500 in Ahmedabad. The last damaging earthquake in the region, the magnitude 7 Anjar earthquake of 21 July 1956, caused 115 deaths.

The epicenter of the 2001 Bhuj earthquake is located about 15 km northwest of Bhachau and 60 km east of Bhuj. The maximum damage was of MM intensity X in an area of 100 km by 60 km (see the figure). Total collapse of nonengineered houses and ground cracks of up to 1-m width were witnessed in the epicentral region. As expected, damage in river floodplains was much worse than in hard rock areas. In Ahmedabad, 250 km from the epicenter, many highrise buildings collapsed, possibly because of faulty design. In Anjar, Bhachau, Gandhidham, and Ahmedabad, multistoried buildings sank up to one floor into the ground, possibly because of a quicksandlike effect in dry sandy soil areas. The earthquake caused widespread liquefaction in the Great Rann saline-marshy lowlands to the north and the Little Rann to the southeast. As a result of soil liquefaction and subsidence, railway lines were heavily damaged, as were several small and medium-sized dams. The earthquake was felt as far away as Chennai on the southeastern coast of India.

The Harvard focal mechanism solution of the Bhuj earthquake indicates a thrust fault with strike of 65°, dip of 50°, and slip of 50°. The maximum dislocation, for a southward dipping fault plane, is estimated as about 8.5 m (*2*). Depth estimates vary from 10 to 23 km. The earthquake was followed by more than 100 aftershock events of magnitude above 4, including 10 events of magnitude above 5. Focal mechanism solutions of a few of the major aftershocks also indicate a thrust environment.

The epicenter of the main shock lies close to the eastern part of the Kutch Mainland Fault (*3*) (see the figure). The earthquake occurred about 400 km east of the Herat-Chaman plate boundary and more than 1000 km south of



Map of the 2001 Bhuj earthquake. The epicenter is marked with a star. Isoseismals in MM intensity scale (Roman numerals) are shown as green broken lines. The epicenters of a few aftershocks, determined with data from a local network set up by the National Geophysical Research Institute of India, are shown as blue dots. KMU, Kutch Mainland Uplift. Major faults (red lines): ABF, Allah Bund Fault; IBF, Island Belt Fault; KMF, Kutch Mainland Fault; KF, Katrol Fault. (**Inset**) The Indian plate boundaries (dark blue lines) form a triple junction northwest of the Kutch region. AMD, Ahmedabad; CHN, Chennai.

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the Himalayan plate boundary (see the inset in the figure). It may therefore be classified as an intraplate earthquake. Such earthquakes are rare, accounting for less than 0.5% of global seismicity (*4*). However, the proximity to the triple junction (see the inset in the figure) formed by the Indian, Arabian, and African plates complicates the tectonics of the Kutch region and influences the local tectonic processes considerably. The presence of several faults in this region may be related to previous episodes of rifting associated with plume activity as the Indian plate traversed active hotspots since its breakup from Gondwanaland 120 million years ago.

The surface geology of the 2001 earthquake epicentral region comprises Mesozoic (245 to 65 million years old) sediments overlying an uplifted granitic basement. The region lies outside the basalt-covered areas of southern Kutch, which are part of the 65- to 60-million-year-old Deccan traps, one of the largest volcanic provinces in the world. Erosion of the younger sedimentary layers and the Deccan traps in the uplifted region may have left an isostatic imbalance (a gravitational instability of landmass). The focal mechanisms of Kutch earthquakes such as the 1956 Anjar earthquake (*5*), the 1819 Rann of Kutch earthquake, and a few others indicate reverse faulting, where two blocks of a fault slide over one another. Hence, under the prevailing compressional stress field caused by the northward collision of the Indian tectonic plate with Eurasia, preexisting normal faults associated with the possible plume-related Early Mesozoic rifting (*6*), may be getting reactivated as reverse faults.

On the Seismic Zoning Map of India (*7*), prepared by the Indian Standards Institution (*8*), the Kutch region lies in zone V—the zone of highest seismic potential, on par with the plate boundary regions adjoining the Himalayan belt and northeast India. The seismic hazard map of the Indian region (*9*) indicates a 10% probability that ground acceleration in the Kutch region will exceed 0.25 times the gravitational acceleration in a period of 50 years. Nonadherence to the high-risk zone building codes is chiefly responsible for the damage to many recently constructed multistoried buildings during the recent earthquake. The damage potential could be reduced substantially by strict implementation of building codes, retrofitting of important buildings particularly in zones IV and V, popularization of simple, inexpensive methods to strengthen old buildings and rural dwellings, and microzonation studies (as undertaken by the government for Jabalpur in central India) to prepare risk maps of important cities.

If these steps are implemented in a timely manner, India will be much better prepared to deal with major earthquakes. Other earthquake-prone developing countries should adapt a similar approach to reduce earthquake-related hazards.

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PERSPECTIVES: TRANSDUCTION

When Worlds Collide—Trafficking in JNK

Lawrence S. B. Goldstein

Components of intracellular signal transduction pathways are often organized into signaling modules. As these complexes get larger, however, they face the increasingly difficult problem of how to move within the cell to their sites of action. This problem is particularly acute, for example, in neurons of the human peripheral nervous system—the anatomical separation of the neuronal cell body (where signaling molecules are synthesized) and neuronal termini (where many of them are needed) may span a meter or more. A possible solution has emerged from a number of recent experiments capped by the elegant studies of Verhey *et al.* published in the *Journal of Cell Biology* (*1*). These studies unite the two formerly disparate intracellular worlds of signaling and vesicle transport driven by motor proteins. The intriguing implication is that signaling complexes associated with transport vesicles are moved along microtubules to their distant cellular sites of action by motor proteins such as kinesin-I (see the figure). Furthermore, kinesin motors are attached to the transmembrane proteins of cargo vesicles through specific scaffold molecules that also bind to the signaling complexes.

A key problem in understanding how molecular motors direct intracellular transport has been to identify the molecules that connect the motors to cargo vesicles and other organelles. With a yeast two-hybrid screening assay, Verhey *et al.* searched for proteins that bound to the light-chain subunit of kinesin-I. Surprisingly, they identified three known proteins—the JNK interacting proteins JIP-1, JIP-2, and JIP-3—that bound to the putative cargo-binding tetratricopeptide repeat domains in the kinesin-I light chain (*2–5*). JIPs are scaffold proteins that bind to the three kinase components of the JNK signaling pathway: JNK itself [c-Jun NH_2-terminal kinase, a mitogen-activated protein (MAP) kinase], a kinase that phosphorylates JNK such as MKK7 or MKK4 (MAP kinase kinase), and a kinase that phosphorylates MKK7 or MKK4 (MAP kinase kinase kinase). JIP-1 and JIP-2 are related proteins that share 50% amino acid identity. JIP-3 is related to JIP-1 and JIP-2 in name and potential activity only—its sequence and predicted domain organization are completely different.

JIP proteins are thought to organize components of JNK signaling pathways into functional modules that respond to specific signal inputs. Intriguingly, previous work suggests that JIP-1 and JIP-2 may interact with cargo vesicles by binding directly to the cytoplasmic domain of transmembrane low density lipoprotein (LDL) receptors such as ApoER2 (also called reelin), the LDL receptor–related protein (LRP), and megalin (see the figure) (*6*, *7*). Indeed, Verhey *et al.* demonstrate, with coimmunoprecipitation and microtubule-binding assays, that kinesin-I, JIP-1, ApoER2, and a JNK kinase (DLK) can all be found in the same complex. They also show that localization of JIP-1, JIP-2, and DLK to the tips of long processes in cultured neuronlike cells can be perturbed by overexpression of the JIP-binding regions of kinesin light chain. Thus, kinesin-I may be linked to certain transport vesicles through the JIP-1 and JIP-2 scaffold proteins, which bind to transmembrane receptors of the LDL family. This suggestion provides a mechanism

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