to comment on it, however, because the team has a paper on the topic under review at *Nature*.

Radio pulsars are thought to consist of a spinning neutron star—a collapsed star about 10 kilometers across but more massive than our sun—sprouting a magnetic field about a billion times more intense than Earth's. Interactions between the whirling field and particles in the star's thin atmosphere generate radio waves, which stream like a lighthouse beam from the magnetic poles. Astronomers pick up a pulsar's radio blips each time a magnetic pole whirls past our line of sight, says Jonathan Arons of the University of California, Berkeley.

Ordinary radio pulsars, which were discovered more than 30 years ago, emit a blip every second or so. But in the early 1980s, astronomers detected a new class of pulsars that spin nearly 1000 times faster. In a widely held theory, says Arons, the stars "get spun up" to such fantastic rates by accreting matter from a companion at an earlier stage of their lives. As the disk of material spirals inward, it applies a torque to the pulsar's magnetic field, revving up the star.

Bursts of x-rays, emitting from the superheated material that crashes to the surface of the neutron star, should signal the spin-up. But until now, nearly all known x-ray pulsars have had periods longer than a second, probably because they have magnetic fields so powerful that they disrupt the disk of infalling material far from the surface of the star, where the disk is still spinning relatively slowly.

The rotation rate of the new object, SAX J1808.4-3658, suggests that its field must be weak enough to allow the disk to come within about 20 kilometers of the surface. An earlier sighting supports that assumption. In September 1996, the Italian-Dutch BeppoSAX satellite observed x-rays emitted by thermonuclear explosions on what was apparently the same object. The explosions are thought to occur when pressure builds up within a widespread puddle of accreted material on the surface of a neutron star. Such extensive puddles of unburned material could never form on a star that has a powerful magnetic funnel to confine the infalling material, say astrophysicists. "This object has a spin period and an inferred magnetic field that would most likely allow it to become a millisecond radio pulsar when accretion shuts off," says Lars Bildsten of Berkeley. "This is the first such example."

The rapid-fire x-ray pulses are only one sign of a millisecond pulsar being born. The midwife—a companion star—appears to be present as well. In a second result, reported in IAU circulars and accepted at *Nature*, Deepto Chakrabarty and Edward Morgan of the Massachusetts Institute of Technology describe slower variations in the x-ray emission, which seem to show that the pulsar is tightly orbiting a companion star. Chakrabarty, along with Paul Roche of the University of Sussex in the United Kingdom and others, may also have seen the companion star directly, through a ground-based telescope.

Radio astronomers will now watch to see whether a radio pulsar emerges as accretion onto SAX J1808.4-3658, which is now fading, falls off even further. Until then, the infalling material will snuff out the radio bursts. But already, pulsar specialists regard the discovery as a triumph for their theory—and for XTE. "It's one of the things we hoped for from the Rossi mission," says Lamb, "and it's delivered."

–James Glanz

SEISMOLOGY

Can Great Quakes Extend Their Reach?

Earthquakes were once thought to keep to themselves, striking on a schedule determined only by the history of each particular fault. Then seismologists began to realize that every rupturing fault communicates with neighboring faults, instantly reaching out tens or hundreds of kilometers to hasten or delay distant earthquakes (*Science*, 16 February 1996, p. 910). Now a group of geophysicists suggests that these lines of communication extend even farther—and carry much, much slower messages.

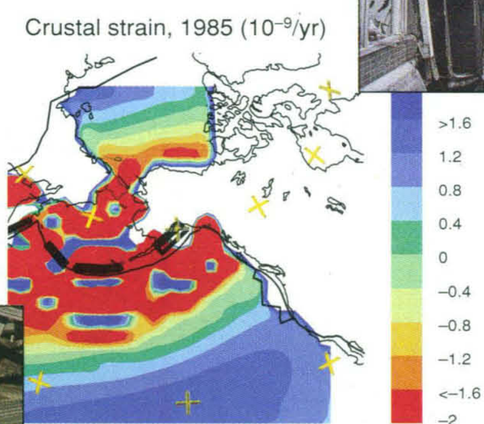
Big quakes can trigger other quakes thousands of kilometers away and decades later, according to calculations presented on page 1245 of this issue of *Science*. Geophysicists Fred F. Pollitz and Roland Bürgmann of the University of California, Davis, and seismologist Barbara Romanowicz of UC Berkeley simulated how stress travels through deep, viscous rock. They found that the great earthquakes that struck the far North Pacific in the 1950s and '60s could have set off wave that triggered a pulse of seismic activity in California in the 1980s.

"It's an exciting possibility," says seismologist Thomas Hanks of the U.S. Geological Survey (USGS) in Menlo Park, California. If the reach of big quakes extends that far, seismologists may be able to make more sense of the comings and goings of earthquakes worldwide, he adds. Researchers are intrigued, though not yet completely convinced. "It could be right," says tectonophysicist Wayne Thatcher of the USGS, "but I think it has a ways to go before being a persuasive argument."

Researchers have long recognized a potential transmission route for long-distance messages among faults: the thin layer of soft rock at depths of 80 kilometers or more called the asthenosphere. There, temperature and pressure combine to soften rock so that, although still solid, it slowly flows over decades. The more rigid tectonic plates that make up Earth's surface, such as the great Pacific Plate, glide along on this softer layer.

But plates don't slide smoothly at their edges. They stick to each other, build up stress, and then jerk forward in earthquakes. The quake redistributes stress nearby, adding stress in some places and relieving it in others. For example, between 1952 and 1965, four great quakes struck along the Aleutians and the Kamchatka Peninsula, where the Pacific Plate is diving beneath the North American Plate. After each quake, the Pacific Plate adjusted to the new plate positions immediately, stretching like a sheet of rubber and triggering flow in the asthenosphere below. Spreading outward through the asthenosphere like the ripple of a pebble dropped in a pond, the wave created by this flow could transmit the stress induced by the quakes.


ALASKASTOCK



SOURCE: POLLITZ *ET AL.*


TAYLOR-MOONEY/SIPA PRESS

Slow wave. Alaskan quakes *(top)* may have started a deep stress wave (deep blue) that triggered California quakes *(left)* 20 years later.

"That [stress] wave has to exist," says Bürgmann. "The only question is how strong is it?" To find out, the group created a computer simulation of elastic plates, ductile asthenosphere, and large earthquakes in the northern North Pacific. In the model, the stress wave generated by the quakes moved southward across the Pacific and northward under the Arctic Ocean at a rate that depended on the viscosity of the asthenosphere. When researchers plugged in a viscosity that Romanowicz calls "reasonable but a bit on the low side" of current estimates, the crest of the stress wave entered the eastern Arctic Ocean in the 1970s; it passed off British Columbia around 1975, and California around 1985. Wherever the wave passed, it briefly accelerated plate motions, which could have spurred earthquake activity.

The timing is a good fit to surges of seismic activity, say Pollitz and his colleagues. According to the model, the wave may have triggered the surge of magnitude 5 and greater quakes observed in the eastern Arctic Basin in the 1980s. To the south, the wave's progress—marked by accelerations of only a couple of millimeters per year—could be seen in pulses of increased seismicity in Northern California in the 1970s and Southern California in the 1980s.

Even the types of earthquakes seemed to fit stress-wave triggering, says the group. The Southern California seismicity mostly took the form of quakes on faults other than the San Andreas. The sides of these faults move chiefly up and down rather than sideways, as the San Andreas does. That feature of the seismicity was noted in 1995 by seismologists Frank Press of the Washington Advisory Group in Washington, D.C., and Clarence Allen of the California Institute of Technology in Pasadena, who speculated that a stress wave oriented to favor vertical fault motions might be responsible. The wave set off by the great Alaskan quakes fits the bill, Pollitz's team says. "The whole thing seems to hang together," says Press.

But others point out that the correlation of the passing wave with a flurry of seismicity could be chance. "There have been many interesting patterns in seismology that have turned out to be wonderful coincidences," says seismologist Lucile Jones of the USGS in Pasadena. And the stress wave, dampened by distance, seems too weak to trigger quakes, other researchers say. The extra strain added by the wave would be "really small," says Thatcher, perhaps a factor of 10 smaller than what's assumed to trigger quakes at short range.

"Yes, the strain changes are small," concedes Romanowicz, "but I don't think anyone has a definite idea of how much strain you need to trigger an earthquake." Bürgmann adds that a coincidence is unlikely, because seismicity along the entire west coast fits the stress-wave theory.

Further tests of this bold idea are in the works. Although existing geodetic networks weren't sensitive enough to catch the subtle stress changes signaling the arrival of the wave, says Bürgmann, current systems should record its departure in the coming decade. Then it should become clear whether distant earthquakes are the interfering busybodies he and his colleagues suspect they are.

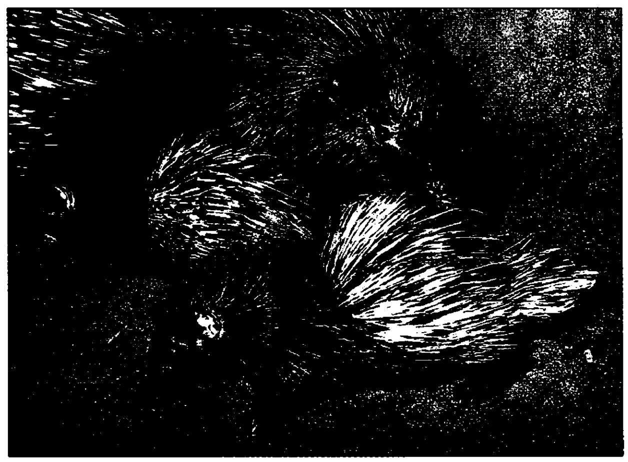
–Richard A. Kerr

ECOLOGY

Ecosystem 'Engineers' Shape Habitats for Other Species

In Israel's Negev desert, some microbes have developed a unique survival strategy: They pave the desert. Several species of bacteria and cyanobacteria secrete long-chain sugars that bind soil and sand into a black crust, which protects their damp colonies from the searing heat. But the microbes' labor benefits other species as well, according to Moshe Shachak and Bertrand Boeken of Ben-Gurion University in Sede Boker, Israel. After a downpour, the asphaltlike patches reduce water absorption by about 30%, increasing runoff, which pools in pits dug by desert porcupines and beetles. Windblown seeds germinate in the moist pits, giving rise to lush oases that can harbor dozens of species. "We see enormous effects ... by a host of tiny organisms," says Shachak.

"Ecosystem engineers" like these microbes have sparked a new approach to assessing how species interact with one another. Shachak, together with ecologist Clive Jones of the Institute of Ecosystem Studies in Millbrook, New York, and John Lawton of Imperial College's Centre for Population Biology in Silwood Park, U.K., have proposed a new concept of how ecosystem engineers, by shaping habitats to their own needs, alter the availability of energy—food, water, or sunlight—and thus dictate the fates of other species.



MICHAEL DICK / ANIMALS ANIMALS

Engineer at ease. The desert porcupine digs holes in the sand that give rise to miniature oases, which attract other species.

The concept has generated quite a stir among environmental scientists since it appeared in the journal *Ecology* last October. "Nobody had stepped back before and asked if this was a general phenomenon, then tried to put down some guiding principles," says David Tilman, an ecologist at the University of Minnesota, St. Paul. "This is one of those rare papers that gets you thinking in a new way." He and others think that after fine-tuning, the concept of ecosystem engineers may be ready to join an elite set of theories, such as natural selection and predator-prey theory, that help explain how species arise and interact.

Missing from ecology's theoretical underpinnings has been a way to account for how species, by altering habitats, perturb other species—even though, as Jones explains, "we've known for a long time that there are things species do to their physical environment that have enormous knock-on effects throughout the ecosystem." Then a few years ago, he and Lawton heard about the Negev story. The scientists soon grasped that ecosystem engineering was far more pervasive than humans erecting skyscrapers or beavers building dams. "Once we started looking in the literature and talking to people about this," says Jones, he and his colleagues realized "how important ecosystem engineers are at affecting species diversity, distribution, and survival."

The concept's guiding principle is that engineers indirectly control the flow of energy within an ecosystem. These species, the ecologists say, can have just as great an influence on an ecosystem as keystone species, or top predators. The concept holds that ecosystem engineers alter habitats through two overarching mechanisms. Autogenic engineers transform ecosystems by their own growth and are integral to the altered environment. Corals, for example, build reefs for their own needs that also serve countless other species. Although some species feed on coral, most, including brittle stars, anemones, and sponges, use reefs only for shelter. Similarly, trees create habitat for myriad species that live in and among tree crotches, where large branches diverge from trunks. Without coral reefs or trees, says Jones, associated species would perish.

The second class of organisms, allogenic engineers, alter the environment and then move on, leaving structures behind. Beavers, for instance, turn stream ecosystems into pond ecosystems by building dams that block stream flow. The pooling water drowns