both the USGS and Lamont models show that this quake "turned off" seismicity over a large part of southern California. But that protection was only temporary. Inevitably, the grinding of tectonic plates slowly increased crustal stress and nibbled at the edges of the 1857 stress shadow. As more and more of the region came out of the shadow, seismic activity returned just after the turn of the century.

The 1857 stress shadow is continuing to shrink. Sykes sees the large 1933 Long Beach and 1992 Landers quakes as examples of faults rupturing within a few decades of emerging from the model's calculated shadow. Ominously, the San Bernardino segment of the San Andreas is due to come out of the 1857 shadow in the next few decades, according to the Lamont model. That, plus the rash of moderate to large quakes around the southern San Andreas since the mid-1980s (*Science*, 10 July 1992, p. 155), and the general belief that this part of the fault could be overdue for rupture (*Science*, 22 July 1988, p. 413), increases the odds that the millions of people living near San Bernardino will be rocked by a near-great quake in the next few decades.

At the same time, northern California is coming out of its own stress shadow. Modeling by Simpson, which he discussed at the AGU meeting, and by Jaumé and Sykes, shows that the great 1906 San Francisco quake cast a stress shadow over most Bay Area faults, imposing a seismic quiescence that only began to lift in the mid-1950s. In 1979, about the time the shadow shrank northward along the Calaveras fault southeast of San Francisco, a sequence of moderate quakes began striking that branch of the San Andreas system.

Farther north lies the worrisome Hayward fault, which cuts through the populous East Bay region and hasn't ruptured since the mid-19th century. According to Simpson's model, the southern end of the Hayward is probably out of the shadow and the northern end is close to being out. But Simpson cautions that many uncertainties remain, such as how much stress a given fault had accumulated before a stress shadow appeared, and how the deep crust responds to stress transfers. For now, conversations among faults will often remain private affairs—but seismologists have at least started to eavesdrop.

–Richard A. Kerr

PARTICLE PHYSICS

Quark Studies Put Theorists in a Spin

AMSTERDAM, THE NETHERLANDS—Eight years ago, a group of European particle physicists studying the internal structure of protons and neutrons—the building blocks of atomic nuclei collectively known as nucleons—made a startling discovery: The three valence quarks within each nucleon, which define its physical properties, do not define its spin. The group, known as the European Muon Collaboration (EMC) and working at the CERN particle physics center near Geneva, calculated the quarks' contribution to be a paltry 20%, a figure that includes contributions from short-lived "sea quarks" created by the gluons that hold the nucleon together. This small fraction presented a major problem for nucleon structure models: If the valence and sea quarks don't provide the spin, what does? The situation was soon dubbed "the spin crisis."

Spin, a fundamental quantum mechanical property of particles, can only assume certain fixed values. Protons and neutrons have a spin of +1/2, while quarks can have spins of +1/2 and –1/2. Until the 1988 EMC results, models of the nucleon simply assumed that its spin was the sum of the spins of the three valence quarks. Within a few years, other groups confirmed the quarks' small contribution, but they came up with widely differing estimates of its size. An experiment known as E142 at the Stanford Linear Accelerator Center (SLAC) in California put it at 57%, and CERN's Spin Muon Collaboration (SMC), successor to EMC, found only 6%. These discrepancies led many researchers to conclude that the experiments were flawed. "We believed there was something wrong with the data," says Stephane Platchkov of France's Atomic Energy Commission at Saclay, south of Paris. More recent results suggest, however, that that comforting assumption is no longer valid: They indicate that the spin crisis seems to be real.

Earlier this month, the three main collaborations that are now investigating quark spin met in Amsterdam to compare notes. Over the past few years, the differences between the teams' results have been decreasing, and at the meeting, results from SMC and another SLAC experiment, E143, both confirmed that quarks contribute around 25% of a nucleon's spin. The third team, the HERMES collaboration from DESY, Germany's particle physics laboratory near Hamburg, which joined the search last year (*Science*, 24 March 1995, p. 1767), is expected to announce a similar figure later this month.

> **"When we compare the asymmetries in the data of SMC and E143, we now see no differences."**
> **—Stephane Platchkov**

The three current groups, as did the EMC team, all use a similar method to assess quark spin. They fire a high-energy beam of electrons or muons, which is spin-polarized—meaning that all their spins are aligned in one direction—into a target of nucleons that are also spin-polarized. Some particles are scattered, deflected from their path, and the probability of scattering by a nucleon is different if their spins are parallel or antiparallel. These differences in scattering probabilities are called asymmetries, and they can be studied by varying the polarization direction of the beam or the target nucleons. Once the asymmetries are known, researchers use quantum theory to calculate the spin contributions made by the quarks.

The three teams found a way around their earlier divergent results by looking more closely at the inner structure of the nucleon. The three valence quarks are bound together in the nucleus by gluons, and researchers soon realized that because quarks exchange, or "radiate," gluons, quantum theory provides "radiative corrections," and these came to the rescue. "When these corrections were calculated and applied to the data, then the different experiments came closer and closer," says SLAC's Linda Stuart, a member of the E143 team. When the latest results are adjusted to compensate for the different beam energies used, they are now in agreement. "When we compare the asymmetries in the data of SMC and E143, we now see no differences," says Platchkov.

But while this has made the experimenters happy, it still leaves theorists with a big problem: Where does the rest of the nucleon spin come from? "We have a part of the spin that is not carried by the quarks, neither the valence quarks nor the quark-antiquark pairs of the sea quarks," says Piet Mulders of NIKHEF, the Dutch National Institute for Nuclear and High-Energy Physics. Most researchers now believe the answer lies with the gluons, but "the question we have now is 'how will we measure this?' " says Mulders.

Also, among the sea quarks, gluons sometimes produce "strange" quark-antiquark pairs, a type of quark that was not expected to occur in normal matter. Both the SMC and E143 have now confirmed reports that these strange quarks make an important negative contribution of about 12% to the nucleon's spin—so reducing the quarks' apparent contribution. So, far from resolving the spin crisis, the closer experimenters look into the nucleon's interior, the stranger it seems.

–Alexander Hellemans

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