The Quiet Before the Quake

Marcia Bjornerud, The New Yorker, 6-9-16

Seismologists are good listeners. In fact, they're all ears. They eavesdrop constantly on the planet, picking up not only vibrations from earthquakes, its loudest outbursts, but also every tectonic creak and groan. In the past decade, a new generation of geophysical instruments and data-processing methods has expanded the spectrum of what is audible, from true earthquakes, which last seconds or minutes, to slow-slip events, which last days, to low-frequency tremor episodes, which last weeks or months. Earth is a noisy, vocal planet that takes full-throated advantage of its thirty-octave range. So when parts of an active plate boundary are found to be completely mute, emitting not even the faintest seismic whispers, geophysicists take note. Along the San Andreas Fault, in central and southern California, there are several such patches, and their stubborn silence has been a persistent mystery. In a paper published this week in *Science*, Junle Jiang and Nadia Lapusta, of Caltech, propose a new model to explain these uncharacteristically taciturn stretches of the fault.

To grasp their argument requires some feeling for the character of the San Andreas and the mechanical behavior of Earth's crust. The fault runs almost the entire length of California, connecting two mid-ocean ridges—underwater formations where oozing volcanoes forge new seafloor. One ridge is off the coast of Cape Mendocino, and the other is in the Gulf of California, off mainland Mexico. In between, the San Andreas cuts through continental crust made of rocks with a wide range of ages, compositions, and geologic features. As a result, the fault's behavior varies significantly along its eight-hundred-mile extent, with different segments responding very differently to the inexorable tectonic shearing between the Pacific and North American Plates. This variability is mostly a good thing, because it means that the whole fault is unlikely to slip all at once in a single cataclysmic earthquake. But the non-uniformity also makes characterizing seismic risk more difficult. Some parts of the fault creep, keeping pace with the motion of the plates, measured in inches per year. Others get stuck for a few decades before letting pent-up stress go in moderate-sized earthquakes. And a few areas, ominously, neither creep nor slip at regular intervals.

Earthquakes along the San Andreas originate at what geologists consider shallow depths, about eight or nine miles down. The rocks there are rigid but brittle, and will fracture like bone china when stressed too much by the motions of the tectonic plates. Below this crispy layer, there is, as in a fresh crème brûlée, a deeper, more pliant level where temperatures are sufficiently high for common minerals like quartz and feldspar to flow plastically as solids. When an earthquake occurs, it begins somewhere in the brittle upper crust and then propagates in all directions. It will generally cease near the base of the brittle zone, because the weak plastic rock below arrests the rupture, in much the same way that rubbery gels act as crack-stoppers between concrete panels on sidewalks or streets. While an earthquake relieves stress on the upper reaches of the fault, the part at the base of the brittle zone, where the rupture ends, may actually become more stressed. On the stretches of the San Andreas that generate regular earthquakes, this area is the source of continuous microseisms, tiny earthquakes smaller than magnitude 2.0 on the Richter scale. They are thought to reflect the long-term relaxation of stresses that were induced during previous major events.

The puzzle is that, on the non-creeping, non-slipping parts of the San Andreas Fault, even microseisms are absent. Significantly, these silent segments correspond with areas that have produced very energetic earthquakes in the historic and prehistoric past—the antecedents of what Californians refer to, with dread and some bravado, as the Big One. These include the great Fort Tejon earthquake of 1857, an event that was almost certainly larger than the infamous 1906 quake in San Francisco, which had an estimated magnitude of 7.8. But if the ruptured zones of these powerful earthquakes ended, as expected, at the base of the brittle crust, there should be more, not less, microseismic activity there.

In the *Science* study, which combines computer modelling of the San Andreas with historical seismic data from Cholame to Coachella, Jiang and Lapusta suggest that the solution to the mystery of the mute fault may be that the great ruptures of the past actually went deeper than previously believed. If these earthquakes penetrated into the warm, malleable layer beneath the upper crust—several miles into the crème of the crème brûlée—then the stress they caused would have been stored there, rather than farther up. In the ensuing decades, that stress would be relaxed not in microseismic rumblings but in silent, viscous flow. As evidence for their theory, Jiang and Lapusta cite outcroppings of ancient fault zones, exhumed by erosion and preserved through geologic happenstance, in which these two modes of deformation are recorded. At these special sites—among them Scotland's Outer Hebrides, the rugged coast of western Norway, and the north woods of Wisconsin—there are smeared-out fault rocks with distinctive veins of dark glassy material, which represent thin films of melt that could only have been generated by frictional heating in large earthquakes.

If Jiang and Lapusta's model is accurate, the unsettling lesson is that the parts of the San Andreas that draw the most attention to themselves through seismic noise are far less dangerous than the quiet ones, silently and stealthily storing up stress over centuries. It is still unclear why these particular regions developed the habit of unleashing large, infrequent earthquakes, but Jiang and Lapusta speculate that they possess unusually uniform frictional resistance, so that when they fail, they fail with terrifying totality. Like a poem whose meaning lies in the space between the lines, the fault's message lies in the stillness between the earthquakes.