Living on the Fault Line

A major earthquake isn’t likely here, but if it comes, watch out.

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This chart shows the location of the Ramapo Fault System, the longest and one of the oldest systems of cracks in the earth’s crust in the Northeast. It also shows the location of all earthquakes of magnitude 2.5 or greater in New Jersey during the last 50 years. The circle in blue indicates the largest known Jersey quake.

Map by Michael Newhouse.

At precisely 8:59 am on February 21, 2010, a magnitude 2.6 earthquake struck New Jersey, its epicenter in Peapack/Gladstone, about seven miles from Bernardsville, NJ. A smaller aftershock followed about two and a half hours later.

After epic earthquakes in Haiti, Chile, Mexico, Indonesia, and China, the 2.6 quake and aftershock that shook parts of New Jersey in February 2010 may seem minor. On the exponential Richter Scale, a magnitude 7.0 quake like the one that hit Haiti in January is almost 4 million times stronger than a quake of 2.6 magnitude. But comparisons of magnitude don’t tell the whole story.

Northern New Jersey straddles the Ramapo Fault, a significant ancient crack in the earth’s crust. The longest fault in the Northeast, it begins in Pennsylvania and moves into New Jersey, trending northeast through Hunterdon, Somerset, Morris, Passaic, and Bergen counties before terminating in New York’s Westchester County, not far from the Indian Point Energy Center, a nuclear power plant. And though scientists dispute how active this roughly 200 million-year-old fault really is, many earthquakes in the state’s surprisingly varied seismic history are believed to have occurred on or near it. The fault line is visible at ground level and likely extends as deep as nine miles below the surface.

During the past 230 years or so, New Jersey has been at the epicenter of nearly 170 earthquakes, according to data compiled by the New Jersey Geological Survey, part of the United States Department of Environmental Protection. The largest known quake struck in 1783, somewhere west of New York City, perhaps in Sussex County. It’s typically listed as 5.3 in magnitude, though that’s an estimate by seismologists who are quick to point out that the concept of magnitude—measuring the relative size of an
earthquake—was not introduced until 1935 by Charles Richter and Beno Gutenberg. Still, for quakes prior to that, scientists are not just guessing.

“We can figure out the damage at the time by going back to old records and newspaper accounts,” says Won-Young Kim, a senior research scientist at Columbia University’s Lamont-Doherty Earth Observatory in Palisades, New York, directly across the New Jersey border. “Once the amount and extent of contemporary damage has been established,” Kim says, “we’re then able to gauge the pattern of ground shaking or intensity of the event—and from there extrapolate its probable magnitude.”

Other earthquakes of magnitude 5 or higher have been felt in New Jersey, although their epicenters laying near New York City. One—which took place in 1737 and was said to have been felt as far north as Boston and as far south as northern Delaware—was probably in the 5 to 5.5 range. In 1884, an earthquake of similar magnitude occurred off New York’s Rockaway Beach. This well-documented event pulled houses off their foundations and caused steeples to topple as far west as Rahway. The shock wave, scientists believe, was felt over 70,000 square miles, from Vermont to Maryland.

Among the largest sub-5 magnitude earthquakes with epicenters in New Jersey, two (a 3.8 and a 4.0) took place on the same day in 1938 in the Lakehurst area in Ocean County. On August 26, 2003, a 3.5 magnitude quake shook the Frenchtown/Milford area in Hunterdon County. On February 3 of last year, a 3.0 magnitude quake occurred in the Morris County town of Mendham. “A lot of people felt this one because of the intense shaking, although the area of intensity wasn’t very wide,” says Lamont-Doherty’s Kim, who visited the site after the event.

After examining the known historical and geological record, Kim and other seismologists have found no clear evidence that an earthquake of greater than 5.3 to 5.5 magnitude has taken place in this area going back to 1737. This doesn’t mean, of course, that one did not take place in the more remote past or that one will not occur in the future; it simply means that a very large quake is less likely to occur here than in other places in the east where the seismic hazard is greater, including areas in South Carolina and northeastern New York State.

But no area on the East Coast is as densely populated or as heavily built-up as parts of New Jersey and its neighbors. For this reason, scientists refer to the Greater New York City-Philadelphia area, which includes New Jersey’s biggest cities, as one of “low earthquake hazard but high vulnerability.” Put simply, the Big One isn’t likely here—but if it comes, especially in certain locations, watch out.

Over millions of years, New Jersey developed four distinct physiographic provinces or regions, which divide the state into a series of diagonal slices, each with its own terrain, rock type, and geological landforms. The northernmost slice is the Valley and Ridge, comprising major portions of Sussex and Warren counties. The southernmost slice is the Coastal Plain, a huge expanse that covers some three-fifths of the state, including all of the Shore counties. Dividing the rest of the state are the Highlands, an area for the most part of solid but brittle rock right below the Valley and Ridge, and the lower lands of the Piedmont, which occupy all of Essex, Hudson, and Union counties, most of Bergen, Hunterdon, and Somerset, and parts of Middlesex, Morris, and Passaic.

For earthquake monitors and scientists, the formation of these last two provinces—the Highlands and the Piedmont—are of special interest. To understand why, consider that prior to the appearance of the Atlantic Ocean, today’s Africa was snuggled cozily up against North America and surrounded by a single enormous ocean. “At that point, you could have had exits off the New Jersey Turnpike for Morocco,” says Alexander Gates, professor of geology and chair of the department of Earth and Environmental Sciences at Rutgers-Newark.

Under the pressure of circulating material within the Earth’s super-hot middle layer, or mantle, what was once a single continent—one that is thought to have included today’s other continents as well—began to stretch and eventually break, producing numerous cracks or faults and ultimately separating to form what became the Atlantic Ocean. In our area, the longest and most active of these many cracks was the Ramapo
Fault, which, through a process known as normal faulting, caused one side of the earth’s crust to slip lower—the Piedmont—relative to the other side—the Highlands. “All this occurred about 225 million years ago,” says Gates. “Back then, you were talking about thousands of feet between the Highlands and the Piedmont and a very active Ramapo Fault.”

Although the northeast-trending Ramapo Fault neatly divides two of New Jersey’s four physiographic provinces, it does not form a so-called plate boundary, as does California’s infamous San Andreas Fault. The Ramapo Fault sits on the North American Plate, which extends past the East Coast to the middle of the Atlantic, where it meets the Mid-Atlantic Ridge, an underwater mountain range in constant flux. The consequences of this intraplate setting are huge: First, as Gates points out, “The predictability of bigger earthquakes on...[such] settings is exceedingly poor, because they don’t occur very often.” Second, the intraplate setting makes it more difficult to link our earthquakes to a major cause or fault, as monitors in California can often do.

This second bit of uncertainty is especially troubling for some people, including some in the media who want a neat story. To get around it, they ignore the differences between plate settings and link all of New Jersey’s earthquakes, either directly or implicitly, to the Ramapo Fault. In effect, such people want the Ramapo Fault “to look like the San Andreas Fault,” says Gates. “They want to be able to point to one big fault that’s causing all of our earthquakes.”

Gates does not think that’s the case, and he has been working with colleagues for a number of years to prove it. “What we have found is that there are smaller faults that generally cut from east to west across the northeast-trending Ramapo Fault,” he explains. “These much smaller faults are all over the place, and they’re actually the ones that are the active faults in the area.”

But what mechanisms are responsible for the formation of these apparently active auxiliary faults? One such mechanism, say scientists, is the westward pressure the Atlantic Ocean exerts on the North American Plate, which for the most part resists any movement. “I think we are in an equilibrium state most of the time,” says Lamont-Doherty’s Kim.

Still, that continuous pressure on the plate we sit on causes stress, and when that stress builds up sufficiently, the earth’s crust has a tendency to break around any weak zones. In our area, the major weak zone is the Ramapo Fault—“an ancient zone of weakness,” as Kim calls it. That zone of weakness exacerbates the formation of auxiliary faults, and thereby the series of minor earthquakes the state has experienced over the years.

All this presupposes, of course, that any intraplate stress in this area will continue to be released gradually, in a series of relatively minor earthquakes or releases of energy. But what if that were not the case? What if the stress continued to build up, and the release of large amounts of energy came all at once? In crude terms, that’s part of the story behind the giant earthquakes that rocked what is now New Madrid, Missouri, between 1811 and 1812. Although estimates of their magnitude have been revised downward in recent years to less than magnitude 8, these earthquakes are generally regarded as among the largest intraplate events to have occurred in the continental United States.

For a number of reasons, earthquakes of plus-6 magnitude are probably not in our future. Still, says Kim, even a magnitude 6 earthquake in certain areas of the state could do considerable damage, especially if its intensity or ground shaking was of sufficient strength. In a state as geologically diverse and densely populated as New Jersey, this is a crucial wild card.

In addition to magnitude, other factors that affect intensity are the distance of the observer or structure from the epicenter, where intensity is the greatest; the depth beneath the surface of the initial rupture, with shallower ruptures producing more ground shaking than deeper ones; and, most significantly, the ground geology or material that the shock wave generated by the earthquake must pass through.
As a rule, softer materials like sand and gravel shake much more intensely than harder materials, because the softer materials are comparatively inefficient energy conductors, so whatever energy is released by the quake tends to be trapped, dispersing much more slowly. (Think of a bowl of Jell-O on a table that’s shaking.)

In contrast, harder materials, like the solid rock found widely in the Highlands, are brittle and break under pressure, but conduct energy well, so that even big shock waves disperse much more rapidly through them, thereby weakening the amount of ground shaking. “If you’ve read any stories about the 1906 earthquake in San Francisco, you know the most intense damage was in those flat, low areas by the Bay, where the soil is soft, and not in the hilly, rocky areas above,” says Karl Muessig, state geologist and NJGS head.

Although the weakest soils are scattered throughout the state, including the Highlands, which besides harder rock also contains areas of glacial lakes, clays, and wetlands, they are most evident in the Piedmont and the Coastal Plain. “The largest expanses of them are in coastal areas where you have salt marshes or large glacial lakes, as in parts of the Passaic River basin,” says Scott Stanford, a research scientist with NJGS and lead author of the estimate. Some of the very weakest soils, Stanford adds, are in areas of filled marshland, including places along the Hudson waterfront, around Newark Bay and the Meadowlands, and along the Arthur Kill.

Faults in these areas—and in the coastal plain generally—are far below the ground, perhaps several hundred to a thousand feet down, making identification difficult. “There are numerous faults upon which you might get earthquake movement that we can’t see, because they’re covered by younger sediments,” Stanford says. This combination of hidden faults and weak soils worries scientists, who are all too aware that parts of the coastal plain and Piedmont are among the most densely populated and developed areas in the state. “Any vulnerable structure on these weak soils would have a higher failure hazard,” Stanford says. And the scary truth is that many structures in New Jersey’s largest cities, not to mention New York City, would be vulnerable, since they’re older and built before anyone gave much thought to earthquake-related engineering and construction codes.

For example, in the study’s loss estimate for Essex County, which includes Newark, the state’s largest city, a magnitude 6 event would result in damage to 81,600 buildings, including almost 10,000 extensively or completely; 36,000 people either displaced from their homes or forced to seek short-term shelter; almost $9 million in economic losses from property damage and business interruption; and close to 3,300 injuries and 50 fatalities.

All of this suggests the central irony of New Jersey geology: The upland areas that are most prone to earthquakes—the counties in or around the Ramapo Fault, which has spawned a network of splay, or auxiliary faults—are much less densely populated and sit, for the most part, on good bedrock. These areas are not invulnerable, certainly, but, by almost all measures, they would not sustain very severe damage, even in the event of a higher magnitude earthquake. The same can’t be said for other parts of the state, where the earthquake hazard is lower but the vulnerability far greater. Here, the best we can do is to prepare—both in terms of better building codes and a constantly improving emergency response.

Meanwhile, scientists like Rutgers’s Gates struggle to understand the Earth’s quirky seismic timetable: “The big thing with earthquakes is that you can commonly predict where they are going to occur,” Gates says. “When they’re going to come, well, we’re nowhere near being able to figure that out.

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