The Pohang earthquake, which struck South Korea last November, caused $52 million in damage. KIM JUN-BEOM/YONHAP VIA AP

Second-largest earthquake in modern South Korean history tied to geothermal plant

By **Paul Voosen** | Apr. 26, 2018 , 2:00 PM

There's a lot to like about geothermal power. Even in regions devoid of natural hot spots, engineers can harvest energy by injecting high-pressure water deep into Earth, where it's heated by hot granite crust before being pumped back up to heat homes or generate power. That was the goal in Pohang, South Korea, where a $38 million pilot plant sought to bring the carbon-free power source to the country. But that plant, it now appears, brought something else: a large, damaging earthquake.

The magnitude-5.5 Pohang earthquake, the second largest in the country's modern history, struck the densely populated region on 15 November 2017, injuring 90 people and causing $52 million in damage. It crumbled walls, cracked roads, and collapsed old buildings. And, according to two studies published today in *Science*, it is likely the largest earthquake ever to be triggered by enhanced geothermal power.

Perched on South Korea's southeast coast and far from grinding tectonic plates, Pohang is an unlikely spot for a big earthquake. Before the geothermal plant's two wells were drilled, there had never been an earthquake there of any significance, says Kwanghee Kim, a seismologist at Pusan National University in Busan, South Korea, and lead author of one study. But while Kim was monitoring the aftermath of an unrelated earthquake in 2016, he began to detect rumbles from Pohang. That prompted his lab to deploy eight temporary seismic sensors at the site, which were finally in place on 10 November 2017. He expected any quakes to be small—after all, the largest previous quake tied to enhanced geothermal power, in Basel, Switzerland, was just 3.4 in magnitude.

It took only 5 days to be proved wrong. "The Pohang earthquake was larger than any predicted by existing theories," Kim says. Although some initial measures placed the source of the quake several kilometers away from the plant, Kim's network revealed that the earthquake, and several of its foreshocks, **all began right below the 4-kilometer-deep well** used to inject water into the subsurface to create the plant's heating reservoir. Indeed, it appears likely that the well's high-pressure water lubricated an unknown fault in the rock, causing it to slip and triggering the quake, Kim says.

A second paper, by European scientists who used regional seismic data, reinforces the South Korean team's results, in particular its shallow depth. That study also points out that an earlier 3.1-magnitude earthquake **also took place near the well bottom**, increasing the odds of a common source. Satellite measures of shifts in the surface after the November 2017 quake support that idea, says Stefan Wiemer, the second study's lead author and director of the Swiss Seismological Service in Zurich. It's clear the locked fault was storing energy that was waiting to be released, Wiemer says. "If that fault would have gone next Tuesday or 50 years from now, we'll never know."

In the past decade, states such as Oklahoma have seen a spike in induced earthquakes, because of the injection of wastewater from hydraulic fracturing and oil and gas production. However, unlike the fracking operations, the water from enhanced geothermal power does not stay underground or cause a long-term buildup of pressure. That has prompted some scientists to base earthquake risk assessments for geothermal operations largely on how the wells are operated, including the amount or rate of liquid injected. The Pohang quake is a sign that this needs to change, and that the risks are higher, Kim says. "[This] should be a wake-up call."

If the results hold up, they will be a troubling development for countries such as Switzerland, which plans to use geothermal power to cut fossil fuels. They will also harm geothermal developers globally, who have only just begun to recover from fears prompted by previous, smaller earthquakes. Perhaps most worrisome, Pohang used a new technique meant to limit earthquake size called "soft

stimulation" just a few months before the temblor. Like all enhanced geothermal methods, this technique injects water under pressure to create cracks in the rock, but does it in limited, gentle ways to limit earthquake size.

The definitive word on the earthquake's source should come from a South Korean government commission, which includes a team of international scientists that will examine seismological records taken by the temporarily shuttered plant. The two new studies will play an important role in fashioning that investigation, says William Ellsworth, a geophysicist at Stanford University in Palo Alto, California, who is working on the government study. Kim's study, in particular, "makes a very strong case that the earthquake began within or near the zone that was stimulated," Ellsworth says.

This shouldn't derail the broader development of enhanced geothermal, Wiemer adds. After all, the United States has found ways to tolerate many larger quakes tied to wastewater injection. And the Pohang event, whatever its cause, will likely be a boon for the study of earthquake formation, Ellsworth adds. Very rarely is the source of a quake so directly imaged. "We have a lot to learn from careful analysis and study of this event."

But residents of Pohang are wondering when things will settle down. Another 4.6-magnitude quake struck during this year's Winter Olympics. They frequently come to Kim seeking answers. Will the seismicity stop? What's the long-term risk? "Whenever I receive questions, I find myself in an awkward situation," Kim says. "We still do not understand what is happening and what will happen."

***Correction, 30 April, 10:50 a.m.:** A previous version of this story implied that wastewater only came from wells produced with hydraulic fracturing; conventional oil and gas drilling in Oklahoma also produces wastewater.*

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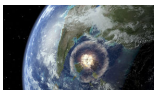

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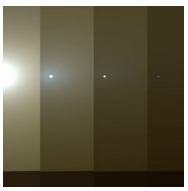

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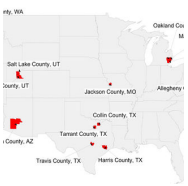

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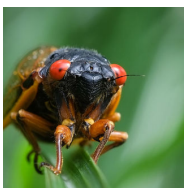

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