## ALOHA, MAGMA!

## Surprise! Geothermal engineers drill into lava

hile drilling deep into Earth, geothermal engineers struck geological gold, opening a never-before-seen window into a classic geologic process: how basalt magma becomes granite. The find, they say, could amount to the first magma observatory on Earth.

Ormat Technologies, a geothermal company, has been producing electrical power on Hawaii's Big Island since 1989. In 2005, the company decided to drill a deep injection well at its site, Puna, located on the eastern part of the island. But about 2.5 kilometers down, the drill suddenly dropped straight through solid rock into molten magma.

That they might drill into magma isn't particularly surprising, says William Teplow, a consulting geologist for Ormat. The Big Island is dominated by active volcanoes, including Kilauea, which has been actively erupting along its eastern rift zone for more than 25 years. "If we had hit molten basalt, it would not be a big surprise," Teplow says.

But the magma they encountered wasn't basaltic.

During drilling, the team was keeping close watch over these wells, located in one of the highest-temperature geothermal fields in the world, with production temperatures hovering around 350 degrees Celsius. Once exposed to the air, the topmost magma in the well cooled rapidly, forming a skin of glass over the still-molten magma below. When the drill bit hit the magma, the team pulled it up and then sank the drill bit once more, this time drilling into the newly formed glass and retrieving the cuttings.

"We knew that they were highly anomalous as soon as we drilled them," Teplow says. The glass cuttings that came back to the surface from the well were clear and colorless — but basalt, when it forms glass, is an inky black. "It was very striking, and we knew immediately that we had some anomalous body of rock."

Teplow brought the cuttings to geologist Bruce Marsh of Johns Hopkins University in Baltimore, Md. Marsh analyzed their chemical composition: They

turned out to be dacite — an intermediate type of volcanic rock between basalt and granite, and chemically distinct from basalt. The team announced their findings at the American Geophysical Union's annual meeting in San Francisco, Calif.

"I was elated," Marsh says. The well, he says, is a window into a classic geologic process: the process by which a basalt magma chemically differentiates into granite, the rock that makes up much of the continents (as opposed to the seafloor). Differentiation is a gradual process: As some of the minerals in the melt cool and solidify, some remain molten longer. As a result, the melt that's left behind becomes more and more chemically different from the original magma.

Although the differentiation of basaltic crust into granitic crust is a fundamental process in geology, making the continents chemically distinct from the ocean floor, geologists never see this process in action. Instead, they have to study it in a "post-mortem" fashion, Marsh says. "We try to piece history back together

## TRACKING THE TIMING OF EARTHQUAKES



Memorial Stadium at the University of California at Berkeley straddles the Hayward Fault, which researchers say is ready to quake.

ow often do earthquakes happen on the same fault? This question has long been the cause of headaches for seismologists who try to calculate earthquake probabilities. They are generally torn between two schools of thought on earthquake occurrence: that earthquakes occur randomly, or that they strike within certain time intervals. But a new study provides evidence that California's southern Hayward Fault shakes regularly, lending credence to the idea that earthquake occurrence on a fault is not random.

The time-independent earthquake model assumes that earthquakes can happen anytime, anywhere on a fault, and that one big quake can immediately follow another because not all stress may be relieved. Such behavior is similar to that of hurricanes, says Seth Stein,



from systems that were once alive." Seeing this process in its "natural habitat," on the other hand, is like "Jurassic Park" — but for geologists, he says.

The find could be a boon to geothermal energy extraction, Teplow says. Around the world, scientists and engineers are looking at sites as much as five kilometers deep inside Earth for hot-enough rock to produce geothermal energy, but at the Puna site, super-hot rock - 1,050 degrees Celsius - is only

2.5 kilometers deep, he says. "All the facilities are in place for studying this mass of hot rock."

There's a lot that's not yet understood about this find and the geothermal field, Marsh says, including the size and shape of the dacite magma body, as well as its age. "This is an unprecedented discovery," he says. "It's just the tip of the iceberg."

**Carolyn Gramling** 

a geophysicist at Northwestern University in Evanston, Ill. "A month after a hurricane hits New Orleans it could easily get hit by another one because there is so much energy out there in the water that no hurricane soaks up much of it," he says. The time-dependent model, on the other hand, suggests that a certain amount of time has to pass after a big earthquake before another one can hit, because time is needed to "reload" a fault and build up enough stress for it to rupture again, Stein says.

Testing which model is correct is difficult, Stein says, because "you need a large and really good history of earthquakes and there aren't many out there."

Large earthquakes are infrequent — the recurrence on the southern Hayward, for example, is about 210 years — and accurate historic records don't go back very far for most faults, says Tom Parsons, a geophysicist at the U.S. Geological Survey in Menlo Park, Calif., and lead author of the new study, published in Geophysical Research Letters. So Parsons examined data on the Hayward Fault assembled from paleoseismic records going back about 2,000 years. Using statistical simulations, he found that the time-dependent model fit the data better than the time-independent model.

But paleoseismic data have their limitations, Parsons says. "If you dig a trench across a fault, you can see horizons in

the sedimentary layers that are offset by earthquakes. But then you have to rely on radiocarbon dating to get the timing and there are always uncertainties." It also isn't always clear whether the tiny pieces of carbon picked from a sediment layer were deposited exactly at the time of an earthquake or a little before or after, he adds.

Parsons' calculations took these uncertainties into account; however, there may be others, Stein says. For example, there is always a possibility of missing an earthquake in the sedimentary record and "if you missed one, then that changes your history." Still, he says, the study makes a "pretty good case" for time-dependent behavior.

The findings have implications for how scientists tackle earthquake hazards in the future, Stein says. "If this holds up and if we find the same pattern on other faults, which we don't know yet, then we can start to be smarter. For example, if we get to the point where we understand where the higher-probability earthquakes are going to be, we would probably put our resources there preferentially and use our earthquake mitigation dollars more effectively."

**Nicole Branan** 

For more information on time-dependent and time-independent earthquake models, see the January issue of EARTH, available through www.earthmagazine.org.

EARTH February 2009 • 19