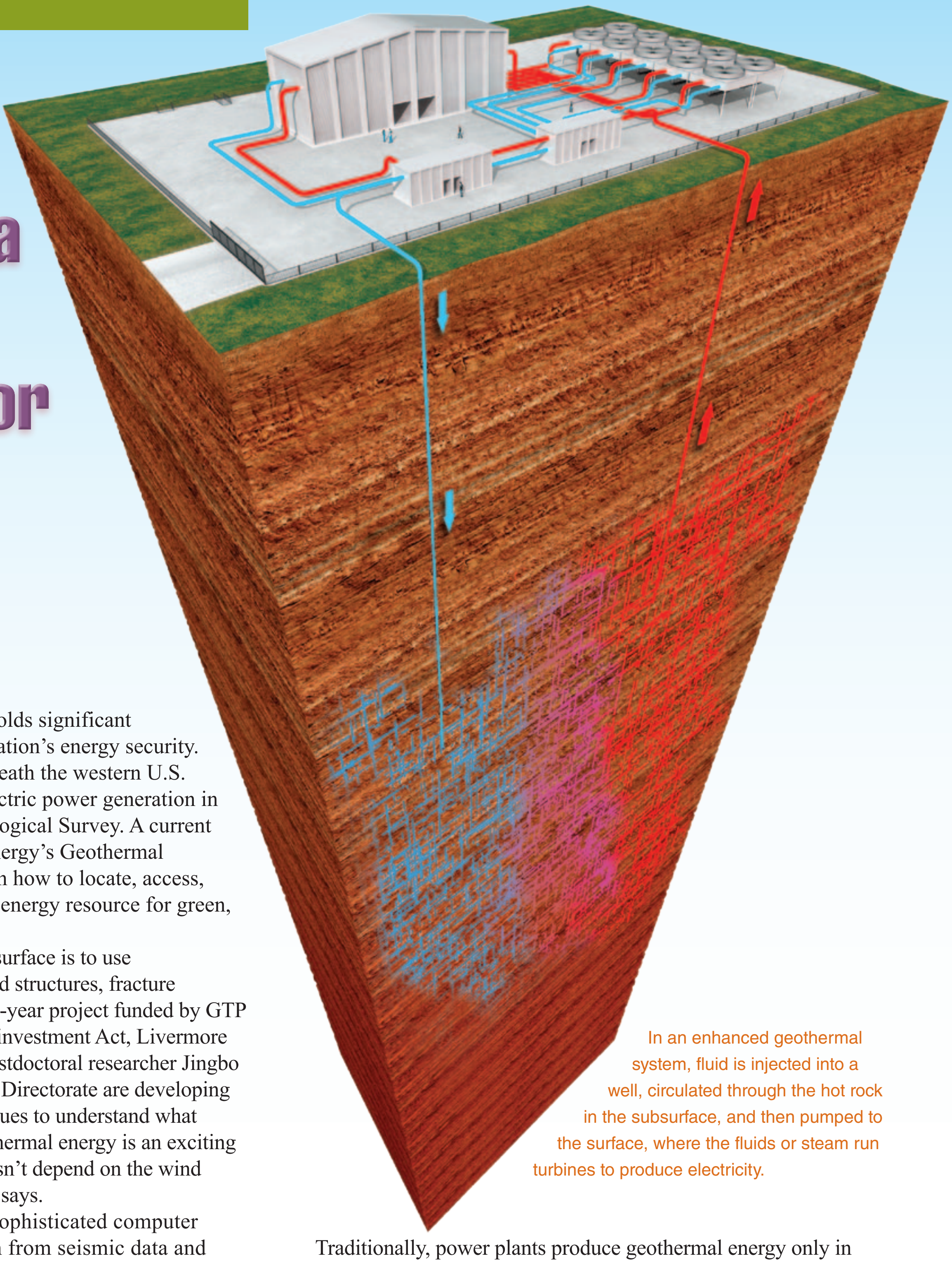
Seismic Data Pinpoint Fractures for Geothermal Energy



In an enhanced geothermal system, fluid is injected into a well, circulated through the hot rock in the subsurface, and then pumped to the surface, where the fluids or steam run turbines to produce electricity.

THE hot rock in Earth's subsurface holds significant potential for helping to ensure the nation's energy security. In particular, geothermal resources beneath the western U.S. could provide a large portion of the electric power generation in the country, according to the U.S. Geological Survey. A current research focus of the Department of Energy's Geothermal Technologies Program (GTP) is to learn how to locate, access, and effectively use this vast renewable energy resource for green, baseload, electric generation.

One method of interrogating the subsurface is to use microseismic events to map underground structures, fracture networks, and fluid pathways. In a three-year project funded by GTP through the American Recovery and Reinvestment Act, Livermore seismologist Dennise Templeton and postdoctoral researcher Jingbo Wang of the Physical and Life Sciences Directorate are developing advanced microseismic analysis techniques to understand what happens beneath Earth's surface. "Geothermal energy is an exciting renewable energy source because it doesn't depend on the wind blowing or the sun shining," Templeton says.

Templeton's team is developing a sophisticated computer algorithm to better extract information from seismic data and ultimately promote the development of cost-effective enhanced geothermal systems (EGSs) that can draw energy from the subsurface and convert it for electric generation. Jeff Roberts, who leads the Laboratory's Renewable Energy Program, says, "Our hope is that we can expand our use of seismic information to understand fluid injection and where that fluid travels in the subsurface."

Traditionally, power plants produce geothermal energy only in high-temperature locations where naturally occurring interconnected cracks are filled with hot water or steam. However, much more geothermal energy is located in dry or impermeable rock, where water or a network of cracks may not be present. The temperature of Earth at a depth of 3 to 10 kilometers is highly variable but can exceed 300°C. EGS technology can be used to enhance existing fractures or create new ones and introduce water into these hot subsurfaces, thereby expanding the number of viable geothermal sites. Once an underground reservoir of water-filled cracks is created, power plants at the surface can either directly produce steam or use the geothermally heated water to create steam, which then turns the turbines that power generators.

Matched Field Processing

Creating and maintaining an underground reservoir, however, can result in the occurrence of microseismic events. Livermore researchers are providing better insight to the development and evolution of an EGS reservoir with the adaptation of a signal-processing technique called matched field processing (MFP). MFP was originally developed by the underwater acoustics community for detecting and tracking sources of underwater sound.

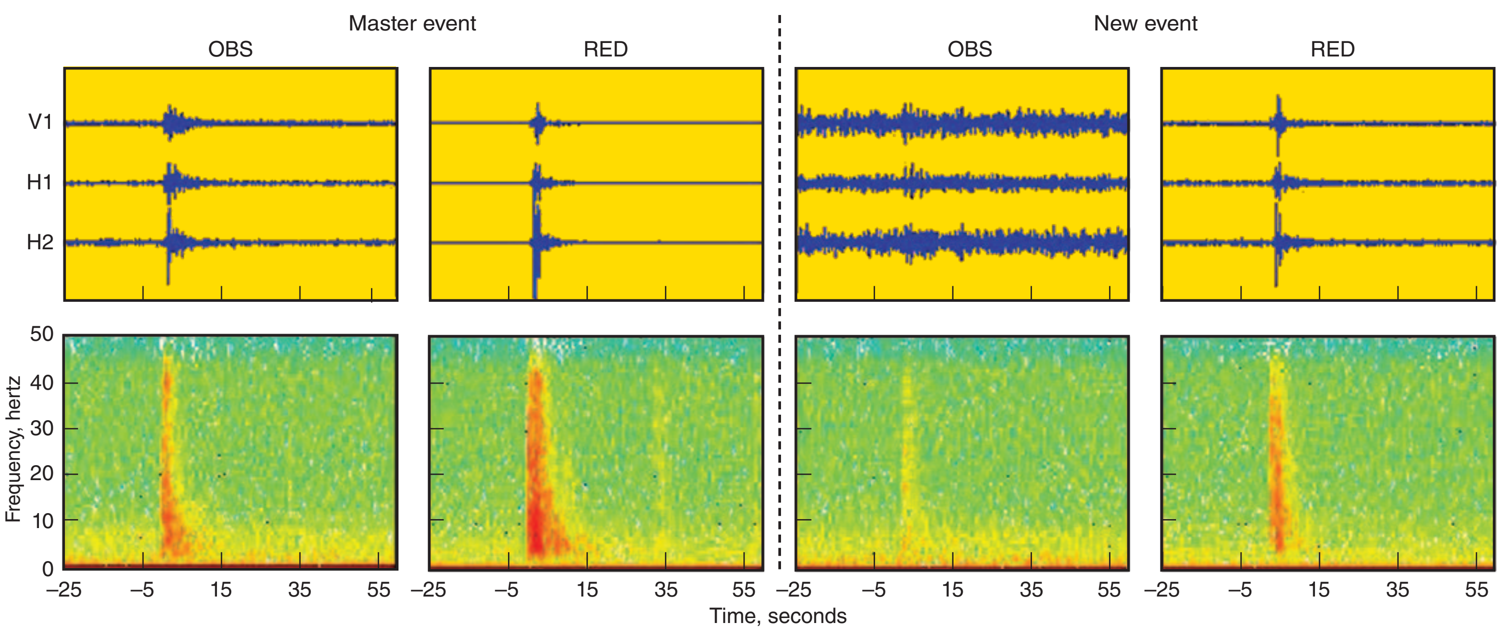
Dave Harris, former program manager for nuclear explosion monitoring and another member of Templeton's team, was among the first to adapt MFP for use with seismic data in an effort to distinguish legitimate mining explosions—multiple charges set up in a series known as ripple fire—from possible nuclear explosions. Harris says, "In geothermal research, we can use MFP to detect and map the distribution of microearthquakes produced by fracture growth. In this way, we can determine where injected water has traveled and how far a fracture has extended." These microearthquakes have tiny seismic signals, many of which have overlapping waveforms when recorded on a seismometer. Templeton emphasizes that the team is measuring very small events that people usually do not feel.

Master Events Serve as Templates

The most successful use of the MFP technique is empirical—that is, observed signals from previously detected microearthquakes serve as templates to look for new events. "Essentially, we break a subsurface area into a collection of cells, and a surface network of seismometers is used to produce a waveform pattern," says Harris. "We then compare the observed data against the waveform pattern for each cell. This comparison through all cells enables us to build a seismicity map of the rock volume surrounding an injection well."

Between November 2009 and December 2010, Livermore seismologists applied empirical MFP to continuously recorded data obtained from seismic stations in the Salton Sea Geothermal Field in Imperial County, California. The regional earthquake catalog listed 1,536 known seismic events in the study area. "We looked through all the events and found 231 events to use as master events," says Wang.

Templeton processed both the master events and the incoming seismic data (at discrete time intervals) and then matched the amplitude and phase of the incoming seismic data with the



In this comparison of seismic signals of a master event and a newly detected event recorded at the Salton Sea Geothermal Field in California, the top plots show three-component (one vertical, two horizontal) seismic records of ground motion as a function of time at two seismic instruments: OBS and RED. The bottom plots show the frequency content of the vertical component of ground motion as it changes with time. Note how the seismic signal of the new event at station OBS is extremely small compared to the background noise.

Livermore seismologist Dennise Templeton (left) and postdoctoral researcher Jingbo Wang install seismometers at AltaRock Energy's Davenport Newberry Enhanced Geothermal System Demonstration Site near Bend, Oregon. (Photo courtesy Pete Erickson/*The Bulletin*.)

precomputed master templates. "We identified 5,357 events in our study area that had magnitudes between 0.0 and 1.1 on the Richter scale, most of which had been previously unrecorded," Templeton says. The Richter scale (used to quantify the energy contained in an earthquake) is logarithmic—a logarithm is a number that shows how many times a base number (such as 10) must be multiplied by itself to produce a third number (such as 100)—so the scale does not start at zero. A –2 event, for example, is the equivalent of the shock generated by dropping a gallon of milk or a brick on the floor. The MFP technique has proven useful in identifying many more seismic events than are recorded in traditional earthquake catalogs. Detecting such low-magnitude events is important for obtaining an early indication of where injected fluids are traveling and determining the fracture network.

A more ambitious approach being investigated is to calculate waveform patterns using a sophisticated geologic model of the subsurface and high-performance computing resources. These synthetic master events would show how a modeled earthquake might look at a specific location on Earth's surface. The modeled earthquakes would then be used to create synthetic master templates.

In an effort to apply MFP to an existing EGS site, Livermore researchers have formed a working partnership with AltaRock Energy, Inc., a renewable energy production and technology company that uses innovative technologies to turn the natural heat within Earth into electricity. The Livermore team has installed Laboratory-owned seismometers at AltaRock's Davenport Newberry EGS Demonstration Site near Bend, Oregon. The Newberry project seeks to demonstrate the viability of improved technology to create geothermal reservoirs that can extract heat from the subsurface in locations where high temperatures can be reached by conventional drilling.

Wang is responsible for processing the preliminary MFP data and analyzing the results to better image the fracture network using the large number of newly identified events. "When we screen MFP detections, we filter out false detections in a predefined frequency band," she says. "We are interested in smaller events because we believe they point to small fault slips and will provide us with a detailed image of the fracture network."

The physical fracture process is complicated and not well understood. With geothermal energy extraction, injected water causes both physical and chemical changes. For example, as water is injected into the reservoir, the subsurface pore pressure increases, which can decrease the static frictional resistance on nearby faults, thereby facilitating seismic slip in the presence of an existing deviatoric stress field. Wang says, "We need a complete picture of the fracture network to help us understand this complex process so we can develop a more realistic model for optimal reservoir design."

Instead of drilling a monitoring well to identify microseismic events in a geothermal reservoir, the researchers use MFP to analyze the data provided from surface seismometers to image the fracture network. "Industry will benefit from this alternative, low-cost, microseismicity mapping method," Wang says.

Templeton notes, "At this early stage, the simulations are written in a Java program and run on my desktop. However, the opportunity exists to develop software for operators of EGS sites to use in identifying fractures and adjusting a well's water pressure without the need for special training in signal-processing algorithms or seismology."

The Livermore team's research is aimed at making geothermal resources a viable energy solution. "We could provide significant baseload electric generation for the entire country for hundreds of years, if we extract a small fraction of the geothermal energy at depth," says Roberts. "It's a phenomenal low-carbon renewable resource."

—*Kris Fury*

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