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LLNL-JRNL-405756

Future Technologies to Enhance Geothermal Energy Recovery

Jeffery J. Roberts, Nalu Kaahaaina, Roger Aines, Jay Zucca, Bill Foxall, Cindy Atkins-Duffin

July 29, 2008

Geothermal Tomorrow

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Jeffery J. Roberts, Nalu Kaahaaina, Roger D. Aines, John J. Zucca, Bill Foxall, and Cynthia E. Atkins-Duffin

Geothermal power is a renewable, low-carbon option for producing base-load (i.e., low-intermittency) electricity. Improved technologies have the potential to access untapped geothermal energy sources, which experts estimate to be greater than 100,000 MWe. However, many technical challenges in areas such as exploration, drilling, reservoir engineering, and energy conversion must be addressed if the United States is to unlock the full potential of Earth's geothermal energy and displace fossil fuels. (For example, see Tester et al., 2006; Green and Nix, 2006; and Western Governors' Association, 2006.) Achieving next-generation geothermal power requires both basic science and applied technology to identify prospective resources and effective extraction strategies.

Lawrence Livermore National Laboratory (LLNL) has a long history of research and development work in support of geothermal power. Key technologies include advances in scaling and brine chemistry, economic and resource assessment, direct use, exploration, geophysics, and geochemistry. For example, a high temperature, multi-spacing, multi-frequency downhole EM induction logging tool (GeoBILT) was developed jointly by LLNL and EMI to enable the detection and orientation of fractures and conductive zones within the reservoir (Figure 1). Livermore researchers also conducted studies to determine how best to stave off increased salinity in the Salton Sea, an important aquatic ecosystem in California.

Since 1995, funding for LLNL's geothermal research has decreased, but the program continues to make important contributions to sustain the nation's energy future. The current efforts, which are highlighted in this report, focus on developing an Engineered Geothermal System (EGS) and on improving technologies for exploration, monitoring, characterization, and geochemistry. Future research will also focus on these areas.

Techniques to Discriminate Geothermal Resources

Most known geothermal resources in the Basin and Range province of the western United States are associated with active fault systems. Studies show that hydrothermal fluids in active fault systems circulate through high permeability fractures from deep underground to relatively shallow levels, where they can be accessed for production. For example, at the Dixie Valley field, hydraulically conductive fractures within the Stillwater fault zone are oriented such that fractures are critically stressed for normal shear failure under the regional tectonic stress field (Barton et al., 1997). In general, therefore, we might expect geothermal resources to occur in areas where seismic strain across faults is extremely high and where faults are favorably oriented with respect to the regional strain tensor. In the Basin and Range, these faults would strike normal to the direction of maximum extension. Expanding this hypothesis, Blewitt et al. (2003)

proposed that geothermal resources occur in areas where fault-normal extension associated with shear strain is the greatest.

Until recently, mapping ground displacements from space of less than 1 cm was extremely difficult. LLNL is applying a new technique and refining it for geothermal applications called repeat-pass Interferometric Synthetic Aperture Radar (InSAR). The method uses the radar imaging of Earth's surface to identify potential geothermal resources. Satellite-borne synthetic aperture radar images Earth's surface during two orbits, recording data at the surface position and using the same viewing geometry during both orbits. The maximum separation (spatial baseline) between the two orbital positions is generally 1 km or less, depending on the radar frequency. The difference between the phases of the two radar returns is proportional to any change in the slant distance (range) from the ground to the radar caused by a subsurface displacement that occurs between the orbits. The topographic contribution is subtracted using a digital elevation model or additional orbits. The displacement contributions are then mapped over the entire radar scene to produce a phase difference map, or interferogram, that can be converted to a range-change map (Figure 2). Under favorable conditions, InSAR can measure displacements as small as a few mm. Displacement maps of geothermal regions using InSAR detect changes in elevation that can be used to locate regions of high strain that are favorable for drilling, and to manage geothermal systems. For example, these techniques can provide independent estimates of the amount of steam removed or fluid injected into a system.

The Stochastic Engine—Converting Data to Decisions

Geophysical data are difficult to acquire and, once obtained, are often hard to interpret. For example, drilling into Earth's subsurface to determine reservoir characteristics at a given location is not only expensive but also provides limited information. Computer models can be made more meaningful when they take into account the uncertainty in those measurements, and combine multiple measurements into one analysis. Stochastic models evaluate many different descriptions of a problem to understand how the small amount of data can result in a range of interpretations. This often requires large numbers of calculations. Using high-performance supercomputers such as Thunder and Atlas LLNL scientists explore groundbreaking ideas in statistical theory to develop stochastic descriptions quantitatively, providing a more complete picture of the subsurface.

This technology, called a stochastic engine, links predictive models, advanced statistical methods, and refined search methods. Using this technology, scientists can incorporate a proposed subsurface configuration into a computer model and produce a geophysical simulation. The simulated result is compared to actual data. If the result is consistent with observed data, it becomes part of the final analysis, leading to a clear understanding of which outcomes are very likely, which are less likely, and where more information could best be used.

The stochastic engine concept uses techniques developed at Livermore and has been applied to a number of research areas including environmental remediation, CO_2 sequestration, and geothermal exploration. The power of the stochastic engine comes from its ability to refine a model by successively narrowing down the possible configurations of a hypothetical model. The refinement is done over progressive layers of data.

For example, suppose an area of interest is known to be composed of seven layers that could be either highly fractured or intact. Geophysical measurement, such as EM, Vp/Vs, or gravity of that volume, gives a value of "11". The stochastic approach calculates which configurations of rock layers, and in which positions, give values close to 11. Each case with a value near 11 is passed on to the next stage of analysis. There, the model will continue to restrict possible configurations but base its decisions on other data types, such as water, temperature, or pressure. For the simple case cited here, scientists can easily compile and compare all the possible configurations. However, for a large area the possibilities are far too numerous and we rely on computational techniques. The stochastic engine helps narrow the solutions by performing an efficient intelligent search through the collection of possible reservoir configurations, rapidly identifying the configurations that most closely match all the data. The stochastic engine is designed to choose system configurations that are consistent with observed data, allowing much more tightly constrained answers than conventional methods. Only the ways the system can possibly exist are considered. The goal is not to find a single answer, but all of the good answers. Our future objective is to adapt the Stochastic Engine to jointly invert multiple geothermal exploration data sets for better defining drilling targets to improve the success rate in finding economic resources

EGS—Controlling Fracture Permeability Evolution

Enhanced geothermal systems (EGS) is a technology that can be used to improve the energy recovery from a reservoir that has insufficient permeability or fluid. The use of EGS has the potential to increase geothermal electrical generation to over 100 GWe in the U.S. by 2050 (Tester, 2006). One technical challenge limiting our ability to utilize enhanced geothermal energy recovery is the changing nature of fracture permeability. Mechanisms such as mineral precipitation and dissolution, flow rate, and stress can affect the underground environment, causing subsurface flow to slow over time or stop completely. EGS research performed at LLNL is aimed at understanding the mechanisms and rate of change to predict the evolution of fracture permeability and to evaluate strategies to enhance and maintain permeability in a given location.

To develop EGS, geophysicists and geochemists in LLNL's Geothermal Program combined laboratory experiments and computer modeling to characterize the hydraulic and geochemical properties of various soil samples (Figure 3). As part of this project, they quantitatively assessed how effective stress, fluid chemistry, and temperature will affect permeability in natural and artificial fractures. They also used current technologies to analyze data from past field experiments, allowing them to separate the physical and chemical processes that affect fracture evolution. For example, flow simulations in the measured aperture field indicate that flow channeling may lead to localized variations in reaction rates. Statistical analysis of fracture apertures for two core samples demonstrated that EGS produced fractures with similar aperture distribution and spatial correlation will have different rates of permeability evolution depending on fluid composition and flow rate. Preliminary results from hydraulic modeling indicate that variations in particle residence times will affect local geochemical reaction rates.

LLNL's expertise at geochemical modeling is critical to the success of EGS and other geothermal technologies. These models help researchers interpret experimental data and extrapolate the results to a broader range of expected conditions. For example, geochemical modeling can simulate the physical changes occurring in a fractured system during fluid transport and to predict how different injections fluids will affect permeability during the average fluid residence period. Numerical models of representative geothermal reservoirs can also be used to optimize production and maximize reservoir lifetime.

A common problem in geothermal recovery is that minerals such as silica and lithium precipitate through flow channels, reducing fracture permeability. Removing the minerals is an expensive, time-consuming process that limits the usefulness of enhanced geothermal recovery. To improve the long-term effectiveness of an EGS reservoir, researchers need to reduce the costs for maintaining fracture permeability. One approach, developed by a team of Livermore geochemists and an industrial partner, is to extract commodity metals from the reservoir for use in other applications. This work recently led to technology licensing for a proprietary process to convert extracted lithium to lithium carbonate, a key component in batteries for electric vehicles and energy storage technology.

Geothermal Research to Improve Energy Security

Energy security is pressing challenge for the United States, but one that offers tremendous opportunity for scientific innovation. Enhanced energy recovery through an engineered geothermal system could help reduce the nation’s dependence on imported oil. However, more work is needed before EGS can be successfully deployed on a large (nation-wide) scale. In particular, the lifetime of EGS reservoirs is not long enough to make this a cost-effective approach for geothermal recovery. In addition, researchers need improved tools to locate the optimum sites for geothermal production and new technologies to access the energy trapped deep underground.

LLNL offers a unique combination of computational, theoretical, modeling, and experimental capabilities that directly address many of the nation’s energy problems, including geothermal energy. The Laboratory’s Geothermal Recovery Program together with other national laboratory, industry and industrial partners is building on its past successes in exploration technologies, geochemical analysis, and EGS processes to develop integrated geophysical approaches for geothermal energy production. Future research activities will focus on enabling technologies for better site selection, reservoir management and EGS.

Figure 1. GeoBILT EM Induction logging tool being deployed at Dixie Valley.

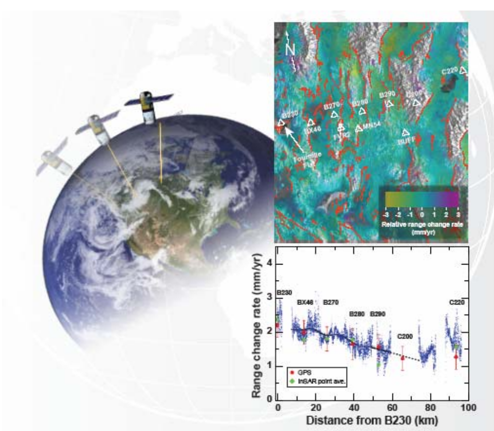

Figure 2. InSAR is used to investigate the role strain concentration plays in localizing geothermal resources in the western Basin and Range. Work was performed to develop and test a method to identify hidden geothermal resources based on detection of localized strain anomalies on a regional basis using InSAR. This technology will provide a cost-effective regional exploration tool that will contribute the goal of

increasing the success rate in finding new economic resources.

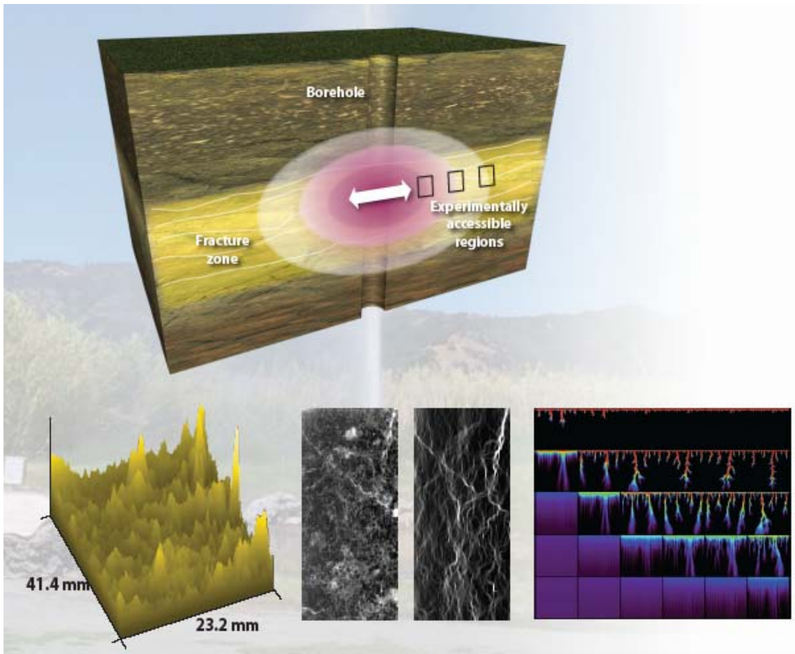

Figure 3. Schematic showing an enhanced geothermal reservoir (top). Permeability is increased in the hot region, and fluids are pumped into the reservoir. Integrated laboratory-scale experimental/computational investigations (bottom images: fracture aperture, flow streamlines, model showing development of channeling, left-to-right) lead to better models of mechanisms that alter transmissivity in Enhanced Geothermal Systems and provide insights into the scaling of important coupled hydraulic/mechanical/chemical/thermal processes that aid in creating and maintaining fracture permeability.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.