Description of Enhanced Geothermal Reservoir Systems: A Feasibility Study

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Summary: The primary driving mechanism for conventional geothermal systems is the natural circulation of hydrothermal waters in porous and permeable rocks. The abundance of such natural sources of hydrothermal circulation is geographically limited. There are, however, abundant distributions of hot granitic basement rocks in the subsurface, saturated with hot waters but with little or no permeability for natural fluid circulation. In addition, there are also such rocks with insufficient water saturation. If these rocks are brittle, they can be made permeable by hydraulic fracturing. Following permeability enhancement, injecting cold fluid from the injection wells, and extracting hot fluids from the production wells can be used for energy production. In many situations, however, the rocks are not brittle and permeability enhancement by hydraulic fracturing is difficult. In such situations also it is possible to convert them into reservoirs using a system where a cold fluid, typically water or supercritical carbon dioxide is injected from the injecting wells and the heated fluid is produced from the producing wells, in which the injection and production wells are connected in a closed loop to ensure steady fluid circulation. Artificially converting a hot rock into a geothermal reservoir by fracturing or by using a closed loop are the enhanced geothermal reservoir systems. To correctly exploit these systems, it is however essential to develop methods to thoroughly understand these reservoir rocks, which requires a detailed modeling study combining the key elements to reservoir description (characterization).

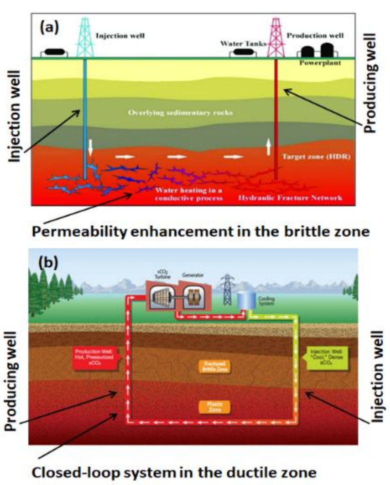

Fig. 1: *Concepts of an enhanced geothermal system by (a) permeability enhancement and (b) a closed-loop.*

The research problem and the long-term benefits: In Fig.1, we outline the idea behind an enhanced geothermal reservoir system (EGRS). As shown in Fig. 1a, by designing a hydraulic fracturing strategy to enhance permeability, and then, by injecting cold fluid through injecting wells, and extracting hot fluid from the producing wells can be used for energy production. The primary requirement for such permeability enhancement followed by injection and production is that the rock must be brittle so that it responds to hydraulic fracturing. In many situations, however, the rock is ductile, which, instead of fracturing, tends to behave plastically. Even such plastic or ductile rocks can be turned into geothermal reservoirs. As shown in Fig. 1b, the injecting and producing wells can be interconnected in a closed-loop system in a way that the injected cold fluid is heated and produced from the producing wells for energy production. For these closed loop systems, using supercritical carbon dioxide (SCO_2) as the circulation fluid is known to be more energy efficient than water.

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Irrespective of permeability enhancement by hydraulic fracturing or using a closed loop, EGRS requires estimating one key parameter- the rock brittleness, which can be obtained by combining well-logs with the azimuthal anisotropy analysis of seismic data (Gray et. al., 2012). In addition, to optimally design hydraulic fracture in a brittle zone three additional geomechanical parameters must be known- (1) closure stress, (2) proppant size and volume, and (3) location of the fracture initiation. These parameters can also be estimated by combining laboratory experiments, well-logs, and seismic inversion (Gray et. al., 2012). Finally, once the production begins, estimating dynamic properties requires combining seismic simulations with fluid flow and geomechanical simulations via rock physics inversion and modeling. Therefore, EGRS characterization requires seamless integration of these different components using a vision, outlined in Fig.2. In this research, we will restrict to the brittle zone of EGRS only and focus on the feasibility of achieving the overall vision of Fig. 2 via hydraulic fracturing followed by fluid injection and production.

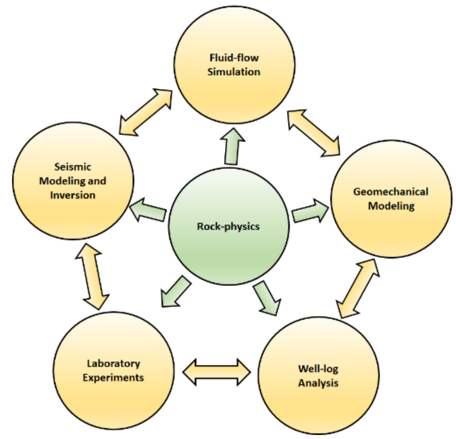

Fig.2: *Overall research vision.*

Considering the natural abundance of hot basement rocks, EGRS is an unlimited resource for clean energy. Additionally, these reservoirs are known to contain critical minerals including lithium, an energy-critical element, needed for high performance battery materials and electrolyte solutions in electric vehicles and other clean-energy storage applications (Weinand et. al., 2023). Consequently, EGRS is vital to the long-term clean energy portfolio and energy-independence.

Short-term objectives: In this research, we will focus only on a synthetic modeling study. By combining laboratory experiments on available core samples with well-logs, regional geology, and tectonic settings, we will first build a static model of seismic, reservoir, and geomechanical properties. Then by simulating hydraulic fractures in the reservoir, we will enhance reservoir permeability, obtain equivalent azimuthally anisotropic reservoir model, and compute synthetic seismograms to build the static reservoir model and static seismic data. Next, by running fluid flow and geomechanical simulations, we will simulate fluid injection and production to build dynamic reservoir models and compute synthetic seismograms as the representatives of dynamic (time-lapse) seismic data. Finally, by combining different modules shown in Fig.2, we will demonstrate the feasibility of the method we propose.

Funding sources: Outcome of this research would allow us to develop future grant proposals for the Federal agencies like DOE and NSF. In addition, many companies in the oil and gas industry are now interested in alternate (clean) energy resources including geothermal energy whom we would approach for additional funding.

References

Gray, D., Anderson, P., Logel, J., Delbecq, F., Schmidt, D., and Schmid, R., 2012, Estimation of stress and geomechanical properties using 3D seismic data, First Break, **30**, 59–68, https://doi.org/10.3997/1365-2397.2011042.

Weinand, J.M., Vandenberg, G., Risch, S., Behrens, J., Pflugrad, N., Linßen, J., and Stolten, D., 2023, Low-carbon lithium extraction makes deep geothermal plants cost-competitive in future energy systems, Advances in Applied Energy, **11**, 100148, https://doi.org/10.1016/j.adapen.2023.100148.

Budget Description

Category	Amount	Comments
Salary, senior personnel	$3,029	0.1-month summer suport for both PI
Salary, graduate student	$11,892	6-month support for one graduate student
Fringe benefits	$1,453	40.9% of the senior personnel and 1.8% of the graduate student salaries
Publication-cost/Page-charges	$1,200	Publication costs and page charges
Graduate student tuition & fees	$5,440	Tuition and fees for the graduate student
Travel	$1,900	Travel expenses to attend conferences
Total fund requested	$24,914	Total project cost

Table 1: *Estimated budget.*

Table 1 is the estimated budget for the research. Justification for each budget item in the above Table is as follows:

- **Salary, senior personnel:** We anticipate each senior personnel (Dejam and Mallick) must dedicate 0.1 month to advising one graduate student to carry out this research.
- **Salary, graduate student:** Although this research would require one graduate student research for the full year, we request only 6 months' support for the student.
- **Fringe benefits:** Calculated at 40.9% of the senior personnel and 1.8% of the graduate student salaries.
- **Publication-cost/Page-charges:** Cost to cover expenses involved for peer-reviewed journal publications.
- **Graduate student tuition & fees:** six-month tuition and fees for the graduate student.
- **Travel:** Expenses to partially cover the travel expenses for attending conferences.