THE NORTHWEST GEYSERS EGS DEMONSTRATION PROJECT PHASE 1: PRE-STIMULATION COUPLED GEOMECHANICAL MODELING TO GUIDE STIMULATION AND MONITORING PLANS

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ABSTRACT
This paper presents activities and results associated with Phase 1 (pre-stimulation phase) of an Enhanced Geothermal System (EGS) demonstration project at the northwest part of The Geysers geothermal field, California. The paper presents development of a 3-D geological model, coupled thermal-hydraulic-mechanical (THM) modeling of proposed stimulation injection as well as current plans for stimulation and monitoring of the site. The project aims at creating an EGS by directly and systematically injecting cool water at relatively low pressure into a known High Temperature (about 280 to 350°C) Zone (HTZ) located under the conventional (240°C) steam reservoir at depths of ~3 km. Accurate micro-earthquake monitoring initiated before the start of the injection will be used as a tool for tracking the development of the EGS and monitoring changes in microseismicity. We first analyzed historic injection and micro-earthquake data from an injection well (Aidlin 11) located about 3 miles to the west of the new EGS demonstration area. Thereafter, we used the same modeling approach to predict the likely extent of the zone of enhanced permeability for a proposed initial injection in two wells (Prati State 31 and Prati 32) at the new EGS demonstration area. Our modeling indicates that the proposed injection scheme will provide additional steam production in the area by creating a zone of permeability enhancement extending about 0.5 km from each injection well which will connect to the overlying conventional steam reservoir, in agreement with the conclusions of Nielson and Moore (2000).

INTRODUCTION
The overall objective of the Northwest Geysers EGS Demonstration project is to develop and demonstrate the technology required to extract energy from the low permeability zones that typically underlie high-temperature geothermal systems. The proposed EGS concept will be developed and demonstrated in an area of the Northwestern Geysers geothermal field, California, which was originally explored for natural steam production in the 1980s. A high temperature zone (HTZ) with temperature up to 350°C was discovered here at a relatively shallow depth (Walters et al., 1988).A number of steam production wells were drilled, but later abandoned because of uneconomically low natural steam production as well as problems with corrosive non-condensable gases (NCG). The plan is to re-open and re-complete two of the abandoned exploratory wells and possibly deepen them for injection and stimulation in the HTZ. An ample

supply of injection water will be provided by the newly available Santa Rosa Geysers Recharge Pipeline. Using injection, the intentions is to lower the NCG, stimulate fracturing in the HTZ, and provide a sustainable amount of usable quality steam.

Other project objectives are:

- To develop and demonstrate the stimulation techniques to create an EGS in a deep, very hot, fractured rock system by the injection of treated wastewater at temperatures substantially lower (several hundred ^{o}C less) than the formation.
- To investigate how such relatively cold-water injection affects the fractured rock system and contributes to the EGS, both mechanically (e.g., cooling shrinkage and fracture shear reactivation) and chemically (e.g., dissolution).
- To demonstrate the technology to monitor and validate the stimulation and sustainability of such an EGS.
- To develop an EGS research field laboratory that can be used for testing EGS stimulation and monitoring technologies including new high temperature logging tools that may be developed by others.

The demonstration project is organized into three phases: Phase 1 (Pre-Stimulation), Phase 2 (Stimulation), and Phase 3 (Monitoring) The project is currently in the Pre-Stimulation phase of securing the necessary regulatory permits, developing a site geologic model, and developing stimulation and monitoring plans to be deployed in Phases 2 and 3.

In this paper we present the activities and results associated with Phase 1. This includes development of a geological model, model simulations of proposed stimulation as well as final stimulation and monitoring plan. The model simulation results estimate the spatial extent of the injection-induced, shear-enhanced fracture permeability and the associated zone of MEQ activity around the injection wells. Guided by the model simulation, we summarize the current stimulation and monitoring plans to be deployed during Phases 2 and 3 of the project.

SITE AND GEOLOGY OF THE EGS AREA

The proposed EGS area in the NW Geysers is an ideal site for an EGS demonstration because of the extremely high temperature gradient within a volume of reduced permeability rock mass that is stressed near its frictional shear strength. The rock mass is fractured, but currently not sufficiently permeable.

The geology of the EGS area is well-characterized and a three-dimensional geologic model was developed for an area of about 8 by 8 km and to the depth of the deepest exploratory wells below 3 km (Figure 1). The high temperature zone (HTZ) with conductive temperature gradients and measured temperatures near 350°C underlies the typical Geysers steam reservoir described here as the “Normal Temperature Reservoir” (NTR). The temperature gradient in the NTR is almost isothermal and near 240°C.

Downhole lithologic and geophysical logs and rock property data from previous core studies were integrated in the three-dimensional geological and structural model of the EGS area. The main geologic units of the model include unfractured graywacke that serves as a caprock, metagraywacke (host to the NTR), hornfelsic graywacke (host to the HTZ), and young (< 1 Ma) granitic intrusive rocks ("felsite") which are thought to be as young as about 10,000 years before the present (Williams et al., 1993), and the heat source to the HTZ in the EGS demonstration area (e.g., Walters et al., 1988; Sternfeld, 1989; Schmitt et al., 2003). Well data, location of microearthquakes (MEQs) and knowledge from previous numerical models were used to create 3-D surfaces corresponding to the main geologic units. These 3-D realizations of the main geologic units together with the incorporation of rock properties from previous unpublished core studies (density, permeability, porosity, and rock strength) constitute the input data for the geologic model near PS31 and P32. The hornfelsic graywacke shown in Fig. 2 is an example of a 3-D geologic model surface.

MODEL SIMULATIONS

In this section, we first present the approach for evaluating the MEQ potential and discuss the basic THM input parameters. We then present modeling of historic injection and MEQ activity at an existing injection well (Aidlin 11), located at the Northwest Geysers about 3 miles to the west of the new EGS demonstration area. The purpose of the Aidlin 11 modeling is to quantify a stress change criterion that defines the spatial extent of the zone of shear enhanced permeability and MEQ activity around an injection well at the Northwest Geysers. Finally, we present model simulation results of the proposed initial injection at the PS-31 and P-32 well pair for the new EGS demonstration area.

Modeling Approach

The coupled THM analysis was conducted with TOUGH-FLAC (Rutqvist et al., 2002), a simulator based on linking the geothermal reservoir simulator TOUGH2 (Pruess et al., 1999) with the geomechanical code FLAC3D (Itasca, 2009). The simulator has the required capabilities for modeling of non-isothermal, multiphase flow processes coupled with stress changes induced by temperature and fluid pressure. The application of this simulator to the Northwest Geysers EGS Demonstration Project follows the approach used by Rutqvist et al. (2006), and Rutqvist and Oldenburg (2007, 2008). One of the main features of our mechanical model is the analysis of stress path and the potential for shear reactivations of fractures in a rock mass that is critically stressed for shear failure (Fig. 3). The concept of a critically stressed rock mass at The Geysers arose from early rock-mechanics studies of Geysers samples that indicated that the rock has undergone extensive hydrothermal alteration and re-crystallization, and that it is highly fractured (Lockner et al., 1982). Lockner et al. (1982) suggested that fracturing has weakened the rock to such an extent that models of the geothermal field should assume that only a frictional sliding load can be supported by the rock, and the authors maintained that shear stress in the region is probably near the rock-mass frictional strengths. Therefore very small perturbations of the stress field could induce seismicity. Based on the concept of a critically stressed rock mass, one of the main mechanisms that we investigate at The Geysers is shear failure along existing fractures caused by small perturbations in the stress state. We evaluate the potential for shear slip under the conservative assumption that fractures of any orientation could exist anywhere (Fig. 3a). Such assumptions were confirmed by studies of fault plane analysis of seismicity at The Geysers by Oppenheimer (1986), which indicated that seismic sources occur from almost randomly oriented fracture planes. One key parameter in estimating the likelihood of shear reactivation along a fracture is the coefficient of static friction, μ, entering the Coulomb shear failure criterion. Cohesionless faults are usually assumed to have a frictional coefficient of 0.6 to 0.85 (e.g., Barton et al., 1995). Moreover, a frictional coefficient of $\mu = 0.6$ is a lower-limit value observed in fractured rock masses (Barton et al., 1995). Thus, using $\mu = 0.6$ in the Coulomb criterion would most likely give a conservative estimate of likely seismicity. For $\mu = 0.6$, the Coulomb criterion for the onset of shear failure can be written in the following form:

$$\sigma'_{1c} = 3\sigma'_3 \tag{1}$$

where σ'_{1c} is the critical maximum principal stress for the onset of shear failure. Thus, shear reactivation of a fracture slip would be induced whenever the maximum principal effective stress is three times higher than the minimum principal stress.

Based on the concept of a critically stressed rock mass, the initial stress will be in a state of incipient failure (Fig. 3b, c and d). By studying how the stress state deviates from this near-critical stress state we may investigate whether the changes in the stress state tend to move the system into failure or away from the state of failure. We also may start at any initial state away from failure and consider if a change in the stress state increases or decreases the likelihood of shear failure. The likelihood of shear reactivation would increase if the change in maximum principal compressive effective stress is more than three times the change in minimum principal effective stress (i.e., if $\Delta\sigma'_1 \geq 3\times\Delta\sigma'_3$). Conversely, the likelihood of shear reactivation would decrease if the change in maximum principal compressive effective stress is less than three times the change in minimum principal effective stress (i.e., if $\Delta\sigma'_1 < 3\times\Delta\sigma'_3$).

Considering that the initial stress might not be exactly at the point of critical stress, we may quantify how much the $\Delta\sigma'_1$ has to exceed $3\times\Delta\sigma'_3$ to induce additional shear reactivation. We therefore define a stress-to-strength change margin as $\Delta\sigma'_{1m} = \Delta\sigma'_1 - 3\times\Delta\sigma'_3$. How large $\Delta\sigma'_{1m}$ needs to be to induce shear reactivation during injection will be quantified by model calibration against historic injection and MEQ data.

THM Input Parameters

The various coupled THM models of The Geysers developed in this study as well as those used in Rutqvist and Oldenburg (2007, 2008) consist of the normal temperature reservoir sandwiched between an impermeable cap and a relatively low-permeability high temperature zone. The equivalent fractured rock permeability in the reservoir is about $1{\bullet}10^{-14}$ m^2 (10 millidarcies) with about 1% porosity.

The initial thermal and hydrological conditions (vertical distributions of temperature, pressure and liquid saturation) for each model are typically established through steady-state multi-phase flow simulations. The initial reservoir temperature in the NTR is about 240°C down to a depth of about 3.5 km and then gradually increases up to 350°C towards the bottom boundary at a depth of 6 km. The relatively low permeability of the HTZ below the NTR is inferred from the steep thermal gradient, which indicates lack of heat convection and dominant conductive heat flow. The steam pressure within the hydraulically confined NTR has gradually decreased with the steam production since the 1960s and is today a few megapascals.

The basic geomechanical properties used in this analysis are generally equivalent to those developed and used by Rutqvist and Oldenburg (2007, 2008). This includes a rock-mass bulk modulus of 3 GPa, which approximately corresponds to values back-calculated by Mossop and Segall (1997) based on strain analyses at The Geysers. The linear thermal expansion coefficient of the rock is set to 1 × 10^{-5} °C^{-1}, corresponding to values determined on core samples of the reservoir rock at high (250 °C) temperature (Mossop and Segall, 1997). Using these properties, Rutqvist and Oldenburg (2007, 2008) simulated the 44 years of production and injection from the early 1960s in a reservoir-wide cross-section. The simulation of 44 years of steam-production and injection resulted in reservoir-wide pressure and temperature declines of a few MPa and a few degrees, respectively, as well as subsidence of about 0.5 to 1 meter. These numbers are in general agreement with field observations at the Geysers (Mossop and Segall, 1997; Williamson, 1992).

Model Calibration at Aidlin 11

We first analyzed and modeled historic injection and MEQ data at the Aidlin 11 injection well, located about 3 miles to the west of the new EGS demonstration area. The analysis of the Aidlin 11 data was conducted to study the cause and mechanisms of observed MEQs, and to constrain the stress criterion for the spatial extent of the MEQ zone around an injection well.

Injection in Aidlin 11 began in late 2004 at a relatively small rate (several hundred gallons per minute). The injection rate was held relatively steady until September 2005 when the injection rate sharply increased (Majer and Peterson, 2007). The injection takes place at a depth of 3.5 km near the interface between the normal and high temperature reservoirs. The observed MEQ evolution within a 6 km cube containing the Aidlin 11 injection well has been published by Majer and Peterson (2007). Fig. 4 shows an east-west cross section through the center of the cluster as well as the trace of the well. The seismicity during the first year of near-constant rate injection was concentrated near the bottom of the well. Some of the sparse seismicity away from the injection well may be associated with production wells in the area.

We simulated the response to injection in Aidlin 11 using a three-dimensional model domain that is one-quarter of a 2 km by 2 km block in the horizontal plane and 5.5 km deep. The initial thermal and pressure gradients were calibrated in an initial steady-state simulation as described above. For the model calibration we study the injection and MEQ activities for the first year when injection took place at a relatively constant rate in Aidlin 11. In the modeling a constant average injection rate of 122 gpm (7.7 kg/s) and injection temperature of 90°C were maintained for 1 year.

Figure 5 shows the calculated changes in pressure, liquid saturation, and temperature after 1 year of injection. In general, the temperature change is several tens of degrees, but is confined within the zone of liquid saturation migrating downwards from the bottom of the injection well. The pressure change is only a few MPa, but takes place far beyond the extent of the liquid water zone.

Figure 6 present the rock mass stress-to-strength change margin, $\Delta\sigma'_{1m}$. We present the results for considering THM coupling and only HM coupling. We can observe that when considering full THM coupling, $\Delta\sigma'_{1m}$ is higher and the zone of high $\Delta\sigma'_{1m}$ tends to spread farther downwards. The calculated results in Fig. 6 can be compared to the observed MEQ cloud (depicting events with $M \geq 0.8$) around Aidlin 11 (Fig. 4). The extent of the MEQ cloud around Aidlin 11 roughly corresponds to the extent of the blue contour for the THM model. This blue contour corresponds to a zone with a stress-to-strength margin of 1.5 MPa or higher. This means that the maximum compressive effective stress has increased by 1.5 MPa relative to compressive strength.

A closer look at the simulation results indicates that the reduction in effective stress, with unloading of pre-existing fractures with associated loss of shear resistance would be the mechanism leading to shear reactivation. The injection-induced cooling is the most important cause for stress changes in the liquid zone near the well. Away from the well and the wet liquid zone, the pressure changes gives rise to stress changes that also could induce shear reactivation of pre-existing fractures.

Model Predictions at PS-31 and P-32

We analyzed the proposed initial injection at PS-31 and P-32 using the same modeling approach as was employed in modeling Aidlin 11. In this initial model simulation to estimate the extent of the shear-enhanced permeability zone around the injection wells, we use a simplified, but yet representative model of the field (Fig. 7). For example, we extend geological layers horizontally to model boundaries and we assume perfectly vertical wells. This simplified model is sufficient for making a first order estimate of the temporal and spatial extent of the zone of shear-enhanced permeability (corresponding to the extent of the MEQ zone). The wells are located at a horizontal distance of about 500 m N-S from each other and partially penetrate the hornfelsic graywacke ("hornfels") and the HTZ, which extends downward into a granitic intrusion ("felsite").

Table 1 presents the input properties of the main geological units. The permeability values represent fracture permeability taken from Calpine's reservoir model and are several orders of magnitude higher than matrix permeability measured on core samples from the field. The elastic properties are equivalent to those used by Rutqvist and Oldenburg (2007, 2008), which are also effective large-scale rock mass properties, consistent with observed depletion-induced subsidence of The Geysers field.

We simulated a proposed 1-year injection scheme that will be conducted using a carefully monitored series of steps that will increase and then lower injection flow-rates and down-hole pressures (Fig. 8). First there is an initial 8-hour period of relatively high-rate injection that is necessary to collapse the steam bubble in the well bore and nearby formation so that relatively lower sustained rates of liquid water injection are drawn into the fractured reservoir rock under vacuum. Thereafter, the injection scheme consists of 1-month-long steps of increasing and decreasing rates, with 6 months of injection first occurring in PS-31 and then shifted to P-32. The simulated maximum bottom-hole pressures during these steps are about 6.5 MPa in PS-31 and 5.5 MPa in P-32. At this depth the least compressive stress may be bounded to be at least 24 MPa using the frictional strength limit of the rock mass. Thus, the injection pressure is much less than the least principal stress and therefore far below the hydraulic fracturing pressure. The injection is done at a low pressure to avoid hydraulic fracturing, but aims at dilating pre-existing fractures by shear reactivation.

Figure 9 shows changes in pressure, liquid saturation, and temperature, and stress-to-strength change margin after 12 months. The pressure increases and falls off rapidly along with the injection rate and spreads several km, but increases only up to a few MPa (Fig. 9a). A liquid zone forms around each injection well and some downward gravity flow can be observed (Fig. 9b). Substantial cooling is observed where the liquid phase is present (Fig. 9c). A zone with high potential for shear reactivation and associated MEQ grows with the cooling and pressure increase at each injection well. In Fig. 9d, the blue contour zone of high likelihood of reactivation of existing fractures extends about 0.5 km from each injection well. Moreover, this zone connects with the overlying NTR and can thereby provide additional steam production in the area.

STIMULATION AND MONITORING PLAN

Table 2 presents a detailed stimulation plan, including injection schedule, flow tests, static Pressure-Temperature log (PT), tracers, and Pressure-Temperature-Spinner log (PTS). The pre-stimulation modeling indicates that the proposed injection schedule will create a desired zone of enhanced permeability to provide additional quality steam to nearby production wells. We estimate that the exact injection rates, or the sequence of injection steps are not critical for the extent of the enhanced zone of permeability. Rather, the extent of the enhanced permeability zone will depend on the total volume of water injected and the amount of cooling such a volume will induce over the 6 months of injection for each of the two wells.

The injection is planned to be carried out initially at a rather low rate of 200 gpm. Depending on the ability of the fractures to accept the fluid, injection rate will then be increased to (for example) 400, 600 and 800 gpm) The goal is to place the injection directly into the HTZ and prevent water from "U-tubing" up the annulus of the well liner and into the overlying NTR. "U-tubing" will be prevented by adjusting the injection rates and resulting water levels by using downhole pressure measurements. Very often, geothermal wells exhibit a nonlinear relationship between injection rate (M) and feed zone pressure (p). Decrease in the slope of p versus M curve indicates an increase in injectivity, and possibly an increase in fracture aperture. The suggested injection program (e.g., injection at 200, 400, 600, 800, 600, 400 and 200 gpm) is designed to ascertain if the pressure increase will result in the opening up of pre-existing fractures in the HTZ, and whether this change is reversible.

The microseismic activity will be monitored by an existing seismic array that is already being used to determine baseline seismicity for the study area. Closely monitoring the spatial and temporal evolution of the microseismicity serves as an effective method of remotely sensing the development of the enhanced fracture volume, and may provide a future constraint on the conceptual model. The ability to determine precise source locations for MEQs has been enhanced by adding five short-period stations near the EGS area to the existing Calpine-LBNL network of 22 seismic monitoring stations at The Geysers. Based on the real high-precision MEQ location monitoring, the injection schedule can be adjusted to achieve the desired extension of the perceived EGS volume.

The evolution of the EGS volume will be further monitored through 3-D tomography and MEQ source mechanisms studies, satellite based measurements of surface deformations, and geochemical monitoring analysis of injection and production fluids (Figure 10). These technologies are promising for monitoring and validation of the proposed EGS because they are expected to capture important changes in the geothermal reservoir over the entire EGS volume, including changes in rock mass mechanical properties (as reflected by changes in sonic velocities) and exposure of new fracture surfaces (as reflected in changes in the chemical signature of the produced steam). In addition to these tools, Calpine will also repeatedly log the demonstration wells with its own Pressure-Temperature-Spinner (PTS) tool during pre-stimulation, stimulation and long-term monitoring phases (See Table 2). These tools will be effective to measure changes in injectivity and flow transmissivity of fractures intersecting the well bore.

CONCLUDING REMARKS

This paper presents activities and results associated with Phase 1 (pre-stimulation phase) of an Enhanced Geothermal System (EGS) demonstration project at the northwest part of The Geysers geothermal field, California. The paper presents development of a site descriptive geological model, coupled thermal-hydraulic-mechanical (THM) modeling of proposed stimulation injection as well as current plans for stimulation and monitoring of the site. Our modeling of the proposed initial injection at the well pair PS-31 and P-32 indicates that the injection into a High Temperature Zone (HTZ) is likely to stimulate a zone extending about 0.5 km from each injection well, with reactivation of existing fractures and associated MEQ activity. The modeling indicates that the zone of shear reactivation and likely enhanced permeability in the HTZ is expected to connect to the overlying Normal Temperature Reservoir (NTR) and thereby provide additional steam production in the area, in agreement with an injection stimulation model proposed by Nielson and Moore (2000). Moreover, our analysis shows that for the proposed injection scheme, the most important cause and mechanism for the shear reactivation is cooling and associated thermal-elastic cooling shrinkage of the rock around the injected fluid. The cooling shrinkage results in unloading and associated loss of shear strength in near-critically shear-stressed fractures, which are then reactivated. The model predictions presented in this paper will be compared with observed MEQ evolution once such data become available.

Guided by the encouraging results from our modeling effort, a detailed stimulation and monitoring plan has been finalized. The actual injection will begin at a relatively low rate and the injection schedule will most likely be adjusted to achieve desirable results of a gentle stimulation of pre-existing fractures through cooling effects from the injected water. An important component of the field program is monitoring using real time high precision MEQ locations from the first moment of injection.

We are also working on a number of improvements of the model, including 1) use of exact three-dimensional model geometry based on a detailed geological model, 2) dual continuum model of the fractured rock, and 3) consideration of discrete fractures. These model improvements may be important when making a detailed comparison to the observed MEQ data once it becomes available during the Phase 2 of the project.

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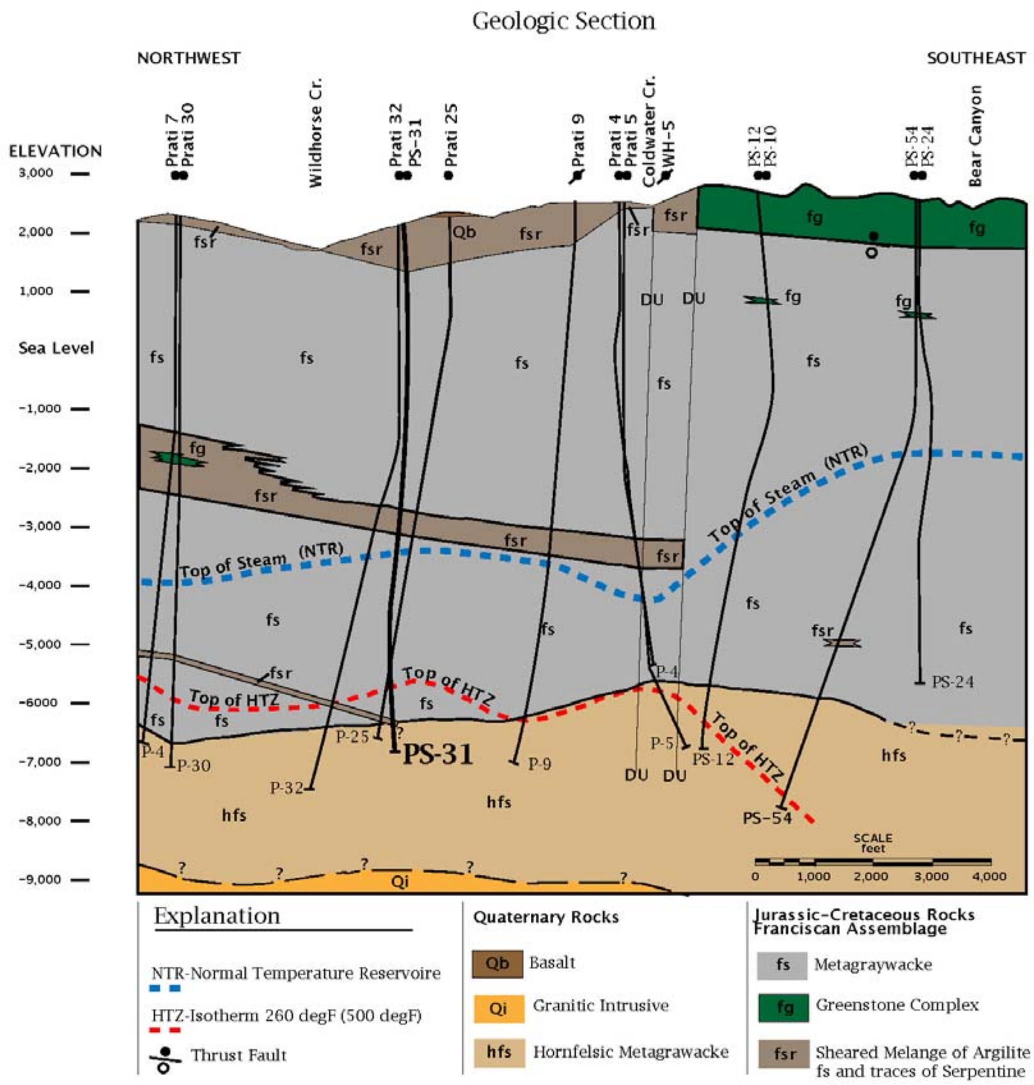


Figure 1. NW-SE geologic cross-section through the NW Geysers including the two wells P-32 and PS-31 that will be reopened for injection directly into the HTZ.

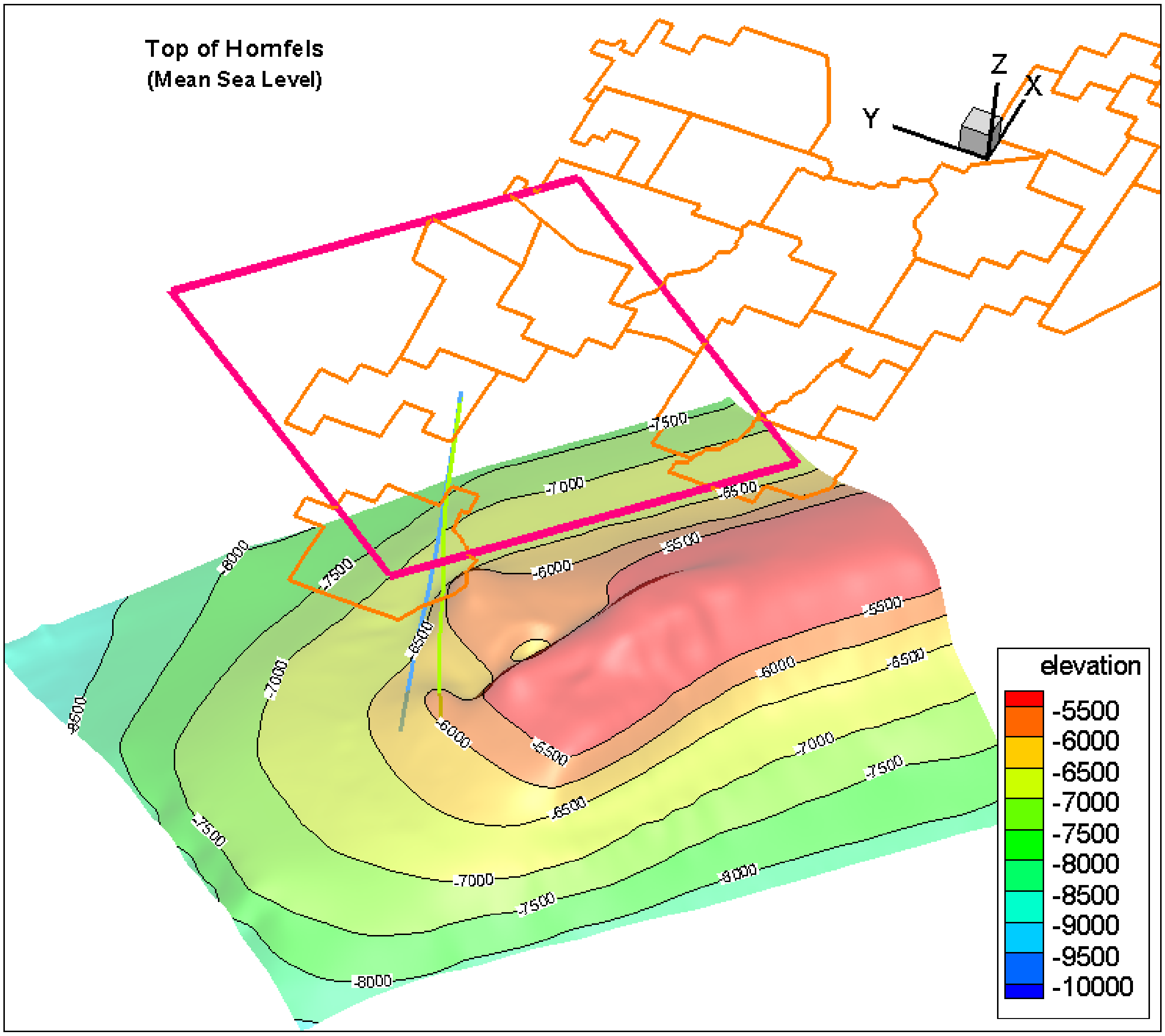


Figure 2. Three dimensional view of the top of hornfels showing PS-31 and P-32 wells. (Elevation= ft/msl).

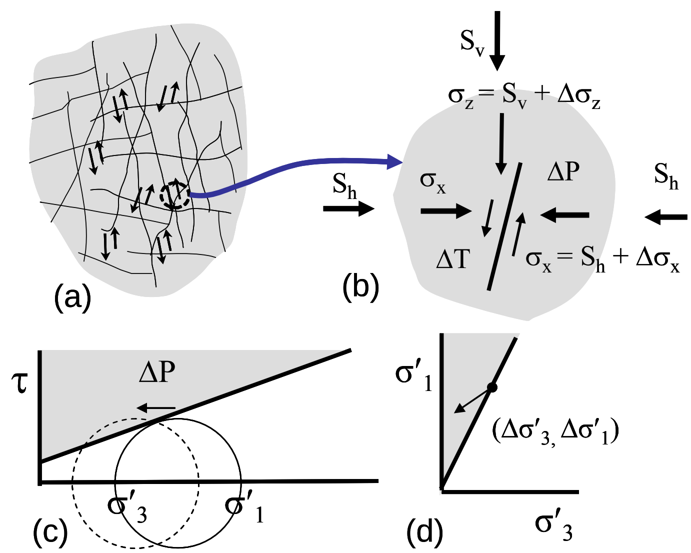


Figure 3. Illustration of the approach for failure analysis to evaluate the potential for induced seismicity at The Geysers (a) Highly fractured rock with randomly oriented fractures, (b) Changes in stress on one fracture plane, (c) Movements of Mohr's circle as a result of increased fluid pressure within a fracture plane for a critically stressed fracture, and (d) corresponding stress path in the (σ'_1, σ'_3) plane.

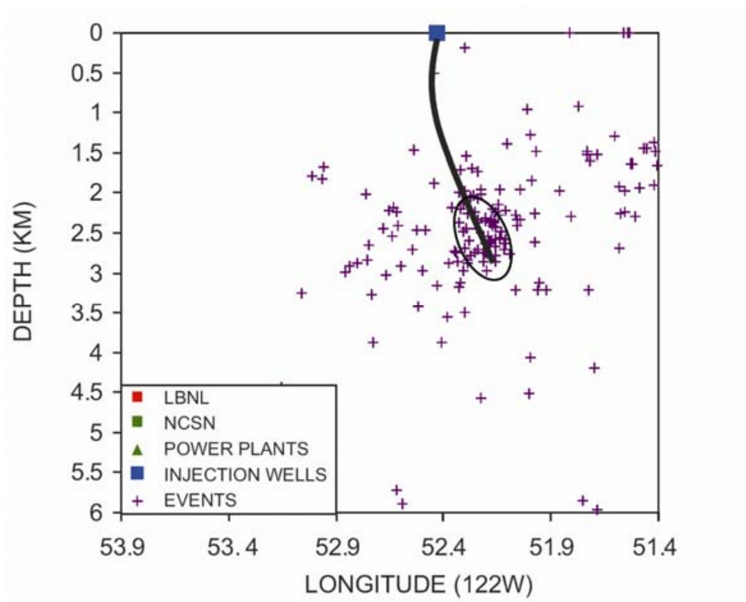


Figure 4. E-W projection through a 6 km cube containing MEQ hypocenters of magnitude 0.8 or larger during 1 year of injection at Aidlin 11 (from Majer and Peterson (2007)).

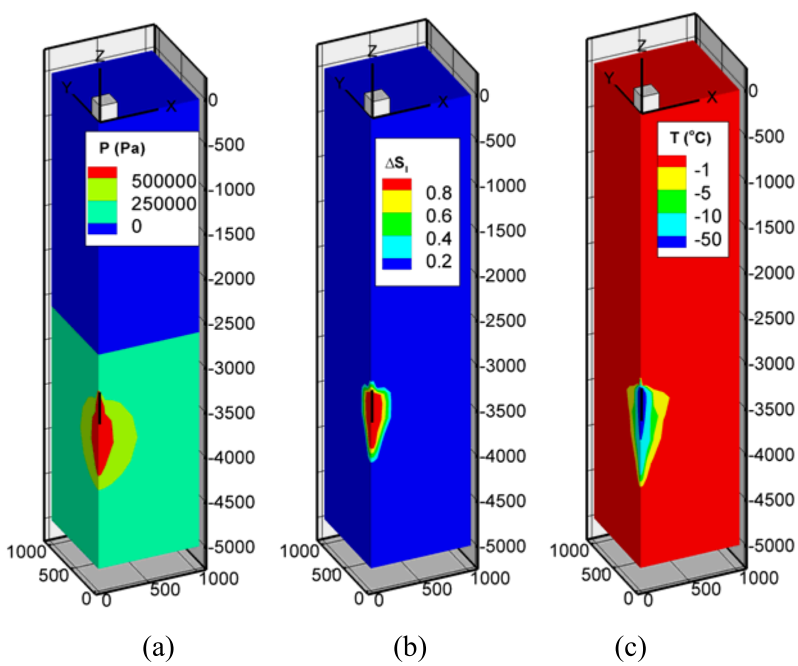


Figure 5. Simulation results of after 1 year of water injection at Aidlin 11: Changes in (a) fluid pressure, (b) liquid saturation, (c) temperature after 1 year of injection.

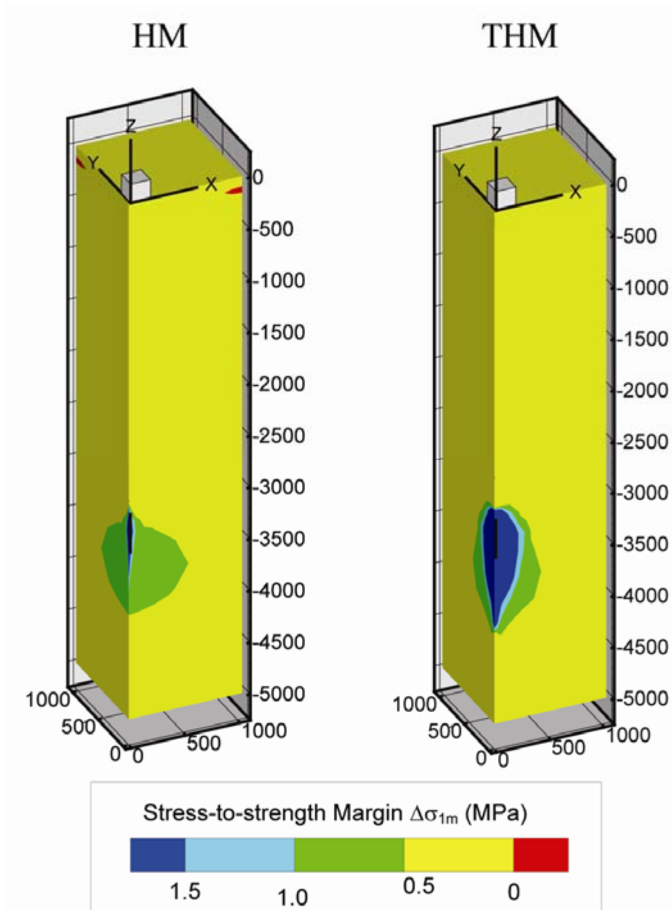


Figure 6. Simulation results of MEQ potential for Aidlin 11 area estimated using stress-to-strength margin, $\Delta\sigma_{1m}$, for HM and THM couplings considered.

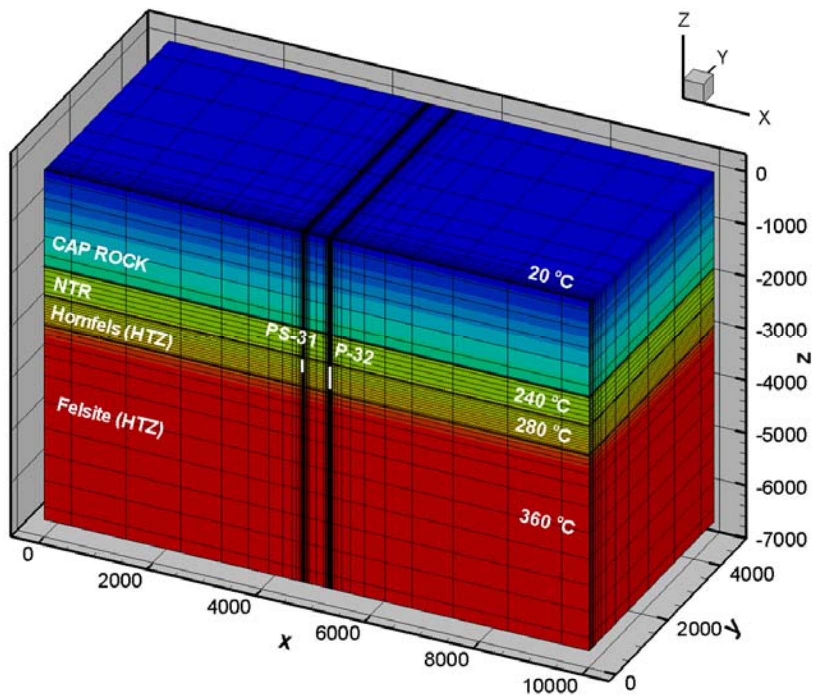
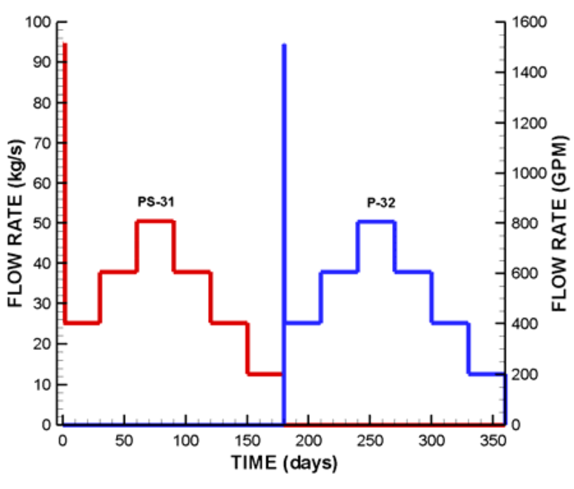
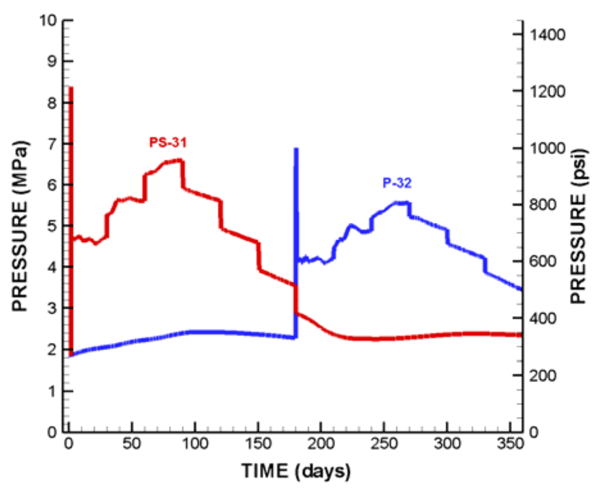


Figure 7. Three dimensional numerical grid with material layers and contours of initial temperature.



(a)



(b)

Figure 8. Injection rates (a) and calculated downhole pressure evolution (b) for the proposed injection schedule.

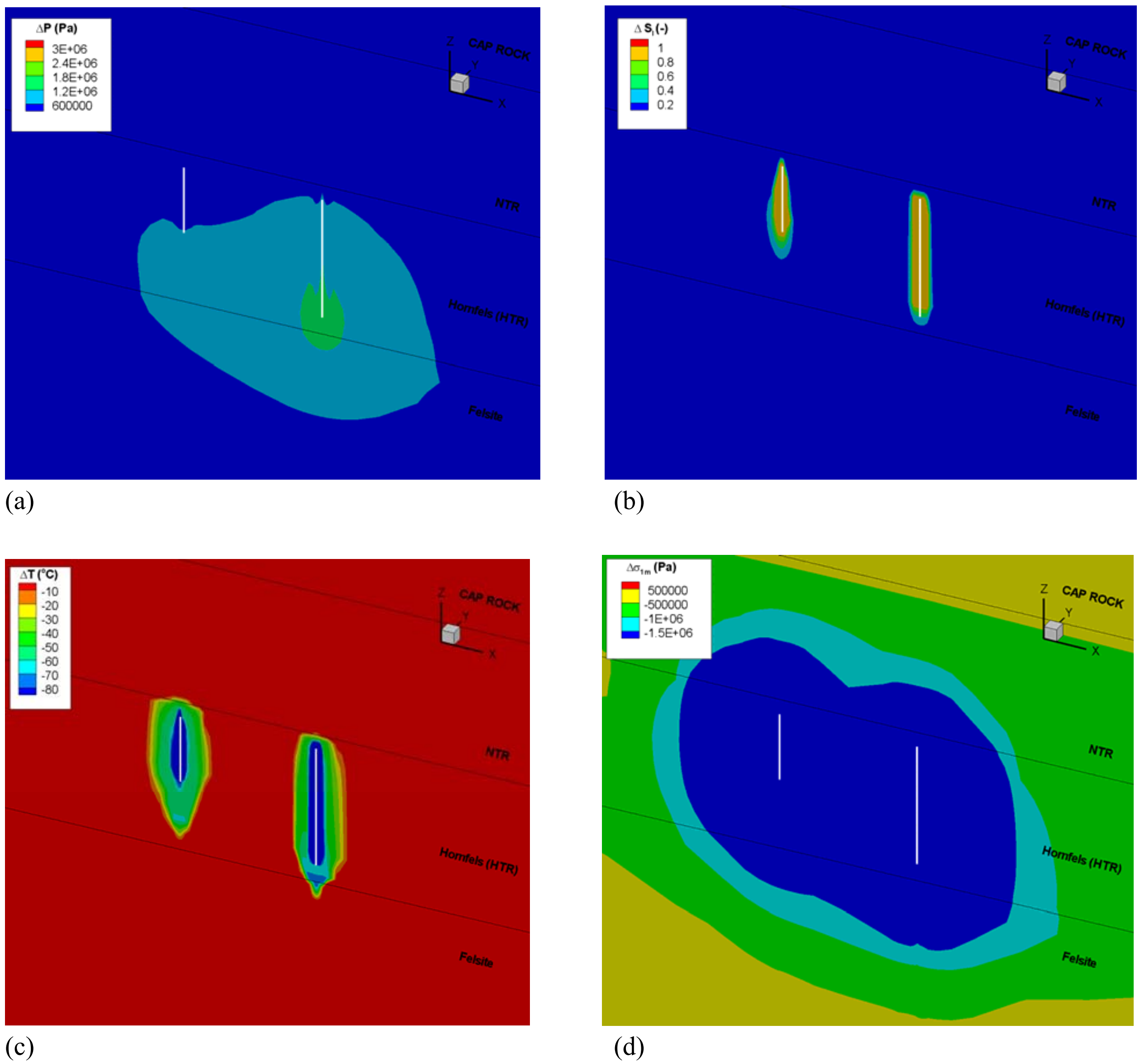


Figure 9. Simulation results of PS-31 and P-32 after 12 months: Changes in (a) fluid pressure, (b) liquid saturation, (c) temperature, and (d) MEQ potential estimated using stress-to-strength margin, $\Delta\sigma_{1m}$

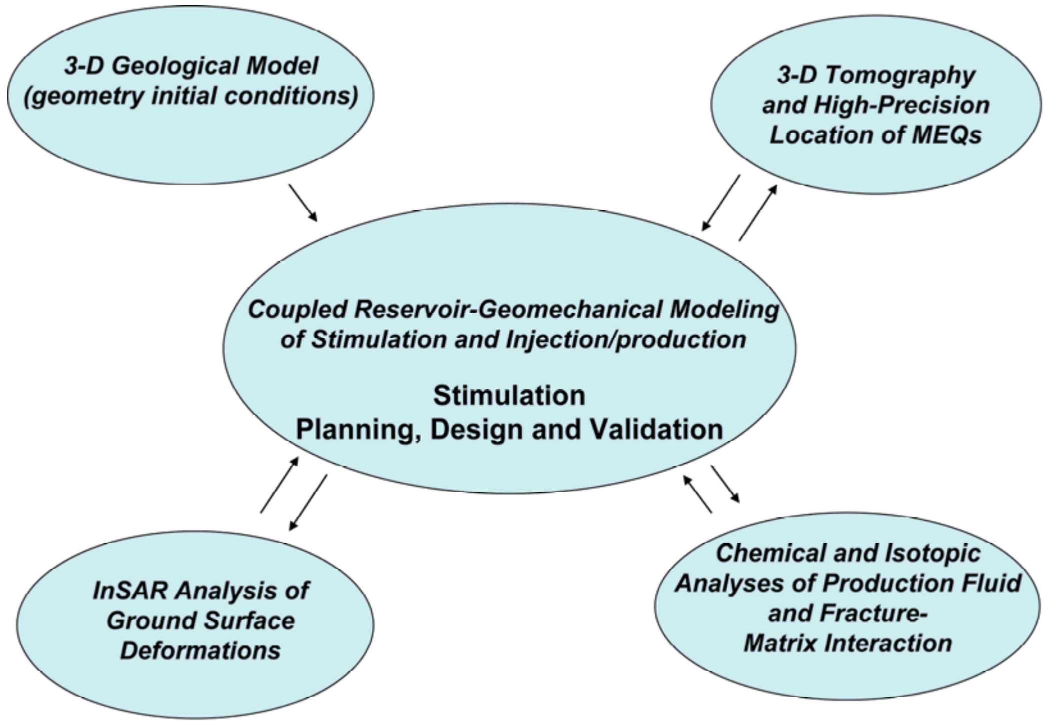


Figure 10. Coupled THM modeling integrated with field monitoring to be deployed in Phase 2 of the Northwest Geysers EGS Demonstration Project.

Table 1. Rock properties for modeling of the initial injection at the Northwest Geysers EGS Demonstration Project. Note that permeability values selected for model are significantly greater than matrix permeability measurements for corresponding core samples, and reflect fracture permeability for these units.

	Graywacke (NTR)	Hornfels (HTZ)	Felsite (HTZ)
Permeability (m^2)	5×10^{-14}	2×10^{-14}	1×10^{-15}
Porosity (-)	0.015	0.01	0.01
Thermal Cond. (W/(m °C))	3.2	3.2	3.2
Specific heat (J/(kg °C))	1000	1000	1000
Bulk Modulus (GPa)	3.3	3.3	3.3
Shear Modulus (GPa)	2	2	2
Thermal expansion coefficient ($°C^{-1}$)	1×10^{-5}	1×10^{-5}	1×10^{-5}

Table 2. Stimulation Plan for Prati State-31 and Prati-32.

Year	Month	Prati State 31	Prati 32
1	1	Re-Open / Work over	
	2	Flow Test	
	3		Re-Open / Work over
	4	Static Pressure-Temperature log (PT) Start Injection (1500 gpm for 8 hrs)	Flow Test
	5	Injection: 5 to 6 Injection steps of 200 gpm to 800 gpm, tracer ammonia, 1 Pressure-Temperature-Spinner log (PTS) per step. 200 gpm steps up to 800 gpm and back	Shut Well - Monitor Pressure
	6		
	7		
	8		
	9		
	10	Shut Well - Monitor Pressure	Start Injection (1500 gpm for 8 hrs) Injection: 5 to 6 Injection steps of 200 gpm to 800 gpm, tracer tritium, 1 PTS per step 200 gpm steps up to 800 gpm and back
	11		
	12		
2	13		
	14		
	15		
	16	Static PT / Start as Injector Injection: 5 to 6 Injection steps, 1 PTS per step	Shut Well - Monitor Pressure
	17		
	18		
	19		
	20		
	21		
	22	Shut Well - Monitor Pressure	Static PT / Start as Injector Injection: 5 to 6 Injection steps, 1 PTS per step
	23		
	24		
3	25		