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The Northwest Geysers EGS Demonstration Project, California Part 1: Characterization and reservoir response to injection

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ABSTRACT

An Enhanced Geothermal System (EGS) Demonstration Project is currently underway in the Northwest Geysers. The project goal is to demonstrate the feasibility of stimulating a deep high-temperature reservoir (HTR) (up to 400 °C, 750 °F). Two previously abandoned wells, Prati State 31 (PS-31) and Prati 32 (P-32), were reopened and deepened to be used as an injection and production doublet to stimulate the HTR. The deepened portions of both wells have conductive temperature gradients of 10 °F/100 ft (182 °C/km), produce connate native fluids and magmatic gas, and the rocks were isotopically unexchanged by meteoric water. The ambient temperature meteoric water injected into these hot dry rocks has evidently created a permeability volume of several cubic kilometers as determined by seismic monitoring. Preliminary isotopic analyses of the injected and produced water indicate that 50–75% of the steam from the created EGS reservoir is injection-derived.

1. Introduction

The Geysers Geothermal field is the world's largest geothermal electricity generating operation and has been in commercial operation since 1960. It is a vapor-dominated geothermal reservoir system that was developed to a maximum installed capacity of 2043 MWe by 1987. Subsequently, a number of peripheral developed areas were abandoned because of resource problems including declining steam pressure, low permeability, corrosive steam and high non-condensible gas (NCG) concentrations. As a result of the high steam withdrawal rates, the reservoir pressure declined until the mid 1990s, when increasing injection rates resulted in a stabilization of the steam production and reservoir pressure. In recent decades, operators have been relying heavily on supplemental water injection to sustain its current generation of 825 MWe.

The concept of Enhanced Geothermal Systems (EGS) at The Geysers differs from other EGS programs pursued elsewhere in the world. At The Geysers, EGS projects target areas which contain a significant portion of the recoverable geothermal energy in the system that is currently underutilized (Nielson and Moore, 2000). The main focus is on the revival of production from peripheral areas by using water injection to increase reservoir pressure, increase permeability, reduce NCG concentrations and mitigate corrosion. Although this scope is somewhat site-specific, the vast unexploited heat resource and existing infrastructure at The Geysers offers an opportunity for significant short-term EGS generation.

The EGS Demonstration Project is in the Northwestern portion of The Geysers geothermal field (Fig. 1) where a high temperature reservoir (HTR) with temperatures up to 400 °C (750 °F) was previously identified (Walters et al., 1992; Walters and Beall, 2002). The HTR underlies a normal temperature reservoir (NTR) where temperatures are about 240 °C (465 °F).

The EGS Demonstration Project area was originally explored in the 1980s with three exploration and development wells in the Central California Power Agency (CCPA) steam field. These wells were never produced due to high concentrations of NCG produced from the HTR and were abandoned in 1999 after the CCPA #1 Power Plant was closed for economic reasons and later decommissioned.

Two of the previously abandoned wells, Prati State 31 (PS-31) and Prati 32 (P-32), were reopened, deepened and re-completed in 2010 for direct injection and stimulation of the HTR. The NTR in the project area is relatively shallow (the base of the NTR is at an elevation of −1800 m mean sea level (m-msl), −6000 ft (ft-msl)) and the project wells are sufficiently deep to penetrate the upper portion of the HTR (Fig. 1).

The intent of the EGS Demonstration Project is to show that the permeability of the HTR can be stimulated by fracture reactivation

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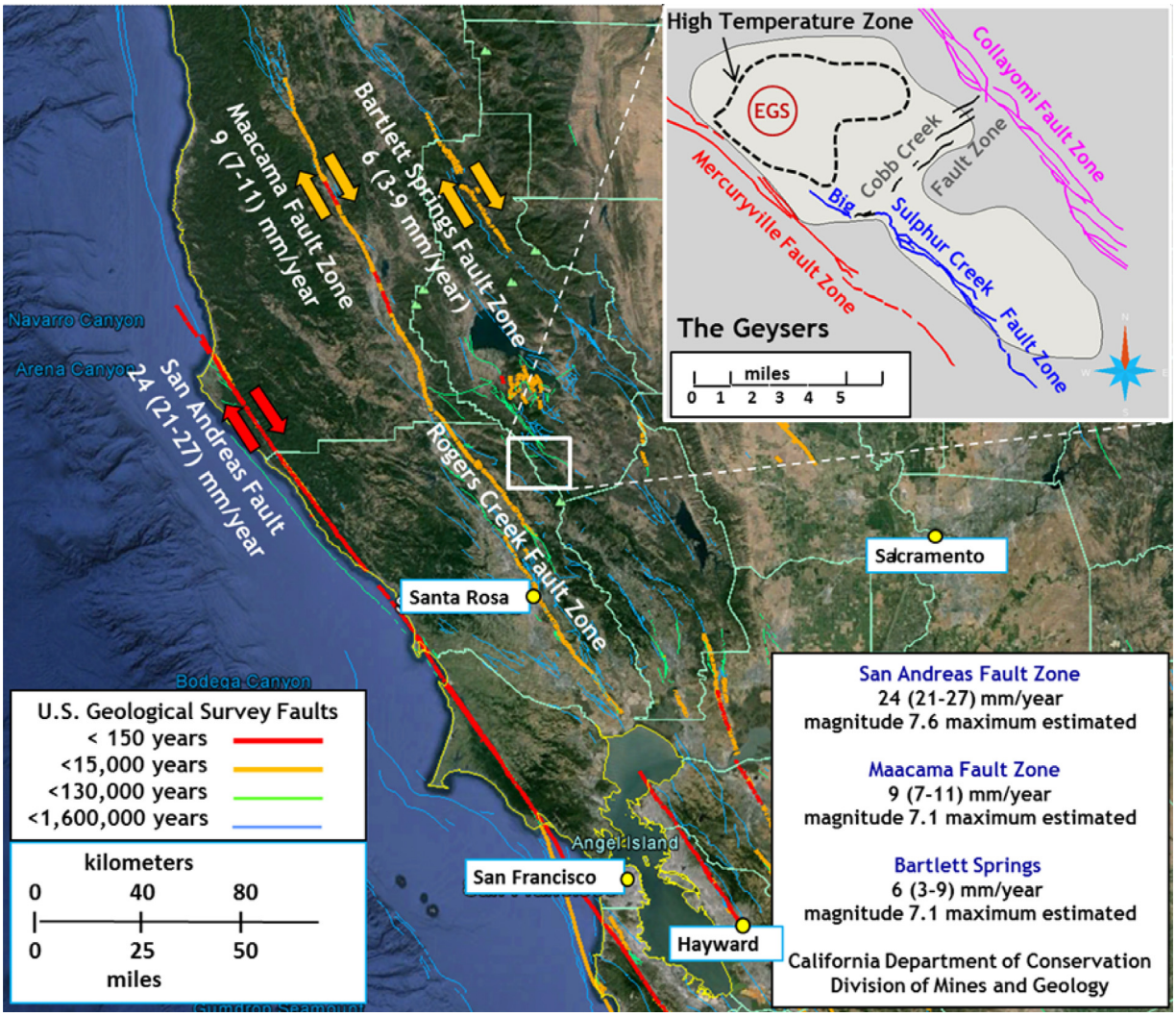

Fig. 1. The San Andreas Fault System, including the Maacama/Rodgers Creek Fault Zone and Bartlett Spring Fault Zone. Only faults with activity in the previous 15,000 years are displayed (California Division of Mines and Geology, 1996). The inset map shows the location of the EGS Demonstration Project and the surrounding high temperature region of the northwest Geysers.

to create a diffuse "cloud" of fractures rather than a localized fracture plane when relatively cool water is injected into a very hot rock volume at low flow rates (65 l/s) and low pressures (<10 MPa). Water injection into the HTR was anticipated to lower the concentrations of NCG as well as to provide a sustainable steam supply for nearby steam production wells. Initiation of this project was also motivated by evidence for an inadvertently created EGS at depths of 3–5 km in the HTR about 3 miles southeast of the EGS Demonstration project area (Stark, 2003).

To date, the data shows a strong and favorable reservoir response to the injection, including increases in pressure and flowrate at nearby production wells, and order-of-magnitude decreases in non-condensible gas content of the produced steam. The area stimulated is evidently partially isolated from the main reservoir to the SE, based on data from wellhead pressures, microearthquake monitoring, noncondensible gas concentrations and rock isotope values. The isolation appears to be controlled by a previously-mapped NE-trending fault zone. The EGS injection experiment was not successful in mitigating the corrosive effects of chloride-bearing steam, which resulted in corroded casing of the production well, PS-31.

The Northwest Geysers EGS Demonstration Project is a collaborative effort between scientists and engineers at Calpine and Lawrence Berkeley National Laboratory (LBNL) and is funded by the US Department of Energy's (DOE) Geothermal Technologies Office and Geysers Power Company (Calpine). The project is organized into three phases:

Phase I: Pre-stimulation. During Phase I, initiated in 2009, a stimulation plan was developed based on a detailed geological model, analysis of historical data, and pre-stimulation modeling (Garcia et al., 2012). 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) constituted the input data for the geologic model created near PS-31 and P-32. A set of stimulation scenarios were presented by Rutqvist et al. (2010) and Rutqvist et al. (2015b) from a coupled thermal, hydraulic, and mechanical (THM) model developed at LBNL.

Phase II: Reservoir stimulation. This phase commenced in October 2011 with injection of tertiary treated wastewater from the Santa Rosa Geysers Recharge Project (SRGRP) into the HTR via P-32 (Garcia et al., 2012). It is important to note that the injection into P-32, as well as all injection at The Geysers, is not pumped and falls from the wellhead under a vacuum of about −0.7 to −0.9 bars (−10 to −13 psig).

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