WELL INTERFERENCE STUDY OF THE MULTI-LAYERED SALTON SEA GEOTHERMAL RESERVOIR

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A well interference testing program of the Salton Sea Geothermal reservoir is being conducted as part of a resource evaluation study by the Earth Sciences Geothermal Industrial Support Program of the Lawrence Livermore Laboratory. Studies to date indicate the reservoir rock to be composed of layered sequences of shales and sands. Wells involved in the testing program are being used in support of, or are in the vicinity of, the MAGMA-SDG&E Geothermal Loop Experimental Facility (GLEF), located in the Salton Sea Geothermal Field (SSGF). Between these wells, a shale layer has been correlated which appears to divide the reservoir into an upper and lower portion. Other thick sand and shale sequences may provide additional stratification. This report describes work in progress on a well testing program designed to determine the horizontal and vertical transmissivity and storage parameters between wells in the vicinity of the GLEF. These tests are being conducted with the cooperation and support of Magma Power Company and San Diego Gas and Electric Company.

The Salton Sea Geothermal Field

The Salton Sea Geothermal Field is located at the southeastern end of the Salton Sea which is within the physiographic province known as the Salton Basin. This basin which forms the northern part of the Colorado River Delta is a sediment filled structural trough called the Salton Trough.[1] The Salton Trough is part of a transition from the oceanic spreading center associated with the East Pacific rise to a major continental fault system that includes the San Andreas Fault.[2] The sequence of sedimentary rocks in the Salton Trough has been determined to be approximately 6000 m thick and composed primarily of detritus from the Colorado River.[3] A Geologic map of part of the Salton Trough that includes the Salton Sea Geothermal Field is shown in Figure 1.[3] Figure 2 shows locations of wells in the SSGF.[3] The shaded portion shows wells currently used in support of the GLEF.

A recent study, by Tewhey (1977), of drill cuttings and core samples from wells in the vicinity of the GLEF indicate the sequence of sedimentary rocks in the SSGF "can be divided into three catagories: (1) cap rock, (2) unaltered reservoir rocks, and (3) hydrothermally altered reservoir rock".[3] The cap rock extends from the surface to approximately 350 m. The first

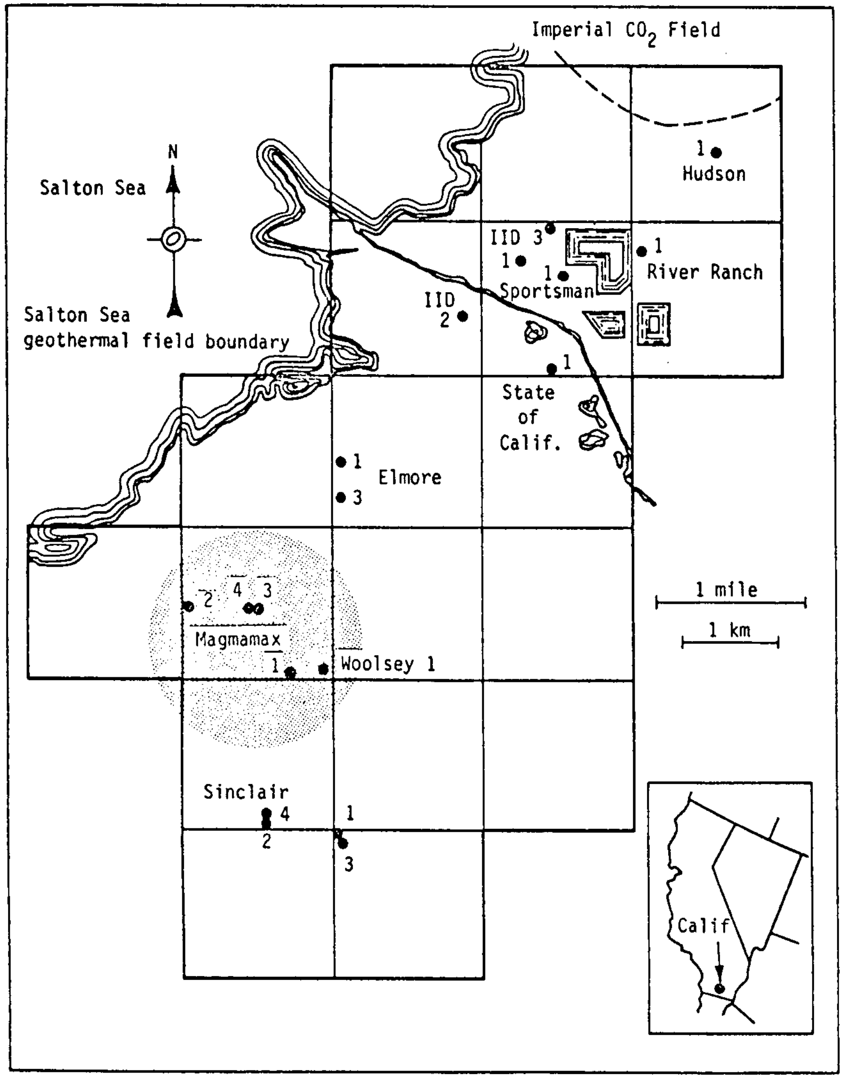

Fig. 2. Well locations in the SSGF. Wells in shaded area are presently used in support of Geothermal Loop Experimental Facility.

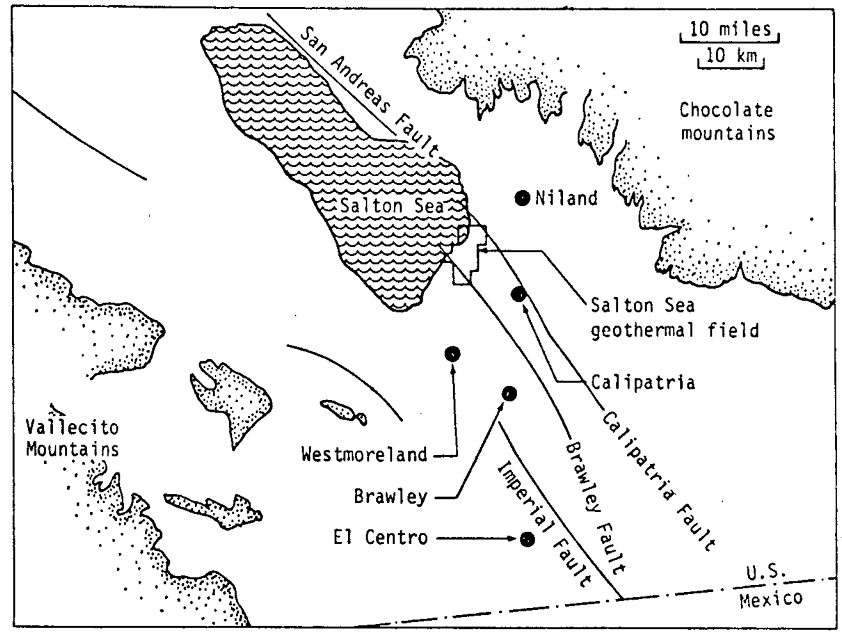

Fig. 1. Location of Salton Sea Geothermal Field and nearby faults in Imperial Valley.[3]

200 m consist of unconsolidated silt, sand and gravel. The rocks from 200 to 350 m are of low permeability consisting of a carbonate-clay matrix which appears to have undergone self-sealing through interaction with the brine.[3] The reservoir rocks consist of layered sequences of well-indurated shales, sandy-shales and sandstones. The transition from unaltered to hydrothermally altered rock is marked by the appearance of epidote.[3] The hydrothermal alteration appears to reduce the permeability and porosity of the reservoir rock. Secondary porosity and permeability appears to be present and renewable in the reservoir due to fracturing associated with natural seismicity and or hydraulic fracturing.

Description of Wells

The wells involved in this study are shown schematically in Figure 3. The location of the bottom of the cap rock, top of the zone of hydrothermal alteration and construction details in each well can be seen in Figure 3. A sequence of alternating sand and shale beds overlying a major shale break is present in all the wells involved in this study. This apparently continuous shale break was first correlated by Towse and Palmer.[4] The approximately 12 m thick shale divides the main reservoir rock sequence into an upper and lower reservoir. There appear to be additional thick sand and shale sequences which might produce further stratification of the reservoir.

The wells involved in this study are completed with perforations either above or below this correlated shale layer (shale break) except Woolsey #1 which is perforated above and below, see Figure 3. The well testing program is designed to take advantage of the wells being perforated in different lithologic horizons so as to measure the horizontal and verticle flow properties between wells.

Description of Tests

The initial tests, which are in progress, involve the wells in the immediate vicinity of the MAGMA-SDG&D GLEF. These are wells, Magmamax #1, 3, and 4 (MM 1, 3 and 4) and Woolsey #1 (WW 1). MM 1 and MM 4 are completed above the shale break and perforated in same lithologic horizons. MM 3 is perforated just below the shale break and is within 15 m of MM 4. WW 1 has a portion of its perforated interval in the same horizon as MM 1. Production wells for the GLEF are MM 1 and WW 1. They are operated in either a single or two well production mode. MM 3 is used as the injection well and MM 4 is designed as an observation well. To date interference tests have been conducted between MM 1 and WW 1, MM 3 and MM 4, and MM 4 and MM 1.

The interference test between MM 1 and WW 1 was conducted from June 16, 1977 to July 10, 1977. The reservoir had been shut-in for two months prior to the test. In this test, WW 1 was the production well and MM 1 was the observation well. MM 3 was the injection well for the spent brine and its interaction with MM 4 will be discussed later. Pressure was monitored in MM 1 for two weeks prior to starting interference test to establish a baseline pressure. WW 1 was primed using N_2 and commenced flowing

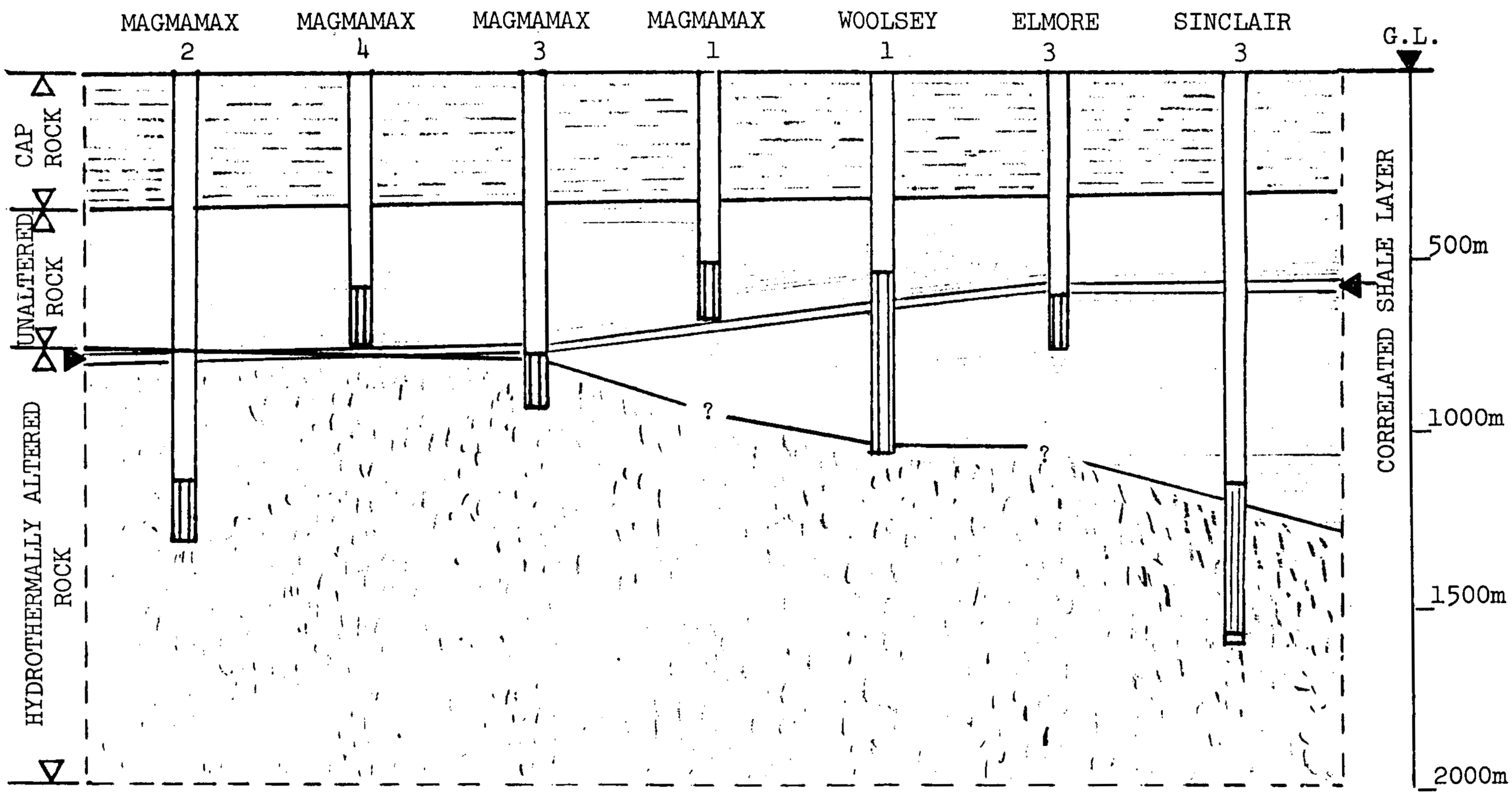

Figure 3: Schematic cross-section of wells involved in well testing program showing completion details within geothermal reservoir. Stripped intervals in wells indicate perforated zones. Note the unaltered rock portion of the reservoir increases in depth as you move away from Magmamax 2 toward Sinclair 3. Distances between wells are not drawn to scale.

on July 2, 1977. Well production was approximately 600-700 GPM. The well was shut-in on July 5. A pressure drawdown was observed in MM 1.

Pressure transient data was measured in MM 1 using a Sperry Sun pressure transmission system (0-1000 psi range). Because of corrosion problems, the pressure transient measurements were made at 30 m below the surface of the static fluid column rather than at reservoir depth. Pressure data recorded for two weeks prior to the test was somewhat noisy with an overall 24-hour pressure variation of 0.3 psi. This ambient noise appears to have been related to the sensitivity of the surface pressure transducer to ambient temperature changes. An overall pressure drop of 1.0 psi was observed during the test period. Analysis of the test data was done using the standard line source solution, log-log, curve matching technique. Interpretation of the data was complicated by a varying production rate and periodic flow reductions during the test to permit a "pigging" operation to be conducted. It was not possible to know exactly the percentage of production from WW 1 which was producing the drawdown in MM 1. An estimated flow rate was used to solve for transmissivity and storage parameters. Results from this test showed the two wells to be in communication and provided an estimate of permeability for the upper reservoir in the 500 md range. To resolve ambiguities present in this test, another test is planned with MM 1 as the producer and WW 1 as the observation well.

The test between MM 3 and MM 4 was conducted from June 16, 1977, thru the end of August. MM 3 was the injection well and MM 4 the observation well. The test was designed to measure the response in MM 4 (perforated above the shale break) to injection in MM 3 (perforated just below shale break). Pressure monitoring during the test was done first with Sperry Sun type equipment and then with a quartz crystal pressure gauge.

Injection pressures during the test averaged approximately 350 psi over static reservoir pressure in MM 3. During the entire period of the test no pressure response was observed in MM 4 which could be related to injection activities at MM 3. Flow rate into the injection well was approximately 600 gpm.

On both the Sperry Sun and quartz crystal pressure gauge, a daily 1.0 to 3.0 psi pressure fluctuation was observed. The diurnal cycle had a high at 03:00 am and a low at 17:30 pm. The phenomena appears to be related to daily heating and cooling of the lubricator. When opened, MM 4 produced a fair amount of CO_2 and seeped fluid at a low rate. When shut-in, the fluid pressure in the lubricator rose within 20 min to approximately 50 psi. Overall response of the well seems to indicate it is partially blocked with sufficient gas and fluid entry to rebuild surface pressure. If there is vertical leakage across the shale break due to injection into MM 3, it is sufficiently small so as not to produce an observable pressure response in partially blocked Magmamax #4 only 15 m away.

The test between MM 4 and MM 1 was conducted for approximately three weeks in September. MM 1 was the production well and MM 4 was the observation well. As in the previous test, no response was observed in MM 4. If a response was present, it was masked by the diurnal pressure noise in MM 4. An additional noise was present in this test due to a leak which developed in the hydraulic line wiper on top of the lubricator.

Additional Testing Plans

Plans are in motion to work over MM 4 so as to improve its performance as an observation well. Recent efforts at the MAGMA-SDG&E GLEF have been directed at installing solids control equipment so as to improve injectability of the spent brine. As a result of these activities, additional tests have not been conducted to date. In the near future, interference tests between MM 1, MM 4, MM 3, and WW 1 will be conducted. Fall-off surveys are also planned for MM 3 using the quartz gauge at reservoir depth. Improved well conditions and equipment should enable these tests to provide less ambiguous results.

Early in 1978, a long term multi-well interference test is planned. Magmamax #2 (MM 2), Elmore #3 (EM 3) and Sinclair #3 (SN 3) will be used as observation wells. The wells will be instrumented with quartz pressure gauges. During the test, MM 1 will be the production well and MM 3 will be the injection well. All three observation wells are perforated below the shale break. EM 3 is perforated in same interval as MM 3. MM 2 and SN 3 are both perforated at greater depth than MM 3. In this configuration, pressure transients recorded in the observation wells should provide a measure of the horizontal and vertical flow characteristics of the lower reservoir.

Upon completion of the well testing program, a formal report of the results will be issued by Lawrence Livermore Laboratory.

REFERENCES

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