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TOOL DEVELOPMENT AND APPLICATION: PRESSURE, TEMPERATURE, SPECTRAL GAMMA RAY LOGGING OF THE SB-15 WELL

Research Results from UNOCAL SB-15 Well

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Logging Tool Development

Sandia's involvement with downhole instrumentation dates from the mid 1970s when work was centered on the development of a high-temperature acoustic borehole televiewer, and the establishment of a list of high-temperature component parts such as resistors, integrated circuits, and sensors. This work evolved into the development of memory logging devices for the US Continental Scientific Drilling Program. These tools were of low cost and very easy to use. Their deployment resulted in scientific advancement in understanding geothermal formations, and a thrust of the current program is to move memory tools from the scientific realm to the commercial environment.

Hostile environment tools found in the traditional logging service industry are capable of operation to 260° C (500° F) for short periods of time, and thus are suitable to some, but not all, geothermal applications. Furthermore, size constraints are imposed by the diamond coring techniques used in some geothermal operations. Taken together, the temperature and the tool diameter provide initial criteria for the design of logging equipment.

The tools developed and utilized in the SB-15 well among other field tests are completely self-contained in that power is obtained from batteries and data are stored in an electronic memory system. Even though memory tools have been around for decades, they have not found common usage due to past limitations in microprocessors and electronic memory density. This situation is changing rapidly due to improvements in digital instrumentation technology.

Three memory tools form the backbone of the initial Sandia tool suite. These tools meet the temperature and size criteria noted below. Pressure/temperature measurements are necessary for the evaluation of geothermal reservoirs, and they are relatively simple to make. Thus, the initial Sandia program concentrated on such a tool, and it has been successfully used in SB-15. This tool will form the basis for future tools since many engineering principles were proven in its evolution. This pressure/temperature tool combination is very useful in characterizing the geothermal reservoir.

Another tool in the Sandia suite measures the natural gamma rays from the formation. This spectral gamma ray tool is useful in defining lithology, paleoflows, and certain clays.

General specifications of these tools include:

- Low cost, yet possess a pedigree for data quality;
- Two inches in diameter or less, so they are suitable for slim, diamond-cored holes;
- Transportable by common air carrier;
- Dewared, operable to 400° C (750° F);
- Operable on a "slick line," not an electric wireline;
- Programmable for different operations and operating conditions.

SB-15 Well Logging History

Three logging runs were made with the pressure temperature log: October 5, 17, and 18, 1994, a few days after completing the drilling and coring of the SB-15 well. The last core had been taken September 29. One hundred barrels of water were used to flush the well on October 11, 1994. A logging run was made on October 17, 1994. and an additional one hundred barrels of water were used to flush the well two hours before the October 18, 1994 logging run. The spectral gamma ray /KUT log was run only on October 17 and 18, 1994.

Pressure and temperature logs were run from 800 ft or 900 ft to the target depth, near 1600 ft, on all three occasions. The pressure/temperature log was run from 10 to 22 ft/min. The spectral gamma ray log was run between 1330 and 1510 ft at 2.25 ft/min on October 17. This log was run five times between 1338 and 1390 ft on October 18: three times at 2.25 ft/min., and two times at 5.5 ft/min.

Preliminary Interpretation of the Data

General Comment

Only a portion of the SB-15 log data taken have been analyzed to date. Sufficient data have been analyzed to verify the viability of these tools, but some data still remain to be analyzed for scientific content. Much of the data necessary to verify the steam entries have been examined (although some pressure and temperature data remains to be replotted). Only a portion of the data from the spectral gamma ray log are available for analysis and correlation with lithology. Fortunately, those data are the summed analysis of the five runs between 1338 and 1390 ft. The remainder of the data will be analyzed before the publication of the SB-15 papers along with the assistance/availability of preliminary data from the other members of the SB-15 science team. Inputs received from the August 24 oral presentation of all the available data will also be incorporated into the publication.

Zero log depth is referenced to the three-inch isolation valve approximately three feet above ground level. An accurate core-to-log depth correlation will be made.

Pressure, Temperature Logging on October 5, 1994 Prior to Flushing the SB-15 Well: Correlation with other Data

The temperature log of October 5, at approximately 1370 ft, indicated a temperature perturbation, which consists of a steep temperature rise of a few degrees F and an increased temperature gradient at approximately 1370 ft. This correlates (approximately) with a vein/fracture seen in the core There is a relatively minor temperature perturbation at approximately 1180 ft, which consists of a small rise of approximately 1/2 degree with little to no increase in gradient. There is a vein/fracture in the core at 1181.5 ft. The pressure data of

October 5, at approximately 1370 ft, indicate a steep rise with an increasing pressure gradient at approximately 1370 ft, There is also some small positive pressure inflection at approximately 1180 ft.

The daily drilling reports indicate total lost circulation at 1369 ft. From that depth to the end of the drilling/coring it was necessary to drill blind. Prior to that, 80% drilling fluid returns had been obtained.

There was momentary lost circulation prior to that, at 1052 ft. From that point, drilling fluid returns diminished from 90 to 80% (although flow meters were not on-line to corroborate this). The pressure/temperature logs really did not show evidence of a steam entry in the vicinity of that horizon.

On the basis of pressure, temperature, core, and daily drilling report data, a steam entry at approximately 1370 ft is postulated. A minor steam entry at 1180 ft is possible. (Other very minors steam entries of even smaller magnitude than the one at 1180 ft are possible.)

Pressure, Temperature Logging on October 17
After Flushing the Well, October 11
but before Flushing the Well on October 18:
Correlation With other Data

The temperature log shows temperature rises of a couple of degrees with gradient increases at approximately 1530 and 1570 ft. The October 17 temperature log also shows minor "bumps' at 1370 and 1190 ft. Presumably, the flushing of SB-15 on October 11 still suppresses these earlier observed entries.

The October 17 pressure log shows strong positive inflections at approximately 1530 and 1570 ft. This log also shows a slight "bump" at approximately 1180 ft and a larger "bump" at 1370 ft consistent with the results of the earlier logging run on October 5. Conversely, the temperature and pressure logs of October 5 do show minor positive inflections or "bumps" at approximately these two greater depths. It may be noteworthy that these inflections are superimposed on steeper temperature and pressure gradients, presumably as a result of the first major steam entry at 1370 ft, perhaps tending to mask evidence of further downhole phenomena.

Pressure, Temperature Logging 2 Hours After Flushing the SB-15 Well, October 18:
Correlation with Other Data

The post-water-injection temperature log of October 18 shows enhanced wellbore cooling at approximately 1320 ft and below, some very minor cooling at approximately 1180 ft and below, and additional cooling at approximately 1530 ft and below. Cooling would be expected if steam entries were located at those horizons. Lower temperatures would be expected below these entries because as steam reenters the wellbore and flows upward, it raises the rock temperature faster **above** the vein/fracture than below it. Veins/fractures in the core are also found at these approximate depths. Therefore, on the basis of pressure and temperature logs on October 17 and

18 (with corroboration from the pressure/temperature logs of October 5), the perturbations around 1530 ft are interpreted as characteristic of one or two additional steam entries.

Spectral Gamma Ray Logging on October 18: Correlation With Other Data

Spectral gamma well logs can detect naturally occurring gamma-emitting elements as potassium, uranium, and thorium within differing well lithologies. Over the logged region, 1330 to 1510 ft, the uranium and thorium windows count rates were uniform. Almost no thorium counts were recorded. Uranium counts were slightly elevated. No inference about the lithology related to the three naturally-occurring radioactive materials have been made at this date.

The potassium peak window exhibits a double gamma ray peak at approximately 1371 ft and 1374 ft, with the more prominent gamma ray peak being deeper. This gamma ray activity is presumably due to the high clay content of the large fractures/veins and argillite observed in the core at this depth. Minor gamma ray peaks at approximately 1340 ft and 1350 ft and around 1390 ft may be due to clay rich veins (1349 ft), or argillite stringers between 1374 ft and 1400 ft. The depth in all these correlations is approximate.