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CHEMICAL LOGGING, A GEOTHERMAL TECHNIQUE

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ABSTRACT

Chemical logging studies conducted at the Department of Energy's Raft River Geothermal Test Site in south central Idaho resulted in the development of a technique to assist in geothermal well drilling and resource development. Calcium-alkalinity ratios plotted versus drill depth assisted in defining warm and hot water aquifers. Correlations between the calcium-alkalinity log and lithologic logs were used to determine aquifer types and detection of hot water zones 15-120 m before drill penetration.

INEL-1 at the Idaho National Engineering Laboratory site in eastern Idaho represents the second area where this was applied. Calcium-alkalinity ratio, lithologic, and compensated neutron logs correlated well and were used to define the water-producing zones penetrated by the well. This well is located in an area of different geologic and hydrologic characteristics.

INTRODUCTION

Chemical logging is a technique developed for geothermal applications which provides geochemical information during drilling. Usually a number of water-producing zones are penetrated during well drilling operations. Water quality information could be obtained by flowing the well at each aquifer, but this would interrupt drilling operations and would be very expensive. Unfortunately, when the well is cased, this information is lost. Using chemical logs, however, water quality can be inferred in less time and with much less expense.

Chemical and lithologic logging are similar in that both are accomplished during drilling and without interference to the drilling operation, and both require frequent sampling at specified intervals of drilling depth. They differ in that chemical logs are developed from drill fluids and lithologic logs from drill cuttings. Chemical logs are chemical profiles of the formation fluids, and lithologic logs are geological profiles.

Chemical logging developed empirically and its operation is not well understood. Work is planned which will identify the mechanism.

This paper describes correlations between chemical, lithologic, and geophysical logs at Raft River in south central Idaho and a well drilled on the site of the Idaho National Engineering Laboratory in eastern Idaho.

REVIEW

Chemical logging was first conducted during the drilling of Raft River well RRGI-6 at the Raft River Geothermal Test Site. Samples, collected at intervals of 60-120 m, were analyzed for pH, conductivity, chloride, fluoride, silica, hardness, and alkalinity. Logs were prepared by plotting the concentrations of the individual chemical species and ratios of these species to the drill depth at which the samples were collected. The most significant result was the correlation between the calcium-bicarbonate ratio log and the temperature log; the chemical log was displaced uphole approximately 120 m.

The results of this study were so encouraging that chemical logs were generated during drilling of Raft River wells RRGP-4, RRGP-5, and RRGI-7. These studies showed the calcium-bicarbonate ratio to be a temperature/flow indicator (Allen et al., 1979). Direction of deflection indicates fresh or geothermal water and amplitude correlates with flow.

Results at Raft River proved that chemical logging can be a valuable tool in geothermal well drilling and that chemical logs are useful aids in reservoir evaluation. The major question was whether this was a site-specific technique. The first opportunity to chemically log a well outside of Raft River was when the Department of Energy contracted to drill a geothermal well (INEL-1) on the Idaho National Engineering Laboratory site.

Geology

Local geology at Raft River defined by lithologic logs of the geothermal wells is dominated by unconsolidated tuffaceous sediments, sandstones, and conglomerates of reworked volcanic material over a basement of consolidated shist, quartzite, and quartz monzonite. The lithologic log of INEL-1 discloses consolidated basalts, rhyolitic tuffs, and interbedded tuffaceous sediments.

DISCLAIMER

DISCLAIMER

Geochemistry

Classifying the geothermal water from Raft River and INEL-1 according to Ellis and Mahon (1977) revealed a significant difference in origin. Raft River geothermal water fits the criteria for alkali-chloride waters, which are found in many developed geothermal areas in both volcanic and sedimentary rocks. The INEL-1 water would be classified a bicarbonate type which is found in volcanic geothermal areas where steam containing carbon dioxide and hydrogen sulfide condenses into an aquifer solution forming neutral-pH bicarbonate or bicarbonate-sulfate solutions. Sodium is often the main cation. Table 1 shows the chemical composition of RRGE-1 and INEL-1.

Table 1. Chemical composition of RRGE-1 and INEL-1.[1]

Chemical Species	INEL-1 2072'-TD	RRGE-1 Raft River
Ca	3.0	53.5
Cl	28	776
F	10.0	6.32
HCO_3	680	63.9
SiO_2	82	120
Conductivity	1500	3373
pH	8.00	7.3
SO_4	81	60.2
Na	419	445

[1] Values expressed as mg/l except for conductivity which is μs.

PRINCIPLES OF CHEMICAL LOGGING

Chemical logs are a plot of the changes in chemical composition of the drill fluid. These changes may be the result of dilution of the drill fluid by water from water-producing zones penetrated by the drill bit. Another possible mechanism is that water flow through the rock alters the formation through reaction and ion exchange. When the drill penetrates this altered zone, the drill fluid leaches the exchanged material which yields a changed composition in the drill fluid. It has been determined in other chemical studies performed at Raft River that very little mixing takes place as the water travels uphole to the mud pit (McAtee, 1978). Diluted drill fluid flows into the mud pit, is mixed, and becomes part of the background chemical composition of the drill fluid. If the water-producing zone has a high flow rate, it will eventually dilute the drill fluid until its chemical composition is dominant.

Return water composition depends on the chemical composition of makeup water, drilling mud composition, and flow or exchange from water-producing zones. Because of these variables, chemical log interpretation can be complex. However, the logs for some of the chemical species and ratios are good. Correlations of these logs with lithological and geophysical logs will be discussed next in the report.

EXPERIMENTAL

Samples of the drill return fluid were collected from the drill fluid return in either one-liter plastic bottles (when water was used for drilling fluid) or five-liter plastic bottles (when drilling mud was used). The samples were filtered to remove the drill mud and cuttings. Additional filtering was performed on the sample when required for a particular analysis. Samples were analyzed for pH, conductivity, chloride, fluoride, silica, hardness, and alkalinity (or bicarbonate) according to procedures described by Brown, Skougstad, and Fishman (1970).

Special analysis techniques were not required for the water samples from Raft River or INEL-1. However, some difficulty was encountered in filtering samples containing drilling mud because of its viscosity. At the Idaho Chemical Processing Plant, an ultra-centrifuge was used to separate drilling mud before filtering.

RESULTS

Throughout this report, reference is made to both calcium-to-bicarbonate and calcium-alkalinity ratios. To clarify this, it is important to explain the use of drill mud and its control in the drilling operation. During drilling, water is used to lubricate the drill string, wash the drill cuttings from the borehole, stabilize the hole, and cool the drill bit. When water is inadequate to meet these requirements or if drill fluid loss is high, drill mud is added. The physical characteristics of the drill mud, such as viscosity, weight, density, and thickness, are partially controlled by pH. The pH of the drill fluid when drill mud was used ranged between 9.0 and 11.5. When water is used, the pH is ≈ 7.5 to 8.5 and bicarbonate ions are the dominant species. Bicarbonate shifts to carbonate ion at a pH of 11 to 12 (Heu, 1970). To simplify this system, the total alkalinity minus the hydroxyl ion concentration is used to determine the calcium-to-alkalinity ratio.

Comparison of Calcium-Bicarbonate and Lithologic Logs for Well RRGP-4A

The calcium-bicarbonate log for the Raft River well RRGP-4A was significant for three reasons:

1. The chemical log identified the aquifer systems of the well.
2. When correlated with the lithologic log, the types of water encountered could be determined.
3. The chemical log was kept current during the drilling operation and the hot water aquifers at 1535 and 1595 m depth were detected ≈ 15 m before drill penetration.

Figure 1 shows the calcium-bicarbonate chemilog and the lithologic log. Aquifers are located at 700-870, 1520-1580, and 1580-1650 m depth.

These were identified by drill rate changes and geophysical logs as well as the chemical log. All three water-producing zones indicate hot water.

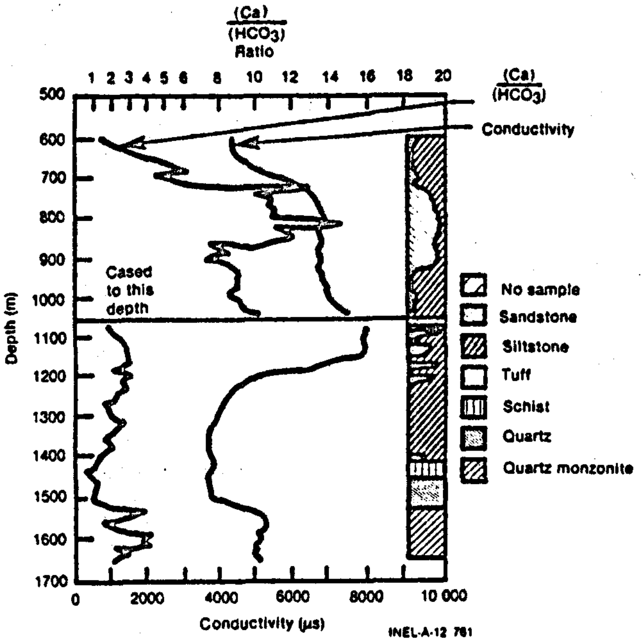

Fig. 1 Calcium-bicarbonate ratio and conductivity chemical log.

$[Ca^{++}]/[HCO_3^-]$ Chemical Log and Lithologic Log for Well RRGP-4A

The aquifer identified by the chemical log at 700-870 m depth corresponds with the increased sandstone shown in the lithologic log. This is considered a permeable aquifer system and was the first injection zone at Raft River. Water-producing zones at 1520-1580 and 1580-1650 m depth are in quartz monzonite or basement rock as shown on the lithologic log. This is a fracture or fault-dominated system which is typical for geothermal wells at Raft River. The chemical log is typical of low flow and this was verified by testing.

Neutron Logs for Well INEL-1

Well INEL-1 is located a few miles north of the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory and was drilled to a depth of approximately 3450 m.

Figure 2 shows the calcium-alkalinity and neutron compensated logs for INEL-1. Neutron logs are used to determine formation porosity. Log response indicates the amount of hydrogen in the formation and consequently is a measure of liquid-filled porosity. Correlating the neutron log with other porosity logs improves the accuracy of the porosity values and the lithologic identification. The neutron log in figure 2 was correlated to the lithologic log. The higher porosity areas corresponded well with the contact surfaces and fractures identified in the lithologic log. Off-scale caliper log readings are evidence of borehole washout areas due to formation water. Comparing washout areas in the borehole to the neutron log showed good correlation.

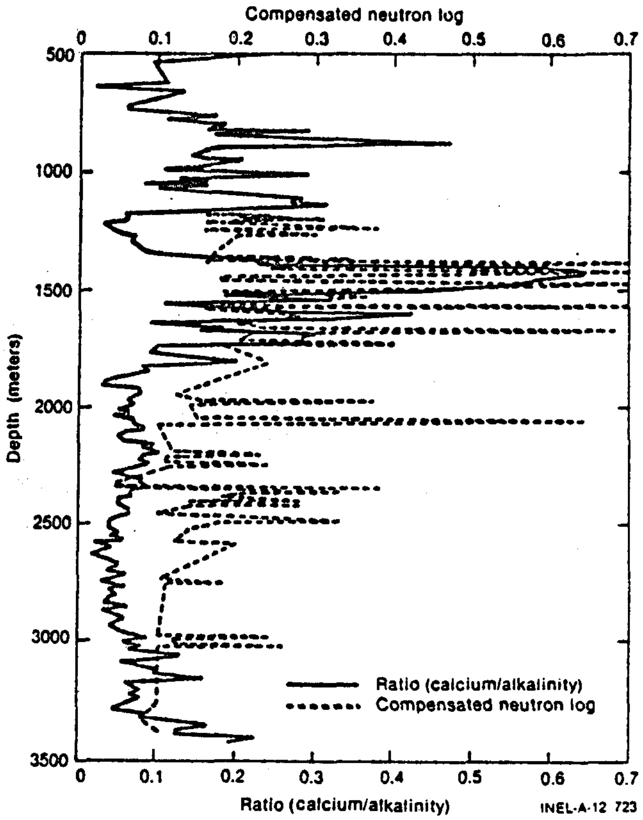

Fig. 2 Calcium-alkalinity ratio and compensated neutron logs.

Correlating the calcium-alkalinity log and the compensated neutron log between 1400-1600 m was significant. This zone within the borehole has the highest porosity; the chemical log depends on both water temperature and formation flow to determine the amplitude of the calcium-alkalinity ratio. This would indicate that the borehole area having the highest porosity is the area of highest formation water flow. From the depth of 1900 m to 3000 m, the porosity decreases and the chemical log gives no indication of any water flows. Below the depth of 3000 m the neutron log shows no areas with any significant porosity values. The chemical log, however, at the depths of 3100, 3200, and 3400 m indicates the possibility of hot water at low flow rates, possibly from small fractures which are not detected by the neutron log. Future well development of INEL-1 may furnish additional borehole information.

Comparison of Calcium-Alkalinity with Caliper (Maximum Readings) Logs for INEL-1

Figure 3 shows the calcium-alkalinity and the caliper (maximum readings) logs. Areas of maximum porosity are located at the same depths of many of the maximum reading areas of the caliper log, especially between 1400 to 1700 m. This means that the areas with the highest calcium-alkalinity ratios correlate well with borehole washout areas. This could be interpreted that the formations with the greatest flow are located between the depths of 1400 to 1700 m, which is the location of the highest calcium-alkalinity ratios. Flow tests between 1036 and 1490 m produced water at a temperature of ≈ 50°C with an estimated flow rate of ≈ 4000 l/m.

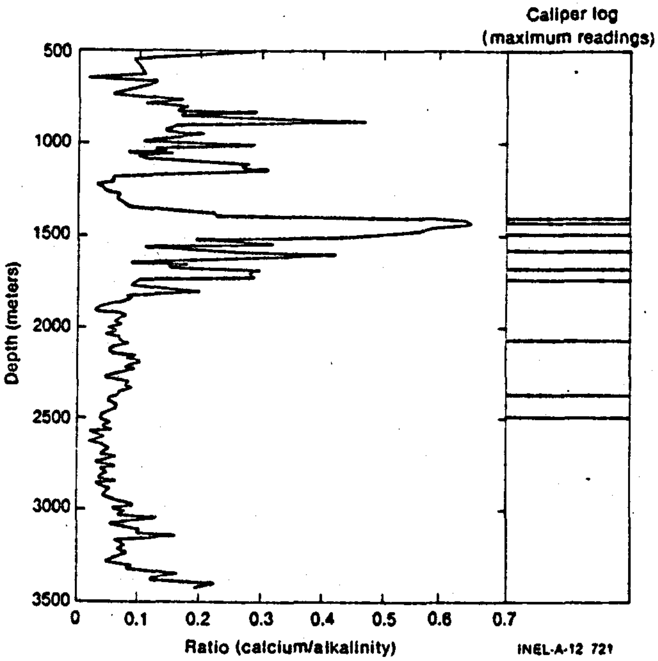

Fig. 3 Calcium-alkalinity ratio and caliper logs. Caliper log shows areas of maximum readings.

Comparison of Calcium-Alkalinity with Lithologic Logs for INEL-1

Figure 4 shows the calcium-alkalinity and lithologic logs. The lithologic log aids in identification of fracture zones and contact points between different zones. Correlation of these zones to the high-porosity zones defined by the compensated-neutron log and the washout zones of the caliper log are good between 1200-3400 m depth. Comparison of thè calcium-alkalinity log to the lithologic log correlates well between 1400-1800 m and 3000 m. Since the chemical log, to show change, is dependent on drill fluid dilution by an aquifer, it is inferred that the chemical log defines the water-producing zones in INEL-1. This effect is obvious at well bore depths between 1800-3000 m has a number of high porosity-fractured zones not defined by the chemical log. It is assumed that these zones did not produce enough water to affect the chemical composition of the well and consequently the chemical log.

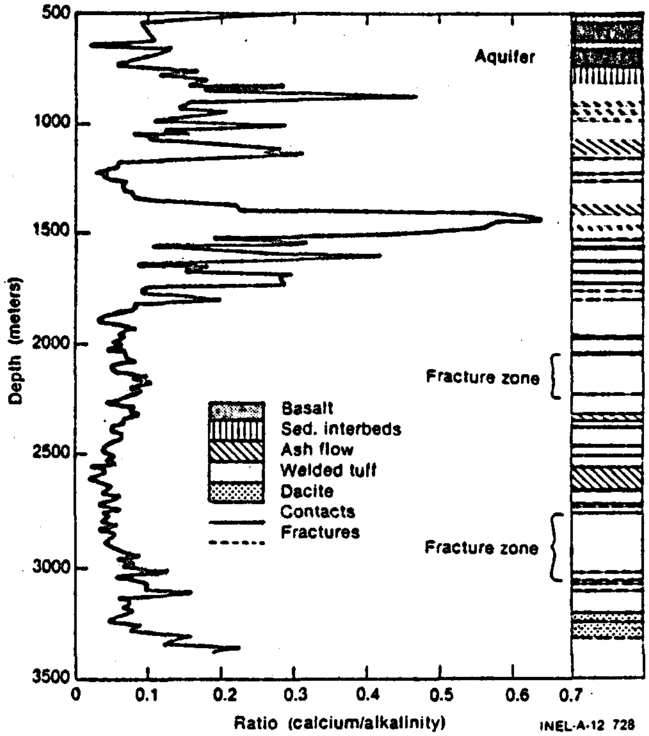

Fig. 4 Calcium-alkalinity ratio and lithologic logs.

CONCLUSION

The correlation studies discussed in this report have supported the validity of the chemical logging concept. Not only did the log of the calcium-alkalinity ratio define the aquifer system at the intermediate depths of INEL-1, it defined the very low production hot-water aquifers near the bottom of the borehole. The geophysical and lithologic logs did define the production zones at the same depths, but were prepared following well completion. The chemical log was prepared within 24 hours of sampling during the drilling operation without interferring with drilling. This chemical logging study indicated that the method is not site-specific to the Raft River valley. Future studies in other areas will determine if the chemical logging technique is valid in defining hot and warm geothermal aquifers.

ACKNOWLEDGMENTS

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