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LITHOLOGY DETERMINATION FROM DIGITIZED WELL LOGS -- EXAMPLES FROM ORE-IDA No.1 GEOTHERMAL WELL, ONTARIO, OREGON

Subir K. Sanyal, GeothermEx, Inc., Berkeley, California
W. E. Glenn, University of Utah Research Institute, Salt Lake City, Utah

ABSTRACT
This paper presents some of the advantages and pitfalls of lithology determination from digitized well logs. Examples are provided from the Ore-Ida No.1 geothermal well in Ontario, Oregon, drilled through a sequence of siltstone, clay, tuff and basalt/andesite. The use of histograms and crossplots to differentiate various lithological units and to identify alteration is illustrated.

INTRODUCTION
The identification and quantitative assessment of the lithology in a geothermal formation can be accomplished from digitized well logs. Although an examination of the drill cuttings is the first step in lithology identification, a drill cuttings log provides only a crude and/or incomplete lithological profile in a geothermal well. There are several reasons for this:

1. Samples cannot often be collected fast enough during periods of rapid drilling.
2. Hole sloughing causes mixing of cuttings from various zones.
3. Samples may flow into the lost circulation zones and not be recovered ("blind drilling").
4. In zones of lost circulation, cuttings recovery from lost circulation material may be difficult.
5. It is difficult to estimate accurately the time required to transfer the cuttings to the surface, thereby making errors in the depths of origin of the cuttings.
6. Identification of lithology from cuttings is often difficult or misleading because of the small size of cuttings.

METHODOLOGY
Digitized well logs can be used to refine and supplement a drill cuttings log to obtain an accurate lithologic profile. Either real-time digital recording of data or digitization of analog data can be used for this purpose. However, in either case the digitized data should be checked for correct calibration and "depth shifting" and "environmental corrections" performed. Depth shifting is required to correct logs for uneven stretching of the cable. Environmental corrections are required to correct for the distorting effect of the borehole environment on formation response. The most important correction required is that for borehole enlargement. Corrections for mud type, mud-cake thickness, temperature, etc., should be made when appropriate. However, a qualitative determination of the lithology can usually be accomplished without most of these corrections; a quantitative analysis requires all corrections. The digitized, edited data are stored on a computer tape and retrieved for analysis.

The analysis consists of several steps. The first step is to compare the analog traces of the other logs with the drill cuttings log and arrive at a preliminary set of diagnostic criteria for each of the basic lithological components encountered in the well. This comparison also helps refine the drill cuttings log and divide the well data into several vertical depth intervals, each broadly corresponding to an apparently distinct lithological entity. Each interval may be a few feet to a few hundred feet in thickness. The data within each interval are then subjected to various statistical analyses to further define the lithological make-up of each interval. In its simplest form, this step consists of the preparation of histograms, frequency plots, "Z-plots," etc. Histograms of a log response data, such as bulk density, is inspected for evidence of single or multiple lithological components, the presence of gradational composition, etc. A frequency plot is a plot of one log response variable against another (such as bulk density against gamma ray intensity) with the frequency of occurrence of a specific data point on the plot shown by an alphanumeric character. Characters 1 through 9 and A through Z indicate frequencies of 1 through 9 and 10 through 35. Special characters can be used to represent a frequency of over 35. From clustering of points the presence of various lithological components, evidence of rock alteration, presence of gas or fractures, etc. can be recognized. Either a visual "pattern recognition" approach or a quantitative cluster analysis can be applied at this stage. "Z-plots" are similar to frequency plots, except that a third variable (the Z-
variable) replaces the frequency variable on the plot of one log response against another. The Z-variable can be any log response other than the responses representing the two horizontal coordinate axes. Through "pattern recognition," Z-plots also can be used for lithology differentiation, and identification of rock alteration, fractures, gas, etc. Once a qualitative analysis of the lithology is made based on the histograms and crossplots, quantitative analysis is possible. However, in this paper only qualitative analysis is discussed.

EXAMPLES FROM ORE-IDA No.1

Ore-Ida No. 1 is a deep geothermal test hole drilled to 10,054 feet at Ontario, Oregon. Sanyal, et al (1980) presented the results of a well-site interpretation effort of the logs from this well. Since a well-site interpretation could be highly subjective, it was felt that a computer-aided analysis was warranted. The well logs were digitized, edited and stored on computer tapes. This digitized data base was used in a qualitative (but subjective) interpretation effort of the logs from this well. When a specific interval was composed of a single rock type, diagnosis was easy. When two or more lithological components were mixed, diagnosis from log response is difficult. Use of histograms and crossplots in such cases usually resolves the problem. For example, in Ore-Ida No. 1 distinction of thin (a few feet) siltstone layers from claystone layers was almost impossible from drill cuttings. Z-plots resolved this problem, while histograms were not useful. In Figure 1, the data from a 375 foot interval, described as siltstone/claystone is crossplotted as bulk density ($\rho$) vs. neutron porosity ($\phi_N$) with the Z-axis being the interval transit time ($\Delta t$). The tighter cluster of siltstone with lower density (because of higher true porosity) and lower neutron porosity (lower hydrogen content) can be separated from the broad cluster representing claystones. Claystone zones show higher $\rho$ and higher $\phi_N$ than siltstone zones; the $\phi_N$ is higher as the rock contains more clay (and hence more hydrogen).

Many zones in this well were described as mixtures of siltstone/claystone with basalt/diabase. Figure 2 shows an example of a histogram of gamma ray intensity (GR) in a 277 ft zone which clearly shows bimodal distribution. The peak corresponding to lower GR represents basalt/diabase response; the higher GR peak represents siltstone/claystone. Figure 3 shows a Z-plot of $\rho$ vs. $\phi_N$ with $\Delta t$ in the Z-axis. Here, the basalt/diabase cluster is identified by its high $\rho$, low $\phi_N$, low $\Delta t$ and low GR (not shown here).

Figure 4 shows a Z-plot for a 357 ft interval described as a mixture of tuff and basalt/diabase. Figure 4 presents $\rho$ vs. $\phi_N$ with GR as Z-variable for this interval. The basalt/diabase cluster is distinguished from tuff by its higher $\rho$, higher $\phi_N$, lower GR, and lower $\Delta t$ (not shown here).

Figure 5 presents a $\rho$ vs. $\phi_N$ plot with resistivity ($R$) in the Z-axis for a 255 ft interval of basalt, parts of which are altered (saucesseritized) and parts are fractured. Alteration increases $\phi_N$ because of the addition of hydroxyl ions, but does not change $\rho$ significantly. Fracturing reduces $\rho$ and increases $\phi_N$ linearly with the increase in secondary porosity.

Figure 6 presents a plot of $\rho$ vs. $\phi_N$ with $\Delta t$ as Z-variable for a highly enlarged hole section (249 ft thick) consisting of partially altered basalt. The unaltered basalt cluster is easily identified. The long linear trend of points is caused by excessive hole enlargement. Note that the lowermost points on the plot show $\Delta t$ values of the order of 200 microseconds per foot, which is the $\Delta t$ of water. This implies that hole enlargement is so large that true formation response is not available for these zones. The uppermost points in the linear trend represent altered basalt, which have caused hole enlargement by sloughing.

CONCLUSIONS

1. Drill cuttings data provides only a crude and/or incomplete lithological profile in a geothermal well.

2. Analysis of digitized well logs can be used to diagnose presence of various lithological components, rock alteration, fractures, etc.

3. Hole enlargement can mask true reservoir response.

NOMENCLATURE

$\rho$ = Bulk Density (gms/cc)
$\phi_N$ = Neutron Porosity (percent)
$\Delta t$ = Interval Transmit Time (microsec/ft)
GR = Gamma Ray (API Unit)
R = Resistivity

REFERENCES

FIGURE 1. \( \rho \) vs. \( \phi_N \) with \( \Delta t \) as \( Z \)-variable.

FIGURE 2. GP Histogram

FIGURE 3. \( \rho \) vs. \( \phi_N \) with \( \Delta t \) as \( Z \)-variable.
FIGURE 4. Z-Plot of $\rho$ vs. $\phi_N$ with Gamma Ray.

FIGURE 5. Z-Plot of $\rho$ vs. $\phi_N$ with Resistivity.

FIGURE 6. Z-Plot of $\rho$ vs. $\phi_N$ with $\Delta t$. 

INTERVAL TRANSIT TIME
MICROSEC/FT

$0 < 0$  $< 20$  $0 < 1 < 40$
$20 < 2 < 60$
$40 < 3 < 80$
$60 < 4 < 100$
$80 < 5 < 120$
$100 < 6 < 140$
$120 < 7 < 160$
$140 < 8 < 180$
$160 < 9 < 200$
$180 < 10 < 220$
$200 < 11 < 240$
$220 < 12 < 240$
$240 < 13 < 240$

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