ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

GEOPHYSICAL LOGGING IN THE IRDP HOLE IN REYDARFJÖRDUR, ICELAND

Field data and preliminary report

VALGARÐUR STEFÁNSSON

Geothermal Division

OS79003/JHD02
Reykjavík, January 1979

GEOPHYSICAL LOGGING IN THE IRDP HOLE IN REYDARFJÖRDUR, ICELAND

Field data and preliminary report

VALGARÐUR STEFÁNSSON

Geothermal Division

OS79003/JHD02
Reykjavík, January 1979

CONTENTS

ÁGRIP (ABSTRACT IN ICELANDIC)

Birtar eru niðurstöður jarðeðlisfræðilegra borholumælinga í 1920 m djúpri kjarnaholu við Áreyjar í Reyðarfirði. Mældar stærðir eru: náttúruleg gamma geislun, nevtrónu-nevtrónu poruhluti, gamma-gamma eðlisþyngd, holuvídd, sjálfspenna, 16 og 64 tommu normal eðlisviðnám, hitastig, mismunahiti, mismunasegulmögnun (CCL), hljóðhraði og dempun hljóðbylgju. Frumniðurstöður sýna mjög gott samræmi milli borholumælinga og kjarnalýsinga. Innbyrðis samræmi er einnig gott milli jarðeðlisfræðilegra mæliaðferða. Borholumælingarnar sýna, að massív innskot hafa "fínstrúktúr".

0. ABSTRACT

Field data of the geophysical logging in the continuously cored 1920 m deep Iceland Research Drilling Project hole at Áreyjar in Reydarfjördur, Iceland, are presented. Natural gamma ray, neutron-neutron porosity, gamma-gamma density, caliper, self potential, 16" and 64" normal resistivity, temperature, differential temperature, differential magnetic permeability (CCL), sonic velocity and sonic wave attenuation were measured. Preliminary results show very pronounced relationship between physical and lithological parameters. The internal consistency of different geophysical logs is good. Fine structure effects in massive intrusions are recorded in the geophysical logs.

1. INTRODUCTION

Geophysical logging of the continuously cored 1920 m deep Iceland Research Drilling Project hole at Áreyjar in Reydarfjördur was carried out by the Icelandic National Energy Authority (NEA). The field measurements were carried out during the period August 24-26, 1978, and were partly repeated in September 1978 when the 580 m top section of the NQ casing had been removed from the hole. During the latter period, an attempt was also made to measure the sonic velocity with a hired sonic-bond tool. Several runs were made in accordance with the operating procedure recommended by the manufacturer. However, the results seemed to be unrealistic and for a long time it was considered that the measurements were a failure. For this reason, the sonic log is not included in this report.

The sonic velocity in iron is used as a calibratian point in the operating recommendation from the manufacturer. By further investigation of the sonic log, and the conditions present in the experiment, it was found, that the thin casing in the Reydarfjördur well seems to have no effect on the sonic result. By this reconstruction of the experiment a meaningful interpretation of the sonic log can be made, and the correspondence between the sonic log and the neutron-neutron log is good.

The field data of the sonic measurements from the surface to 1300 m depth will be presented as soon as possible in a separate report.

In this report the logging tools used at Reydarfjördur are described, and the main parameters affecting each log are mentioned. The logging data are presented on two big drawings, 1 x 4 m size each. The scales on the drawings are the same as used during the measurement in the field.

There is no quantitative interpretation of the data in this report, but the most prominent anomalies in the logs are pointed out, and a comparison is made between some of the logging data and the geological section (core description).

2. DESCRIPTION OF THE MEASUREMENTS

The logging equipment used for the measurements at Reydarfjördur were manufactured by Gearhart-Owen Industries in Texas. The logging cable is a four-conductor 9/32" O.D. with Tefzel isolation. The instrumentation is described in the following sections.

2.1 Natural gamma ray.

The down hole tool used was a 1 11/16" O.D. Gamma Ray - CCL - Neutron Tool with 1 3/8" x 18" Geiger and 1" x 6" He3 Neutron Detector. The GO number is 02-9205-00. The total gamma ray intensity was recorded on an analog recorder and with GO (02-9823-07) RMM 208 Rate Meter Module. The time constant used was 80 sec. The gamma detector was calibrated by 02-9902-03 Radioactive Gamma Ray Calibrator, and the measurements are presented in API gamma units.

2.2 Neutron-neutron porosity.

The n-n measurements were conducted with the same down hole tool as described in 2.1 and with a similar surface recording equipment. The ratemeter RMM 208 was used, and the time constant in the neutron channel was 10 sec. The radioactive source was 3 Cu Am Be 241 and the spacing was 13". The detector was calibrated with 02-9903-01 Neutron Calibrator in accordance with instructions of the manufacturer. The measurements are presented as API neutron units. Correction curves for hole size effects are available from Gearhart-Owen for 6", 7 1/2" and 9", but not for smaller diameters. An extrapolation to the actual diameter of the borehole at Reydarfjördur could be made from these curves. However, that method is not accurate.

The correction curves available from Gearhart-Owen are shown in Figs. 1-4.

2.3 Gamma-gamma density.

The down hole instrument used was a 02-9241-00 Density Tool, 1 11/16" O.D. The radioactive source was 125 µCu Cs 137. The surface instruments were the same as described in 2.1 and 2.2. The time constant was 10 sec.

There is no calibration procedure specially recommended by Gearhart-Owen. At the NEA, calibration facilities are under construction. At present, the results are only qualitative in the way that higher counting rate means lower density. It is intended to complete the laboratory calibration within a few months in order to correlate the measurements to core data.

2.4 Caliper.

The down hole instrument used was a 02-9380-03 1 1/4" O.D. 3 Arm Caliper Tool. The surface instruments used were RMM 208 and a recorder. The tool was calibrated before and after each run.

2.5 Resistivity and self-potential.

The down hole instrument used was a 1" O.D. tool, constructed at the NEA with the same spatial dimension as the "E" Log Tool from Gearhart-Owen (04-9701-02).

The arrangement of the electrodes is of "normal type" with 16" and 64" spacings. The surface instruments used were from Gearhart-Owen, 02-9813-01 ELM 202 "E" Log Module and 02-9814-01 SCA 002 Syncronous Converter. The set-up was calibrated in accordance with recommendations from GO (calibration box) and the unit on the record is ohmmeter (Ωm) for the resistivity and mV for the SP measurements.

2.6 Temperature and differential temperature.

The down hole instrument was a 02-9361-00 1 7/16" O.D. Differential Temperature Tool. The surface instruments were a RMM 208 and a 02-9824-02 DTM 203 Differential Temperature Module. The absolute value of the temperature as well as the temperature gradient is recorded simultaneously. With the logging speed used (10 m/min) and the delay in the DTM 203 the differential temperature recorded is proportional to the temperature difference over 1 m spacing in the well. The scale on the differential temperature is arbitrary. However, the sensitivity used was the same as has been found empirically to give good results in other wells in Iceland. The temperature equipment from Gearhart-Owen used in this hole gives a digital-read-out in degrees Celsius. The whole setup has been calibrated at the NEA in Iceland, and it is found that the relative accuracy of the equipment is within ± 0.5°C. However, a constant displacement of up to 1-2°C of the absolute value is present. In the records accompanying this report, this constant correction has not been carried out.

2.7 CCL - Casing Collar Locator.

As the name of this method indicates, these measurements are intended to locate the connections of casing pipes in boreholes. The principle of the measurement is very simple. The tool consists of a coil between two permanent magnets. When the magnetic permeability surrounding the tool changes, a current is induced in the coil. This current is transmitted to the surface and recorded. The temperature tool has a CCL function inbuilt, and the registration of the differential magnetic permeability in open hole was registered as a byproduct of the temperature measurements. The results are only qualitative, but it may be of interest to correlate these with the magnetic properties of the core.

3. PRELIMINARY RESULTS

As the quantitative measurements on the core are not yet available (chemical composition, density, etc. of units) and as some of the calibrations of the tools are as yet incomplete, a quantitative correlation between logging (measurement) and the core data cannot be made at this stage. However, an attempt will be made in this chapter to point out some of the most outstanding correlations between the core description and the geophysical parameters.

3.1 Natural gamma ray.

The measured parameter in this log is the natural gamma radiation from the rock surrounding the well. The level of "typical Icelandic rock" is not established so far. The general level in the hole in Reydarfjördur seems though to be somewhat higher than registrated in other wells in Iceland to date. This is most likely due to the small diameter of the well, but could also be due to the more differentiated nature of the rocks in

Reydarfjördur as compared to strata in other localities where natural gamma rays have been measured.

The isotopes contributing to the natural activity are ^{40}K and isotopes in the uranium and thorium series. The amount of U and Th in Icelandic basalts have been reported to be 0.2-3.4 ppm (Heier et.al. 1966, Sun and Bor-ming Jahn 1975) and the variation in K_2O is known to be 0.1-10%.

In magmatic differentiation U, Th as well as K tend to be more enriched in the acidic phases (e.g. Ryback 1976), and in natural gamma-ray spectral logging (Lock and Hoger 1971) a general positive correlation is found between U and K in sedimentary rocks. The natural gamma-ray log reflects the chemical composition of the rock. However, an investigation on the U and Th contents of the rocks has to be carried out for the interpretation of the gamma ray log.

There are several distinct peaks in the natural gamma-ray curve. All of these anomalies correlate well with the geological log. The anomaly between 920 and 950 m depth is a nice step function which corresponds to an ignimbrite layer at the same depth.

Apart from this correlation the geological log does not suggest any simple explanation of the difference observed in the natural gamma-ray activity, and further interpretation must be based on chemical analyses of the core.

3.2 Gamma-gamma and neutron-neutron measurements.

The bulk density registered by the gamma-gamma measurements shows constant base-line with numerous peaks indicating lower density. In general these zones of lower bulk density are followed by a low counting rate in the neutron-neutron channel, i.e. the decrease in density is due to an increase in porosity. Therefore, the rock density may be expected to be fairly constant in the whole pile penetrated by this well. Most of the changes recorded in the gamma-gamma measurements are due to changes in the porosity of the rock. However, there are important exceptions from this general rule. In the ignimbrite layer (at 920-955 m depth) the n-n log does not show as high a porosity as corresponds to the γ-γ log. In this case the lower bulk density must be due to a variation in the rock density. At 1380 m depth there is a small density low peak which is not followed by a porosity high peak. Further, this anomaly is within a thick section of an aphyric basalt intrusion. Another interesting low density peak is at 1767 m depth also within an intrusion. The big γ-γ anomaly at 1707 m depth is due to a cavity in the well as can be seen on the caliper log.

Within the two thick intrusions at the top of the hole (depth 63-172 m) an interesting fine structure occurs in both the γ-γ and n-n measurements. In this case the anomalies coincide with each other, showing the porosity variation within the intrusions. Besides these narrow peaks in the two intrusions there is further a general trend in the n-n log showing a lower porosity at the bottom (170 m) than at the top (60 m). This variation does not show up in the γ-γ log. On the contrary, the bulk density seems to be somewhat lower at the lower part of this section than in the upper part.

At the bottom of the intrusion between 690-727 m depth there is a prominent low porosity anomaly. This anomaly is believed to be real as this peak coincides with an anomaly in the natural gamma ray channel. The effect could be caused by structural changes across the dyke.

3.3 Caliper log.

The inside surface of the hole is fairly smooth. There is only one cavity located at 1707 m depth, and the effect of this is displayed in the γ-γ and n-n logs. Elsewhere in the hole corrections for differential well effects on the logs are unnecessary.

3.4 Resistivity and self potential measurements.

The peak values of the resistivity (>4000 Ωm) are extremely high. In boreholes elsewhere in Iceland, resistivity values of the order of several thousands of Ωm have only been recorded in what has been interpreted as intrusions from cuttings and data on drilling rate. This turns out to be the general rule for the Reydarfjördur hole too. However, some of the basaltic flow units have very high resistivity. See e.g. the resistivity peaks at 230, 252, 270, 1650, 1730, 1897 and 1907 m depth.

As a general rule, there is a good correlation between the resistivity log, and the γ-γ and n-n logs in the way, that low porosity corresponds to high resistivity. This supports the general rule, that the main factor govering the resistivity in the rocks is the porosity.

Due to the high resistivity values at some places in the well in Reydarfjördur, and due to the linear scale of the instruments, there is little information to be gained from the resistivity variation in the low resistivity region of the hole.

In order to increase the information on the resistivity in the low resistivity regions it should be considered to rerun the resistivity log with a lower range and disregard the high resistivity peaks.

In the SP curve, there is a prominent correlation of negative anomalies with the high resistivity peaks. At the moment there is not an obvious explanation for this observation, and the possibility that this might be an instrument effect cannot be ruled out. It should be pointed out that the instruments are not designed for this resistivity contrast.

The most interesting anomalies in the SP log seem to be the positive anomaly at 490 m depth and the negative anomaly at 1705 m depth. The change in the SP curve at 490 m depth is larger than the corresponding resistivity variation at this depth in the hole. The shape of the SP curve is in agreement with the γ-γ and n-n log at this location.

The variation in the SP curve might be caused by a chemical potential formed by the combination of thin basalt flows with breccia layers. Similar effect would arise from cement in the well. To our knowledge, there was no cementing work done during the drilling of the well.

The other obvious anomaly in the SP log is a negative one at 1705 m depth, which is not in accordance with the resistivity variation at this place. Further there is a small anomaly in the differential temperature log at this location in the hole. This effect is most likely due to the cavity in the hole, but could also be partly affected by a small aquifer.

In agreement with the γ-γ and the n-n logs, the resistivity log shows fine structure effects within the intrusions. This is most conspicuous in the interval from 60-170 m depth. There, both the narrow porosity peaks as well as the previously mentioned general trend within this section as seen by the n-n log, is repeated in the resistivity logs. However, there is a big difference. The resistivity between 80 and 100 m depth is much higher than the corresponding n-n log would indicate. There are exceptions to the simple rule of correspondence between porosity and resistivity, and an additional effect has to be looked for. This effect could either affect the n-n measurement or the resistivity. Hopefully, measurements on the core itself will give some explanations for this.

The interval from 60-170 m depth may serve as a particularly good example to demonstrate the potential of measuring many parameters in well logging in order to pinpoint in detail structural or textural variations in the rock.

3.5 Temperature and differential temperature.

A temperature profile was run in the hole once every week during the drilling after a 24 hour stopping with equipment which was permanently located at Reydarfjördur. This set of data gives valuable information on the rock temperature in the well. The information gained by the temperature and differential temperature measurements carried out after the drilling was completed, is much more limited than the information obtained by the temperature measurements carried out during the drilling. In fact, the differential temperature curve is almost constant, and some of the small aquifers located during the drilling, could not be confirmed by the differential temperature measurement. Aquifers are seen in the differential temperature data at 510, 480 and 635 m depth. The peak at 1350 m depth is due to the end of the casing. At 1710 m depth the anomaly can be caused by the cavity in the well, or might indicate a small aquifer in connection with the cavity.

3.6 CCL - Casing Collar Locator.

As described in 2.7 these measurements are only qualitative and it is not clear yet if this information can be used in a meaningful way. At present we only see that some regions in the hole are more "magnetically quiet" than other regions. The most conspicuous region is that of the shallow intrusions between 60 and 170 m depth.

A preliminary comparison between the CCL-log and the magnetic susceptibility of the core carried out at the drillsite indicated a correlation between these measurements.

4. DISCUSSION

The geophysical logging in the hole in Reydarfjördur is one of the most extensive logging operations performed in Iceland to date. Outside Iceland, we are only aware of similar investigations in oceanic basalts performed in Hawaii in 1973 (Keller et.al. 1974).

The present report is only intended to present the field data. All the field data are of satisfying quality. Steps will be taken to digitize the data to make comparison with parameters measured on the core easier and more reliable.

The preliminary results obtained so far by visual comparison of different measured parameters show that geophysical logging is a very powerful tool to obtain, in a relatively short time, the physical parameters of the rock intersected by a drill hole. When these results can also be cross checked by laboratory measurements on the core, a very complete picture should be obtained. The drill hole at Reydarfjördur with its complete core will clearly serve as a very good calibration hole for geophysical logging instruments. The calibration can subsequently be used for interpretation of logging data in uncored holes and in holes where the core recovery is poor in volcanic sequences.

REFERENCES

K.S. Heier, B.W. Chapell, P.A. Arriens and J.W. Morgan, The Geochemistry of Four Icelandic Basalts, Norsk Geologisk Tidskrift Vol. 46, p. 427-437 (1966).

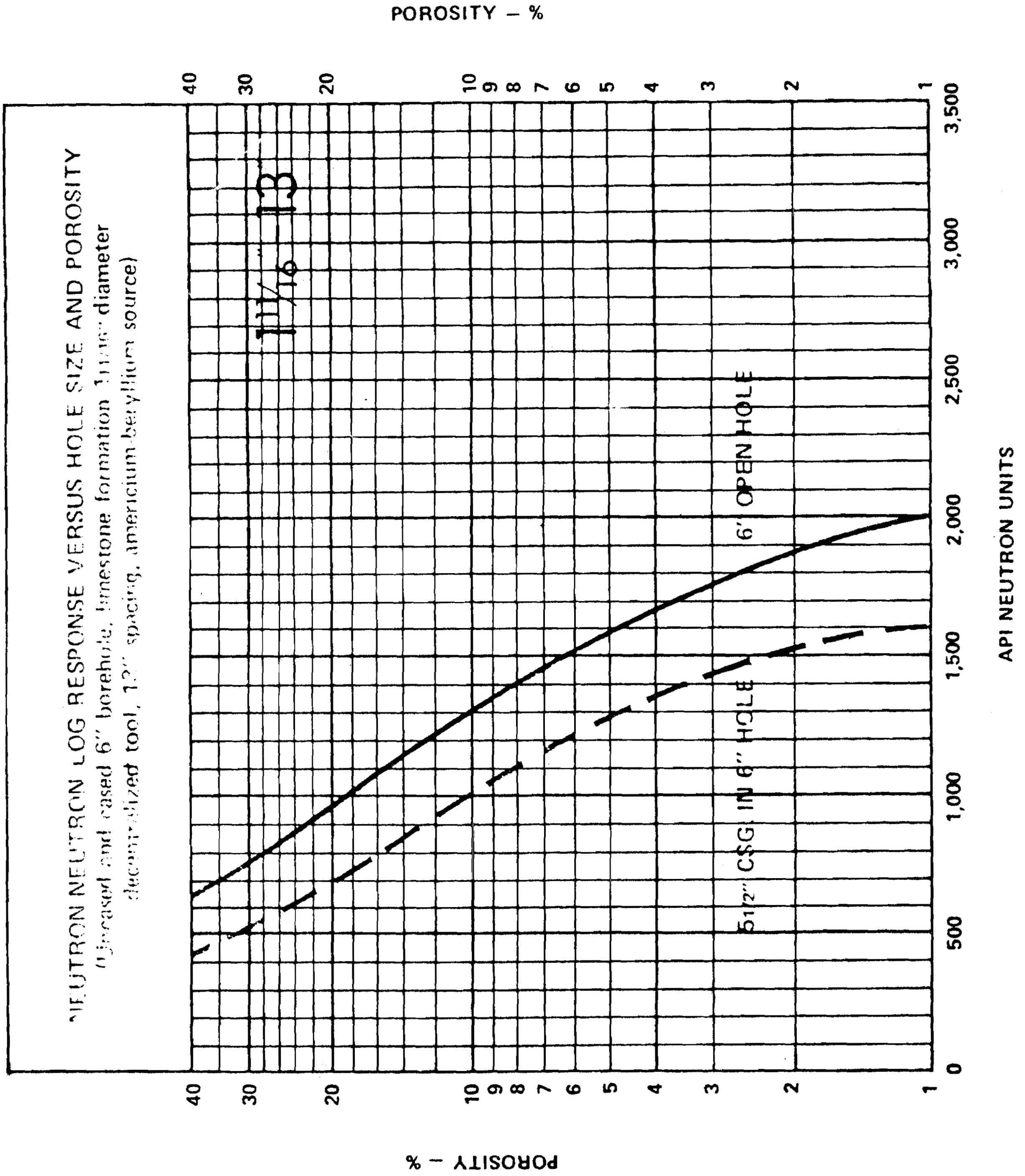
G.V. Keller, J.C. Murray and G.H. Towle, Geophysical Logs from the Kilauea Geothermal Research Drill Hole, Paper L in Transactions of the SPWLA Fifteenth Annual Logging Symposium, SPWLA (1974)

G.A. Lock and W.A. Hoyer, Natural Gamma-Ray Spectral Logging, The Log Analyst, Vol.XI no. 5 p. 3 (1971).

L. Rybach, Radioactive Heat Production; A Physical Property Determined by the Chemistry of Rocks, in Proc. NATO Adv. study Inst. on Petrophysics, Wiley and Sons, New York p. 309-318 (1976).

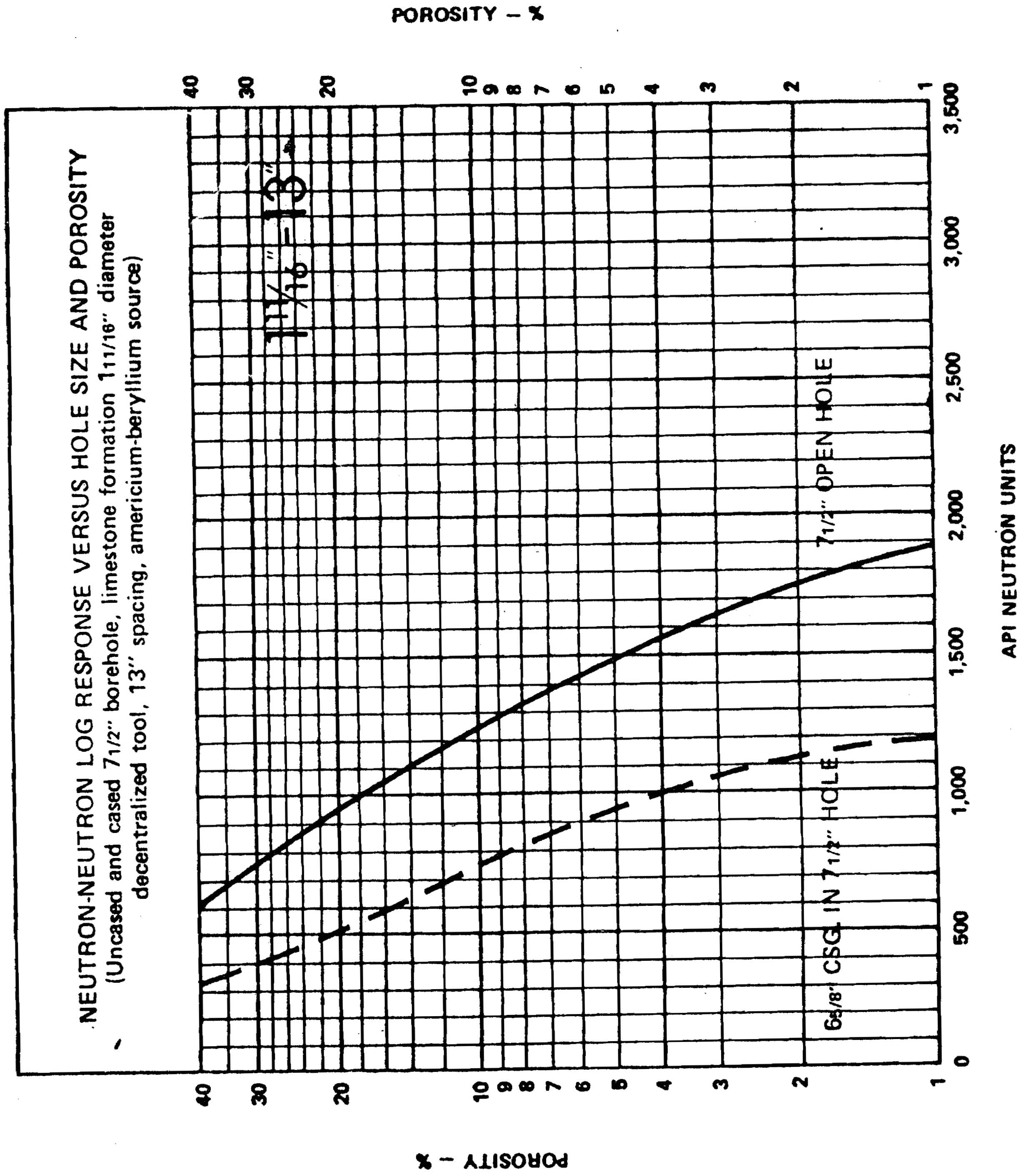
S.-S. Sun and Bor-ming Jahn, Lead and Strontium Isotopes in Post-Glacial Basalt from Iceland, Nature, Vol.255, pp. 527-530 (1975).

Fig. 1



Information from Gearhart-Owen Industries

Fig. 2



Information from Gearhart-Owen Industries

Fig. 3

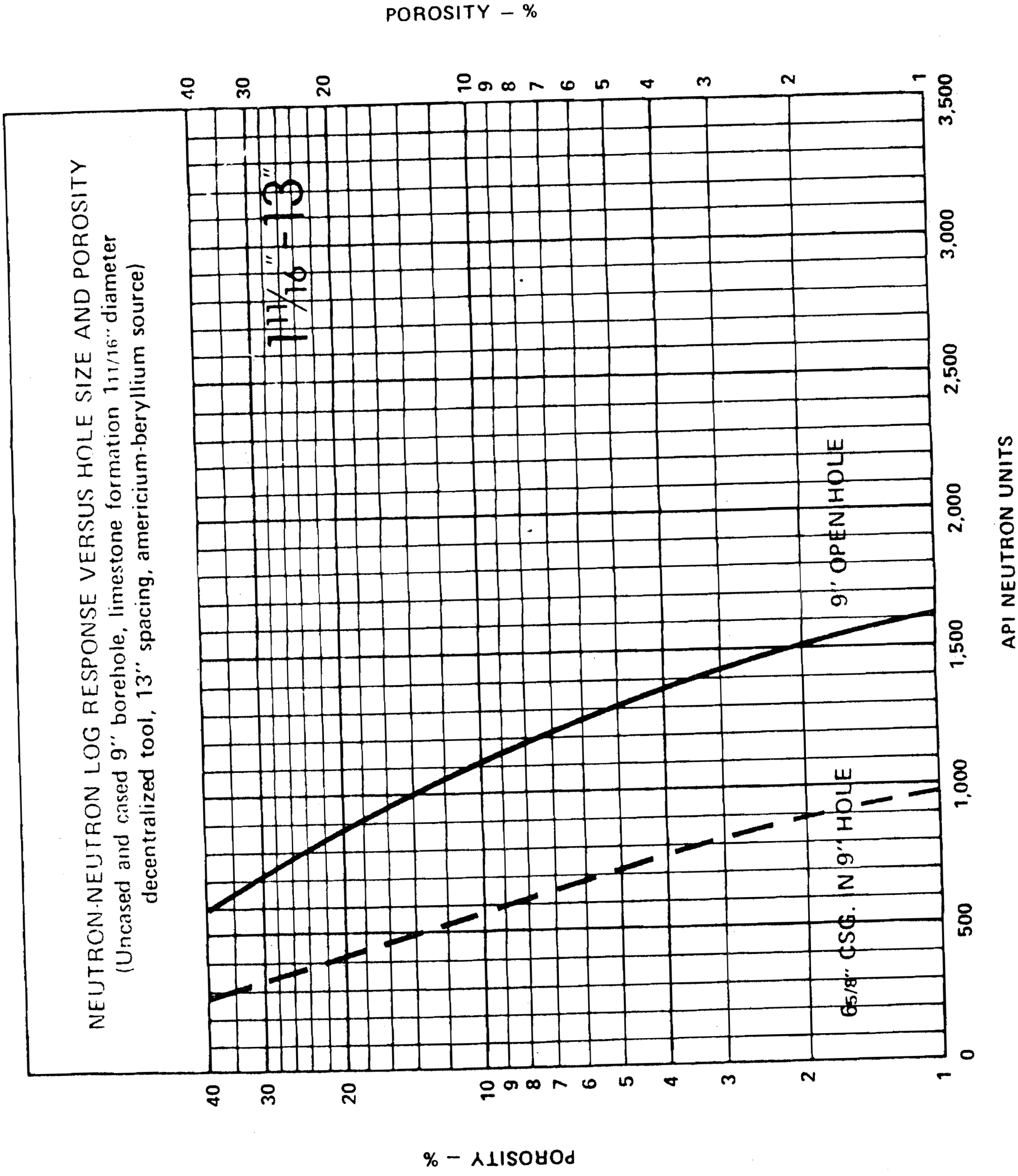
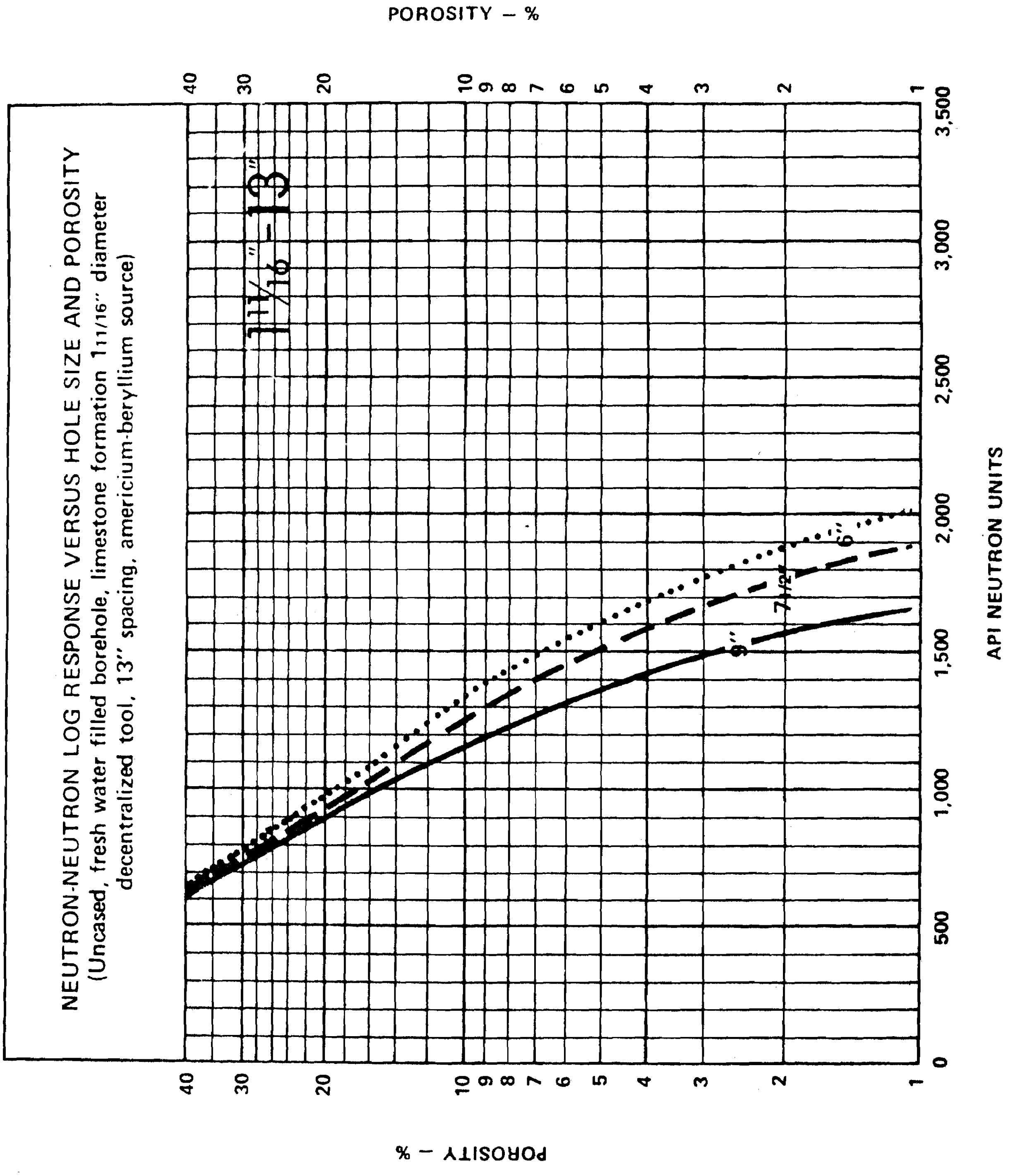

NEUTRON-NEUTRON LOG RESPONSE VERSUS HOLE SIZE AND POROSITY
(Uncased and cased 9" borehole, limestone formation 1 11/16" diameter decentralized tool, 13" spacing, americium-beryllium source)

Fig. 4



NEUTRON-NEUTRON LOG RESPONSE VERSUS HOLE SIZE AND POROSITY
(Uncased, fresh water filled borehole, limestone formation 1 11/16" diameter decentralized tool, 13" spacing, americium-beryllium source)

Information from Gearhart-Owen Industries