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NATIONAL ENERGY AUTHORITY

PROGRESS REPORT

Geophysical logs from Lopra-1 and Vestmanna-1

Valgarður Stefánsson
Helga Tulinius

OS-83021/JHD-06 B

March 1983

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Jarðhitadeild

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Our date Our ref.

Your date Your ref.

The Drilling Committee of the Faroese Government
c/o Landsverkfröðingur Mikkjal Hemsdal
Tinghúsvegur 5
3800 Tórshavn
Föroyar

The present progress report is the first report on the analyses of the geophysical well log data from Lopra-1 and Vestmanna-1 in the Faroes. The work is performed in accordance with the proposal of Orkustofnun of 82.12.09 and the agreement of the Drilling Committee of the Faroes Government as presented in your letter of 83.01.06.

The work on the analyses of the log data is proceding as scheduled and the present progress report deals with:

- Statistical determination of a common reference point for the different logs.
- Well size correction for natural gamma ray log and neutron-neutron porosity logs.
- Calculated porosity for the Lopra-1 well.
- Statistical distribution of porosity in the Lopra-1 well.
- Calculated SiO2 content of the rocks in the Lopra-1 well.
- Statistical distribution of the SiO2 content on the Lopra-1 well.
- First attemt to determine the amount of intermediary sedimentary layers in the hole penetrated by Lopra-1.

The main results obtained so far are:

a) The distribution of porosity in Lopra-1 shows a bimodal form indicating two rock types as seen by the porosity log. About 74% of the hole is a rock type having a mean porosity of 7.4%, wheras the remaining 26% of the pile have mean porosity of 26 +/- 5%.

b) The mean value of the SiO2 content in the Lopra-1 is 49 +/- 3%, reflecting the pure tholeiite nature of the

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basalts at Lopra.

c) The total thickness of sediments determined from the logs in Lopra-1 is found to be 43.6m.

The next steps in this work will include alalyses of the gamma-gamma and resistivity logs as well as cross plots between various logs. The final step is assumed to be the analyses of sonic logs and the comparision with seismic data.

Reykjavík, March 30, 1983

Valgarður Stefánsson

Helga Tulinius

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1 INTRODUCTION

The recearch holes Lopra-1 and Vestmanna-1 were logged by the National Energy Authority (Orkustofnun) of Iceland in September 1981. The parameters measured are:

Temperature
Caliper
Natural gamma ray
Neutron-neutron porosity
Normal resistivity, 16" and 64"
Gamma-gamma density (only Lopra)
Sonic amplitude (only Lopra)
Sonic travel time (only Lopra)

The scope of the present work is to calibrate and analyze this logging data. In the proposal made by Orkustofnun on 82.12.09 the details of the analyzing work are:

A. Determination of zero shift by correlation berween logs.
B. Well size correction of the logging data.
C. Calculations of porosity in per cent and density in kg/m3 as a function of depth by applying calibration curves on the neutron-neutron and gamma-gamma logs.
D. Comparison of calculated values of porosity and density with laboratory values measured on cores.
E. Investigation of calculated density and porosity values to see if they are internally consistent and determination of matrix density for different formations.
F. Calculation of the SiO2 content of the rocks from the natural gamma ray logs.
G. Determination of the "formation factor" and "cementation factor" for the various formations from the resistivity and porosity logs.
H. Determination of fracture porosity by applying the double porosity model.
I. Invesigation of the porosity determinations as obtained from neutron-neutron and sonic travel time logs.
J. Calculation of velocity profiles and comparition with seismic data.
K. Analyses of other interesting problems which might

emerge form the data set.

In a letter dated January 6. 1983 the Drilling Committee of the Faroes Government accepted the proposal made by Orkustofnun.

As no porosity and density measurements have been made on the cores, it will not be possible to carry out item D above.

The work was started on items A, B, C, E, and F, and this first progress report summarizes the results obtained so far. A second progress report is scheduled for August 1,1983 and the final report is to be delivered on the 1st of November 1983.

2 ZERO SHIFT OF LOGS

Only one or two parameters were measured with each probe at Lopra and Vestmanna. The probes are of different length and the sensitive parts of the probes are situated at different distances from the cable head. Futhermore, the zero depth for each run is set manually. Concequently a common zero point for all logs is not well defined. However, as much of the analyzation work relys on the relationship between different parameters recorded in different runs in the hole, it is of vital importance to have the same depth scale for all logs. The method used here, is to cross-correlate two logs with different offsets in depth. The zero shift between logs is determined by finding a maximum in the cross correlation when the logs correlate. If the logs have inverse correlation a minimum in the cross correlation is used to determine the zero shift.

By using this method, the entire log is used to determine the zero shift and differential variations in individual depth scales are evened out. The caliper log was chosen as the reference log, partly because other logs are to be corrected for the well size, and partly because the caliper log has at least one well defined depth point, which is the end of the casing, and could therefore be corrected to absolute depth value. Neutron-neutron and natural gamma ray logs are measured by the same probe giving a fixed depth offset of 158mm between them. The same is true for the 16" and 64" resistivity having a fixed depth offset of 610mm.

Table 1 lists the depth corrections (zero shift for various logs in Lopra-1. Temperature has been ommitted in this table, partly because temperature correlates very little with the other logs, and partly because this work is not intended to analyze the temperature data.

TABLE 1

Depth corrections for the logs in Lopra-1.

Type of log	Zero shift (m)
Caliper	0.0 (reference)
Neutron-neutron	-0.7
Natural gamma	0.9
Resistivity 16"	-0.6
Resistivity 64"	0.0
Gamma-gamma	0.2
Sonic amplitude	-0.3
Sonic travel time	-0.3

3 WELL SIZE CORRECTION

Most of the geophysical parameters measured in Lopra-1 and Vestmanna-1 are sensitive for the well diameter. In some cases like the gamma-gamma and sonic logs, different well diameters influence the log response quite heavily, and may in some cases destroy the information on the surrounding rocks. In other cases like the neutron-neutron, resistivity 64" and temperature the influence of different well size is little or moderate resulting in quite reliable records for the entire depth range. In this chapter the well size correction for natural gamma ray and neutron-neutron logs are treated.

3.1 Correction of natural gamma ray log

The drilling fluid (water or mud) acts as an extra absorbant for the natural gamma ray intensity surrounding the probe. We call the true gamma intensity Io, and the recorded intensity I. The relationship between these intensities is:

$$Io = CF * I$$

where the correction factor CF is a function of the borehole radius R, the radius of the probe Rs, the density of the drilling fluid ρ, and the effective mass absorbtion coefficient of the fluid μp. Here the absorption function $Ap(\mu pR)$ as calculated by Czubek (1981) is used to obtain the correction coefficient CF. We get:

$$CF = 1 / (1 - Ap(\mu pR))$$

Figure 1 shows $Ap(\mu pR)$ as function of Rs/R. In our case Rs, μp, and r are constants and furthermore we assume $\mu p = 0.03 * \rho$. This means that CF is a function of R alone. By using the functions shown on fig. 1 the following expression for CF can be obtained:

$$CF = \frac{1}{1.192 - 0.3937 \log R} + \frac{0.32}{R*R}$$

This expression has been used for well size correction of the natural gamma ray logs.

3.2 Correction of the neutron-neutron log

In general, the effect of the well size on the counting rate in the neutron- neutron log is that the logarithm of the counting rate is a linear function of the well diameter. If Inn is the neutron intensity and D is the diameter of the well we can write:

$$\log Inn = a * D + b$$

where a and b are particular constants for a given probe construction.

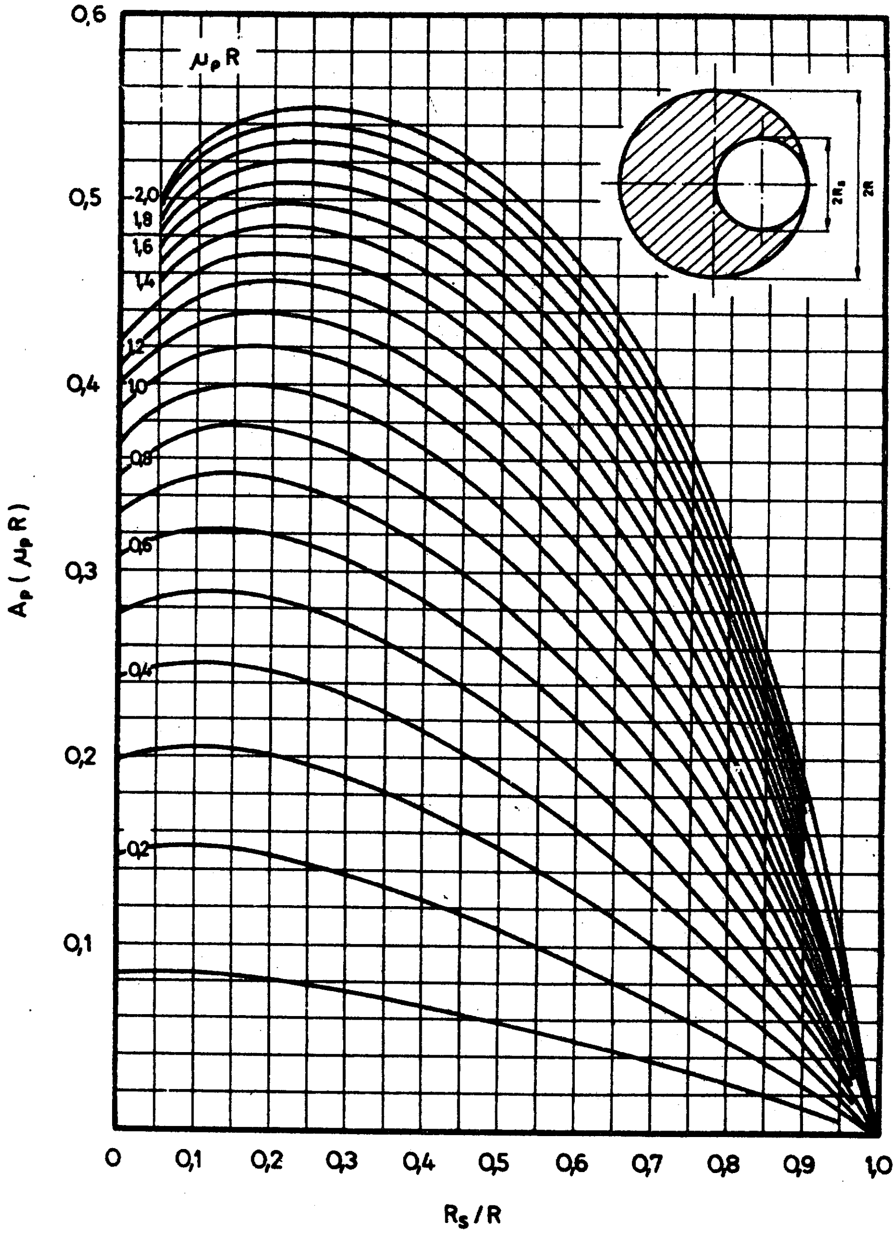


Figure 1. Apsorption function Ap(mpR) of the borehole fluid.

R - borehole radius

Rs - probe radius

μp - 0.03 * r

ρ - fluid density

The neutron-neutron probe used in Lopra-1 and Vestmanna-1 has been used for many years in Iceland and an empirical value :

$$a = -0.0015 \text{ /mm}$$

has been deduced from numerous investigations in wells in the Krafla Geothermal Field (Stefánsson et al., 1983). This value is also in reasonable agreement with calibration curves published by the manufacturer of the probe (GO, 1976). For a fixed diameter Do of the well we can write:

$$\log Inn(Do) = a * Do + b$$

and by dividing Inn(Do) by Inn we obtain:

$$Inn(Do) = X * Inn$$

where:

$$X = 10^{a(Do - D)}$$

In this work Do = 9" = 228.6mm is chosen as reference and all values of the neutron-neutron logs have been corrected to that diameter.

4 POROSITY

4.1 Porosity as function of depth

When all the neutron-neutron data has been corrected to 9" well diameter, calibration curves from the manifacturer of the probe are used to obtain real porosity. The curve for 9" diameter shown in fig. 2 is reproduced from Stefámsson (1979). This calibration curve is actually only valid for limestone , but, as shown by Czubek (1981), the difference between linestone porosity and the porosity of igneous rock should not be larger than 3% in this respect. The calibration curve in fig. 2 should therefore give a reasonable estimate of the porosity of the rocks in the Faroes.

It should also be noted here that the neutron-neutron method is sensitive for the total amount of water in the rock, which means that both water in pores and fissures as well as bounded water will influence the neutron-neutron response. The term "porostiy" as used in this report actually means the total water content of the rock.

Calculated porosity values as function of depth are shown in fig. 3. As some of the porosity values are actually zero, the influence of bounded water seems to be negligible at least for rock units with low porosity.

4.2 Distribution of porosity

The average porosity for the whole pile in Lopra- 1 is found to be 12 +/- 10% (standard deviation). The porosity distribution is shown in fig. 4. This distributin shows a clear bimodal form, indicating two rock types as seen by the neutron-neutron log. In fact this behaviour can also be seen in fig. 3 as the porosity values appear to be either high or low.

In order to separate the two peaks in fig. 4, an exponential function was fitted to the right flank of the first peak and distracted from the total. The second distribution is shown on fig. 5.

The first peak in the porosity distribution has an average

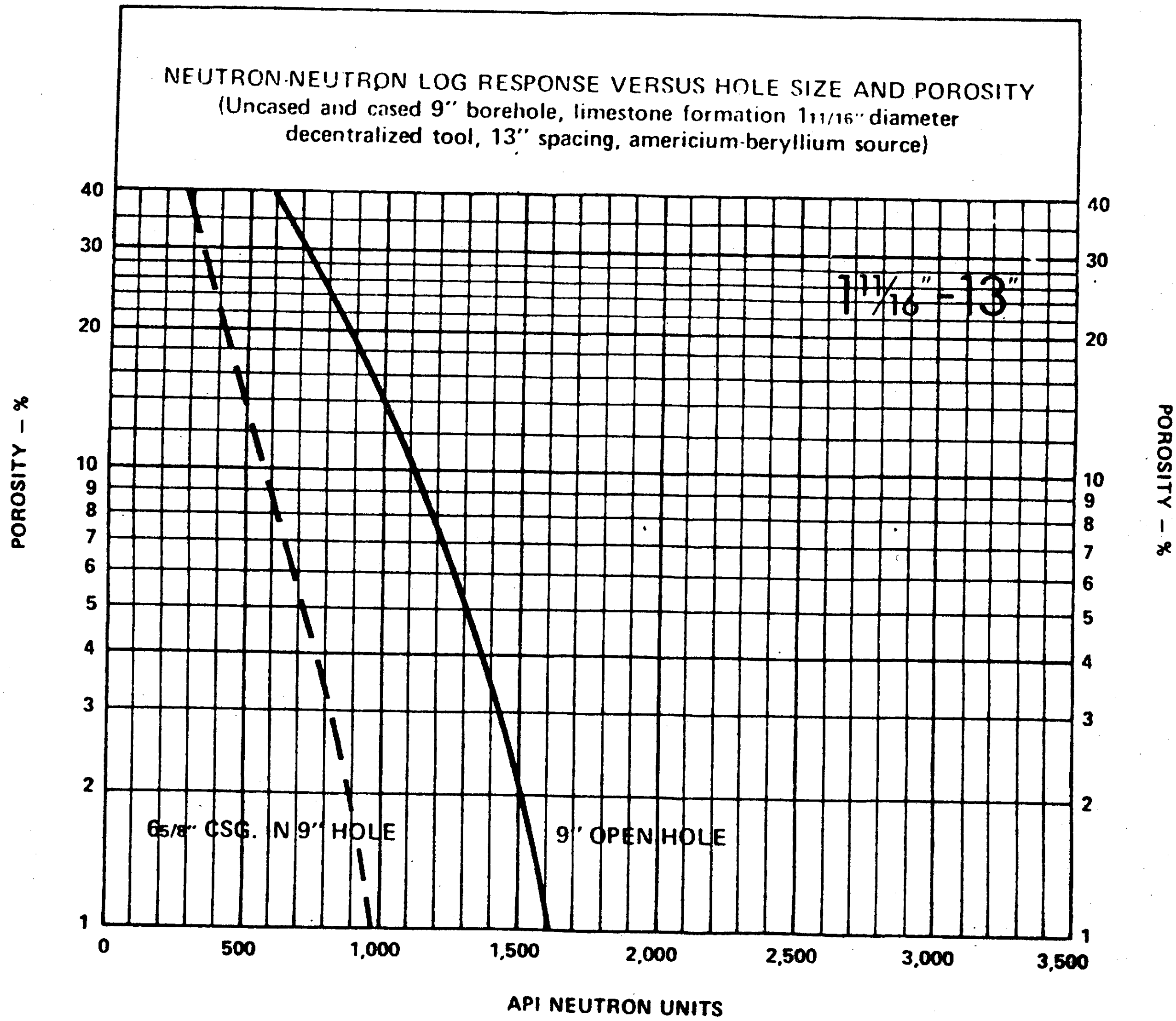


Figure 2. Neutron-neutron log responce versus hole size and porosity.

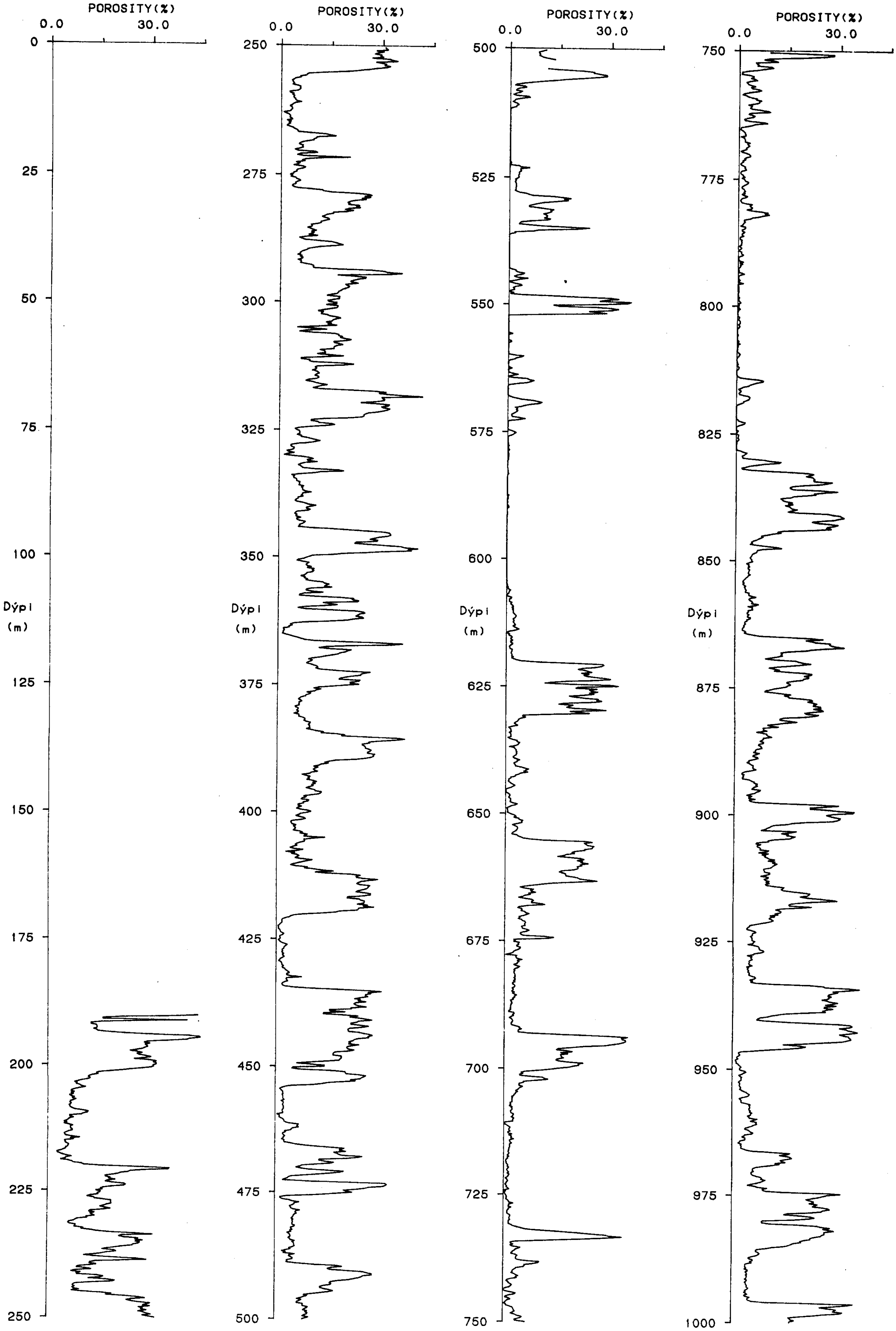
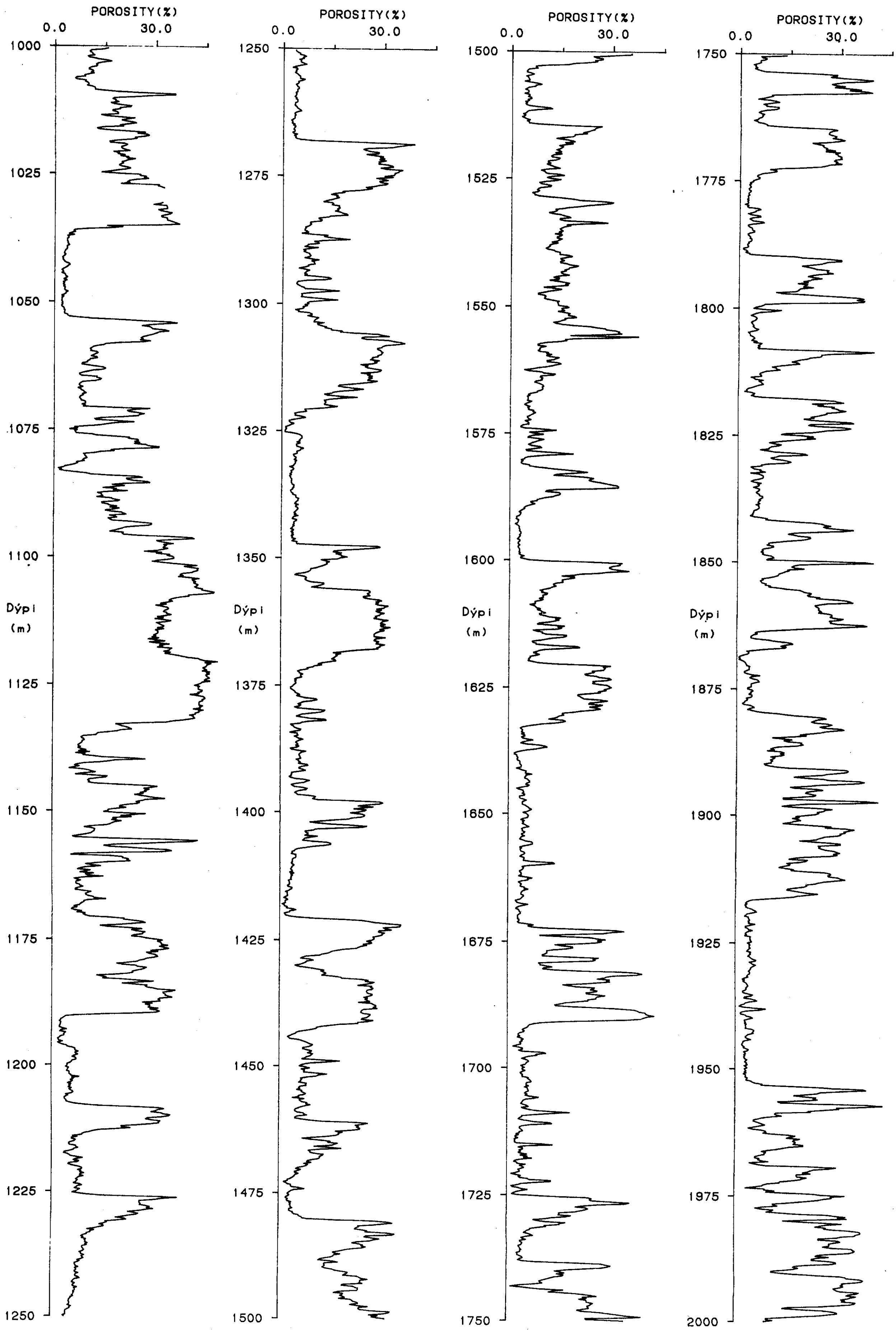


Figure 3. Lopra-1 porosity versus depth.



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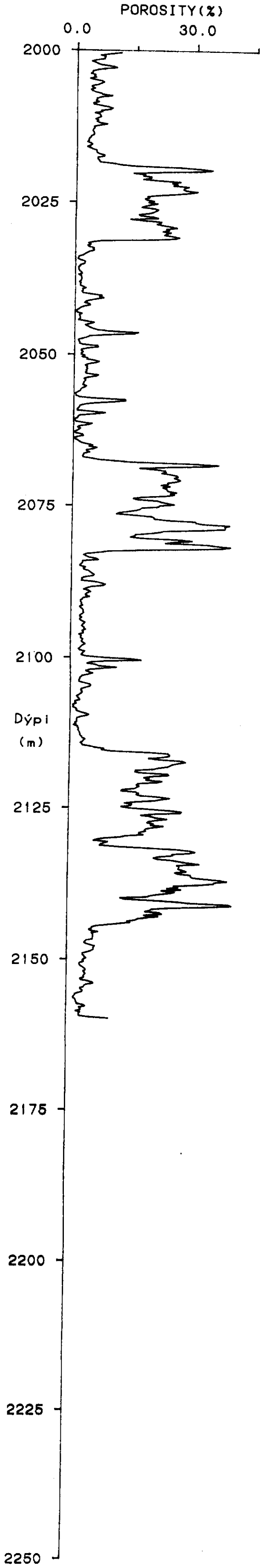

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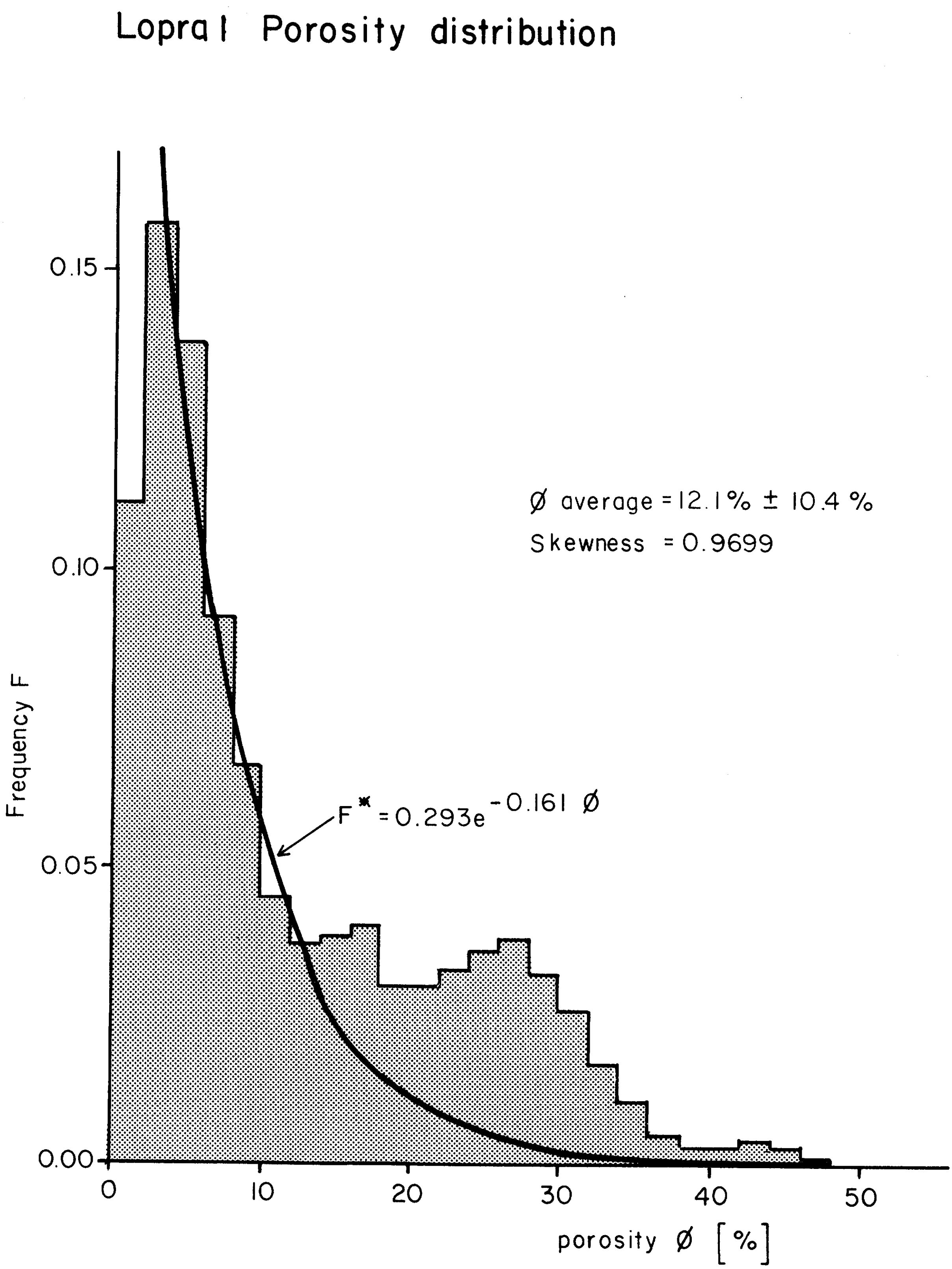


Figure 4. Lopra-1 porosity distribution.

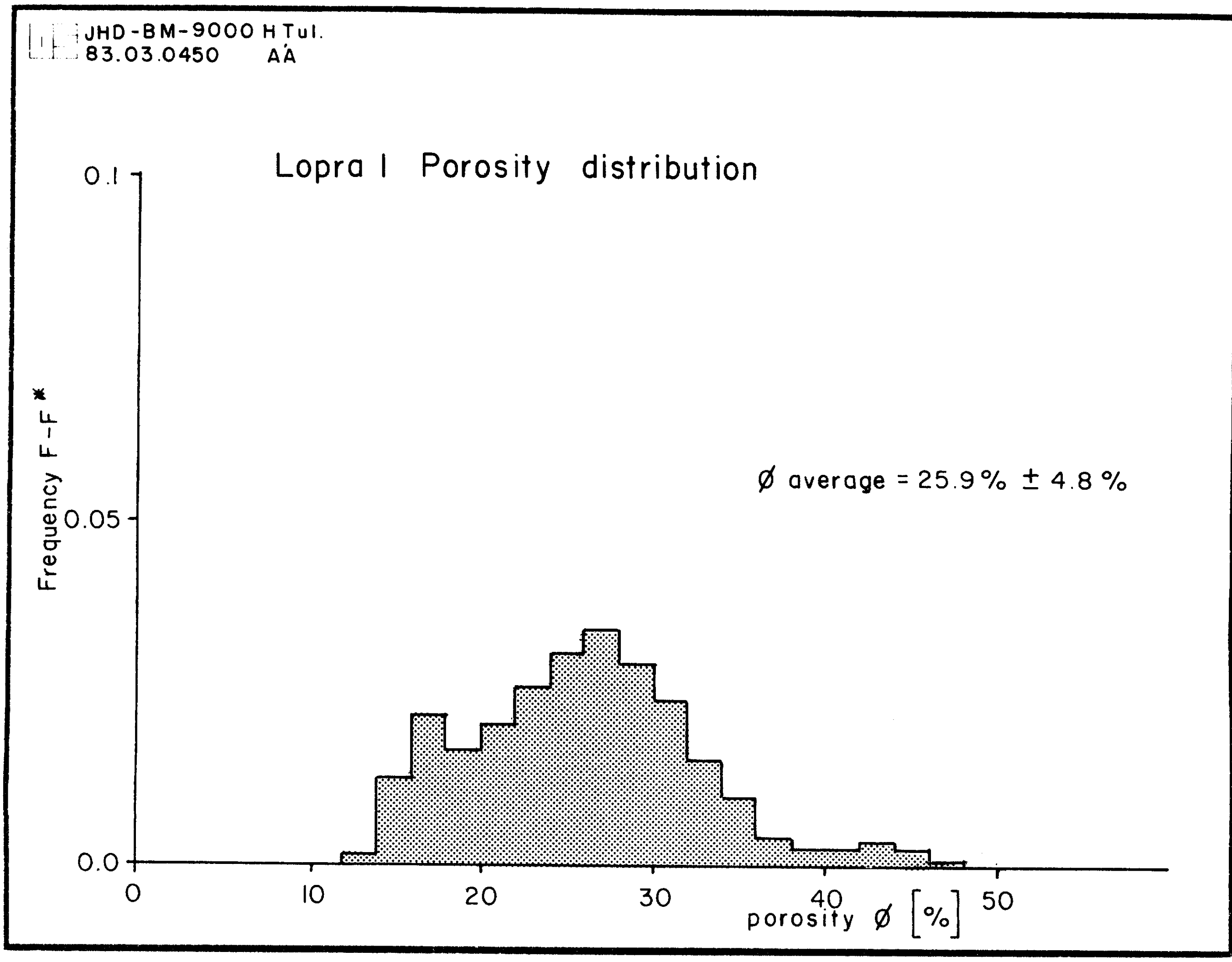


Figure 5. Lopra-1 porosity distribution for rock type 2.

porosity of 7.4 +/- 1.5%, but the maximum occurance is at 2-4%. This rock type represents about 74% of the total pile penetrated by Lopra-1 well. The second peak in the porosity distribution has an average porosity of 26 +/- 5% and the maximum occurence at 26-28%. This rock type is about 26% of the total rock pile penetrated.

5 SILICA CONTENT OF THE ROCKS

The relation between the gamma ray intensity and the SiO2 content of Icelandic rocks has been studied by Stefánsson and Emmerman (1980) and by Stedánsson et al. (1982). It is found that for the tholeiitic trend there is a linear relation between the gamma ray intensity and the SiO2 content of the rocks. For crystalline rocks, the empirical relation:

$$SiO_2 = 0.264 * I_o + 40.6\%$$

has been found applicabe in many locations in Iceland. Here SiO2 is in per cent and Io is the gamma ray intensity in API gamma ray units corrected for the well diameter.

Local variations as well as a shift between tholeiite and mild alkalic trend is observed in the relation between SiO2 and the gamma ray intensity in Iceland. However, as the variation in the gamma ray intensity in the wells in the Faroes is very small, and the rocks there are known to be tholeiite it was considered worthwhile to apply the Icelandic calibration curve for tholeiite on the gammma ray logs in Lopra-1 and Vestmanna-1.

The result is shown in fig. 6, where the SiO2 in per cent is drawn versus depth. The small narrow peaks in this log are all associated with thin sedimentary layers between the lava flows. The increased gamma ray intensity in the sediments is partly caused by induced gamma activity from the neutron source. One of the major objectives for the drilling in Lopra was investigation of deep sediments. The procedure of logging in the downvard direction and therefore inducing gamma ray activity in the sediments was therefore appropriate in order to use the gamma ray log for pinpointing the sediments. The distribution of the SiO2

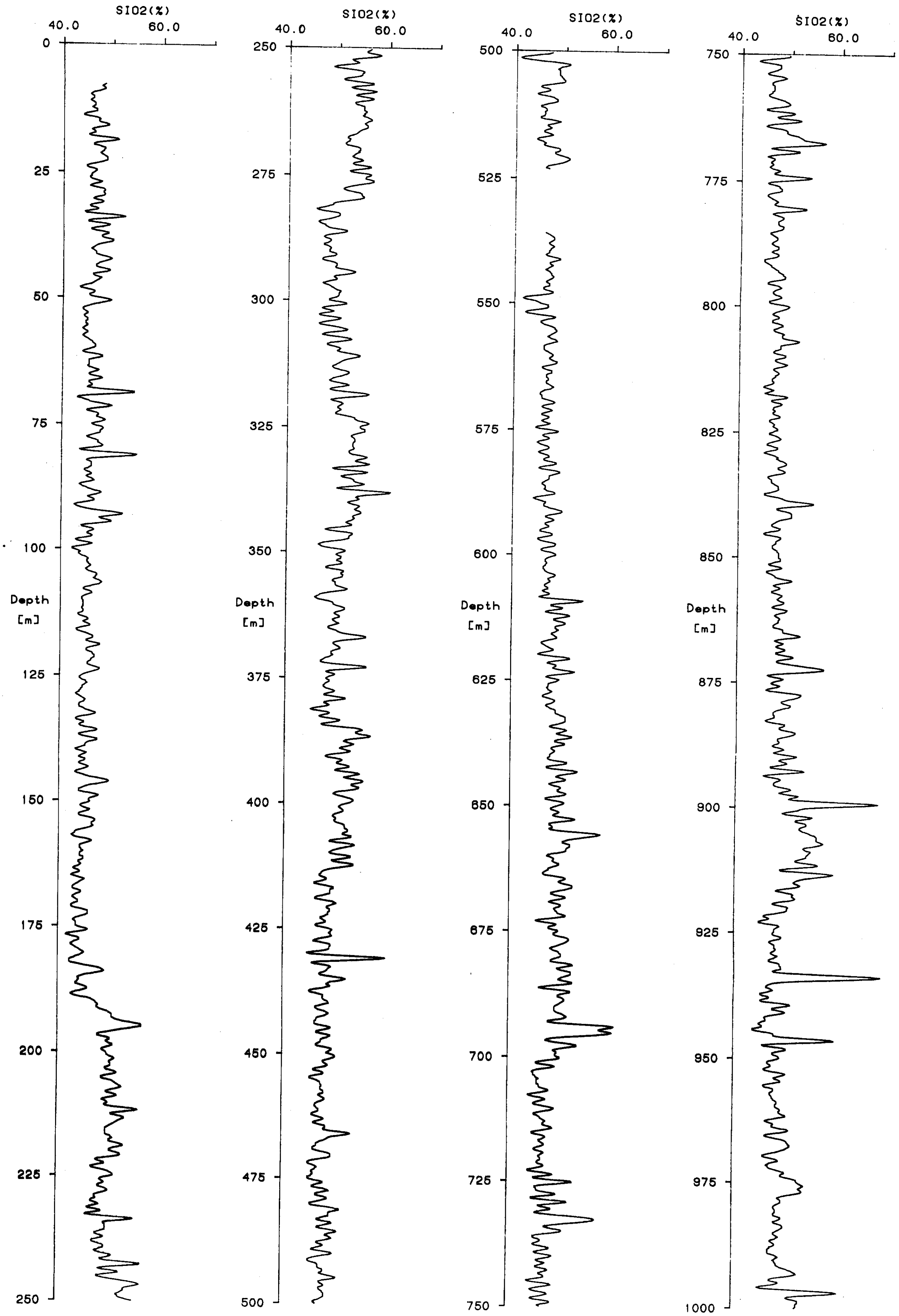
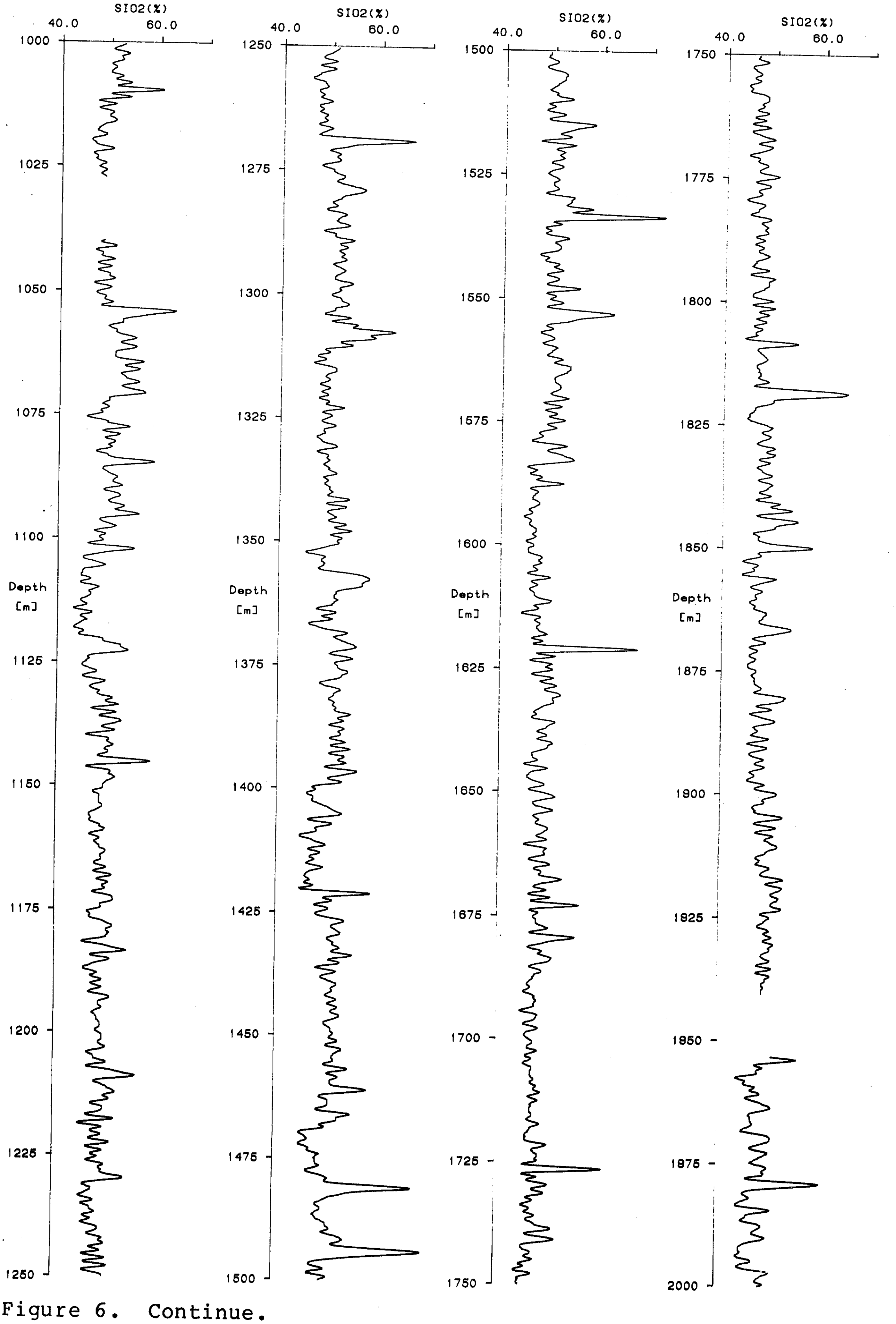


Figure 6. Lopra-1 silica content versus depth.



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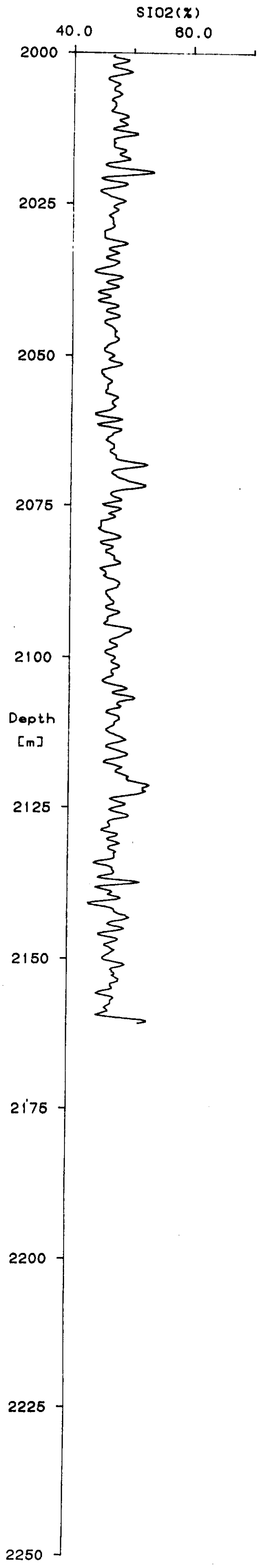

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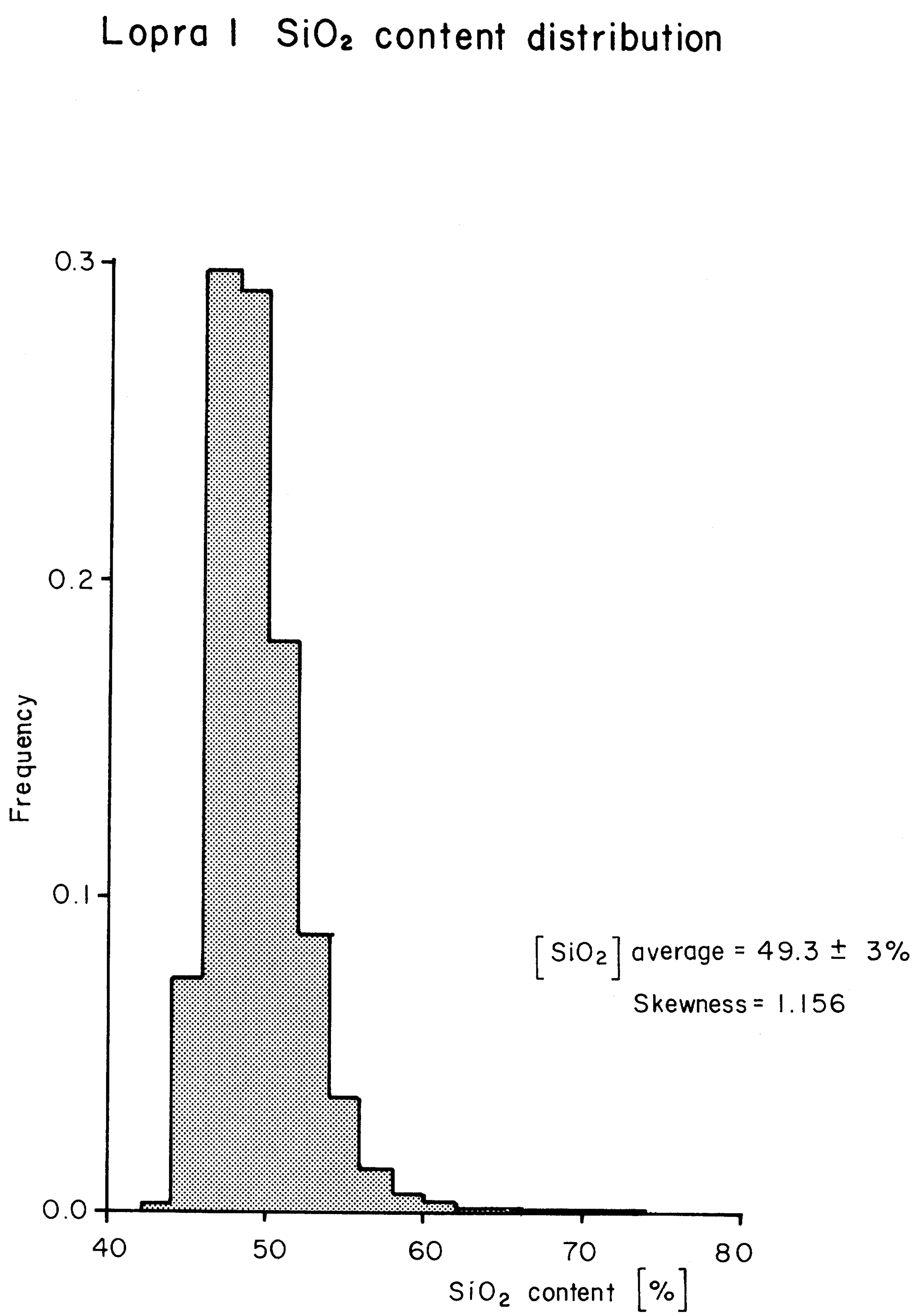

Figure 7. Lopra-1 silica distribution.

content in Lopra-1 is shown in fig. 7. The distribution is rather narrow and shows only one peak. The average SiO2 content is 49 +/- 3% and reflects the pure tholeiite nature of the rocks at Lopra.

Laboratory measurements of the SiO2 contend of lavas and intrusions at Lopra give results in the range from 46.99% to 48.43% (Waagstein et al.,1982) in good agreement with the results of the gamma ray log.

It should be noted, however, that the method of using calibration curves obtaind from Icelandic rocks on rocks in Lopra could easily cause some shift in the absolute value of the SiO2 content, but the relative distribution should not be much affected. The good agreement between laboratory data and the logs indicate, however, that the results shown in figs. 6 and 7 are reasonably reliable.

6 SEDIMENTS

As mentioned earlier, the small induced gammma ray peaks in the gamma ray log were intended to map the sediments in Lopra-1. In order to supress the noise in the data the SiO2 log was correlated with the porosity log. The intervals (high in SiO2 and high in porosity) obtained from this correlation are in almost perfect agreement with the sediments determined from the cuttings (Waagstein et al.,1982), The total thickness of the sediments is estimated for the logs to be 43.6m in good agreement with the accumulated thickness of 35 -40 m reported by Waagstein et al (1982).

7 FUTURE WORK

Futher work on the items treated in this report will continue in order to clear up details in the Lopra well and to include Vestmanna-1. The gamma-gammma resistivity and sonic logs will be corrected and calibrated.

Different cross-plots will be applied. The porosity-density cross-plot will give the consistency of the data and determine matrix density for various formations. The porosity-resistivity cross-plot is intended to give formation and cementation factors of the formations, and might be useful to determine fracture porosity.

The relation between porosity and sonic logs will be investigated and calculation of synthetic seismic profiles will be tried.

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